International Standard

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Second edition
2024-11

Electrically propelled road vehicles — Electrical specifications and tests for voltage class B systems and components —

Part 2: Electrical tests for components

Véhicules à propulsion electrique — Spécifications et essais electriques pour les systèmes et composants de classe B —

Partie 2: Composants et essais electriques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

This second edition cancels and replaces the first edition (ISO 21498-2:2021), which has been technically revised.

The main changes are as follows:

— testcase “Short circuit” has been added;

— Annex B “Testing at different temperatures” has been deleted;

— additional values have been added in Tables B.2 and B.3;

— example current limit values have been added to Table B.4;

— Annex C has been revised;

— methods for conversion from time domain to frequency domain for generated ripple have been revised and moved from main body to informative Annex D.

A list of all parts in the ISO 21498 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The requirements for voltage class B electric circuits used for electric power transfer for the propulsion of electric road vehicles and their characteristics are significantly different to those of voltage class A electric circuits. Moreover, the range of voltage class B is too wide to be used for a component design relating to voltage.

The ISO 21498 series divides voltage class B in a set of voltage sub-classes to enable a component design for each voltage sub-class relating to voltage. It provides appropriate descriptions and definitions for requirements and characteristics of voltage class B systems for electrically propelled vehicles.

The voltage sub-class itself and the component characteristics have a large cost impact on the component design and on the overall design of the electric system. Additionally, a high variety of different voltage sub-classes and operating conditions impedes the use of an existing component in different vehicle models. Standardising voltage sub-classes and characteristics and reducing varieties cuts component and system costs. This allows the decoupling of the system or component designs of a voltage class B electric circuit from the design of the electric energy source. Finally, the exchange of components from different suppliers for different customers is facilitated.

ISO 21498-1 provides definitions of and for voltage sub-classes and characteristics for rechargeable energy storage systems (RESS) and electric propulsion systems. It defines specific values for these sub-classes based on maximum working voltage. Voltage sub-classes listed in ISO 21498-1 are used for voltage class B systems of all kinds of current or future electrically propelled road vehicles.

This document provides electrical tests for electric and electronic components at voltage class B used for electrically propelled road vehicles. All relevant characteristics are covered considering usual driving scenarios as well as deviations from normal operation. The descriptions are generalized and include purpose, setup, procedure and requirements for the tests.

The specifications in this document are not intended to restrict the development of component performance or technology. The given definition of sub-classes does not exclude the use of other maximum operating voltages for an individual system design.

Electrically propelled road vehicles — Electrical specifications and tests for voltage class B systems and components —

Part 2:
Electrical tests for components

1 Scope

This document applies to voltage class B electric propulsion systems and connected auxiliary electric systems of electrically propelled road vehicles. It applies to electric circuits and components in these systems.

This document focuses on the characteristics at the DC voltage class B terminals of these components as specified in ISO 21498-1. It describes testing methods, test conditions and test requirements for components exposed to electrical behaviour caused by the operation of electric loads and power sources.

This document does not cover electrical safety (see ISO 6469-3 and the ISO 5474 series).

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 cited edition applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 8713, *Electrically propelled road vehicles — Vocabulary*

ISO 21498-1, *Electrically propelled road vehicles — Electrical specifications and tests for voltage class B systems and components — Part 1: Voltage sub-classes and characteristics*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 8713 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
customer
party that is interested in using *voltage class B* (3.13) components or systems

[SOURCE: ISO 21498-1:2021, 3.2]

3.2
electric circuit
entire set of interconnected electric/electronic parts through which electrical current is designed to flow under normal operating conditions

[SOURCE: ISO 21498-1:2021, 3.3]

3.3
lower voltage limit
minimum voltage of a *voltage class B* (3.13) sub-class disregarding *transients* (3.10) and *ripple* (3.8)

[SOURCE: ISO 21498-1:2021, 3.4]

3.4
maximum working voltage
highest value of AC voltage (rms) or of DC voltage that can occur under any normal operating conditions according to the *customer's* (3.1) specifications, disregarding *transients* (3.10) and *ripple* (3.8)

[SOURCE: ISO 21498-1:2021, 3.5]

3.5
operating status
General functional behaviour of components which depend directly on the voltage in *voltage class B* (3.13) *electric circuits* (3.2)

[SOURCE: ISO 21498-1:2021, 3.1, modified — The term was originally "component operating status".]

3.6
power network
all components within *voltage class B* (3.13) DC network including their connections

[SOURCE: ISO 21498-1:2021, 3.6]

3.7
rechargeable energy storage system
RESS
rechargeable system that stores energy for delivery of electric energy for the electric drive

EXAMPLE Batteries, capacitors, flywheel.

[SOURCE: ISO 21498-1:2021, 3.7]

3.8
ripple
set of unwanted periodic deviations with respect to the average value of the measured or supplied quantity, occurring at frequencies which can be related to that of components within a system

[SOURCE: ISO 21498-1:2021, 3.8]

3.9
supplier
party that provides *voltage class B* (3.13) components or systems

[SOURCE: ISO 21498-1:2021, 3.9]

3.10
transient
phenomenon or quantity which varies between two consecutive steady states during a short time interval compared to the timescale of interest

[SOURCE: ISO 21498-1:2021, 3.10]

3.11
upper voltage limit
maximum voltage of a *voltage class B* (3.13) sub-class disregarding *transients* (3.10) and *ripple* (3.8)

Note 1 to entry: *Maximum working voltages* (3.4) within a *voltage sub-class* (3.15) are less than or equal to the upper voltage limit.

[SOURCE: ISO 21498-1:2021, 3.11]

3.12
voltage class A
classification of an electric component or circuit with a *maximum working voltage* (3.4) of ≤30 V AC (rms) or ≤60 V DC respectively

[SOURCE: ISO 21498-1:2021, 3.12]

3.13
voltage class B
classification of an electric component or circuit with a *maximum working voltage* (3.4) of (> 30 and ≤ 1 000) V AC (rms) or (> 60 and ≤ 1 500) V DC respectively

[SOURCE: ISO 21498-1:2021, 3.13]

3.14
voltage range
general term covering *voltage sub-class* (3.15), *working voltages* (3.16) and deviations from working voltages

[SOURCE: ISO 21498-1:2021, 3.14]

3.15
voltage sub-class
classification of an electric component or circuit with a DC voltage within the *voltage class B* (3.13)

[SOURCE: ISO 21498-1:2021, 3.15]

3.16
working voltage
AC voltage (rms) or DC voltage that can occur in an electric system under normal operating conditions according to the *customer's* (3.1) specifications, disregarding *transients* (3.10) and *ripple* (3.8)

[SOURCE: ISO 21498-1:2021, 3.16]

4 Abbreviated terms

DUT	device under test
EV	electrically propelled road vehicle
OS	operating status
VCB	voltage class B
VCA	voltage class A

5 General assumptions for voltage class B components

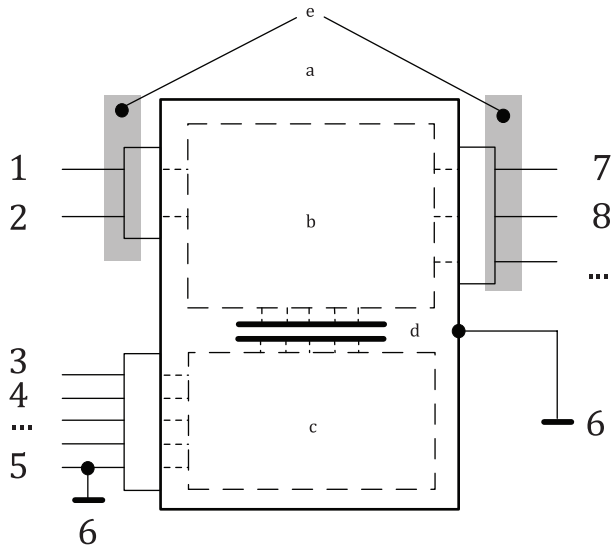
General assumptions and definitions for voltage class B systems shall be in accordance with ISO 21498-1.

Figure 1 shows a generalized view on a voltage class B component. Some of the connections shown may not be available for all voltage class B components. All voltage profiles or voltage values in this document refer to the voltage between the "U_{VCB}+" and "U_{VCB}-" terminals of a voltage class B component, if not otherwise stated.

Annex A gives an overview of typical components within an electrically propelled road vehicle.

A voltage class B component may have multiple interfaces for each type of voltage (see Figure 1: DC voltage class B, AC voltage class B, voltage class A). For example, a DC/DC converter may interface to two voltage class B electric circuits.

A voltage class B component may have multiple DC voltage class B terminals, which can be galvanically separated. The tests described in this document shall be fulfilled for each of the DC voltage class B terminals.



Key

1	VCB positive connection: U_{VCB}+	8	connection to further VCB component (e.g. AC or DC power network)
2	VCB negative connection: U_{VCB}-	a	DUT.
3	VCA power	b	VCB circuit.
4	I/O and bus signals	c	VCA circuit.
5	VCA terminal with direct connection to the reference potential	d	Galvanic separation between VCA and VCB.
6	reference potential	e	VCB terminals under test.
7	connection to further VCB component (e.g. electric motor)		

Figure 1 — Generalized VCB component diagram

Figure 2 summarizes the voltage operating ranges and OS of a voltage class B component at its DC voltage class B terminals. The overvoltage limit, the upper voltage limit and the lower voltage limit are properties of the component.

Each voltage class B component shall have a voltage range in which it can be operated with its specified performance (unlimited operating capability). All designated functions, including short-time overload operations, shall be available. Within this voltage range, the component operates in OS1.

Above a maximum voltage, a component may reduce its performance as specified. This specified voltage is called the maximum unlimited operating voltage ($U_{max\_unlimited\_op}$). The component shall provide its upper limited operating capability until the upper voltage limit (U_{upper_limit}) is reached. In this case, the component operates in OS2.

Above the upper voltage limit (U_{upper_limit}), the component may derate or cut-off its performance for self-protection. The component shall withstand this overvoltage until the overvoltage limit (U_{over_limit}) is reached. In this case, the component operates in OS3 or OS4.

A component shall perform in OS1 until the supply voltage drops to the minimum unlimited operating voltage ($U_{min\_unlimited\_op}$). Between the minimum unlimited operating voltage ($U_{min\_unlimited\_op}$) and the lower voltage limit (U_{lower_limit}), the component may reduce its performance as specified. In this case, the component operates in OS2.

If the supply voltage is below U_{lower_limit}, the component may derate or cut-off its performance. In this case, the component operates in OS3 or OS4.

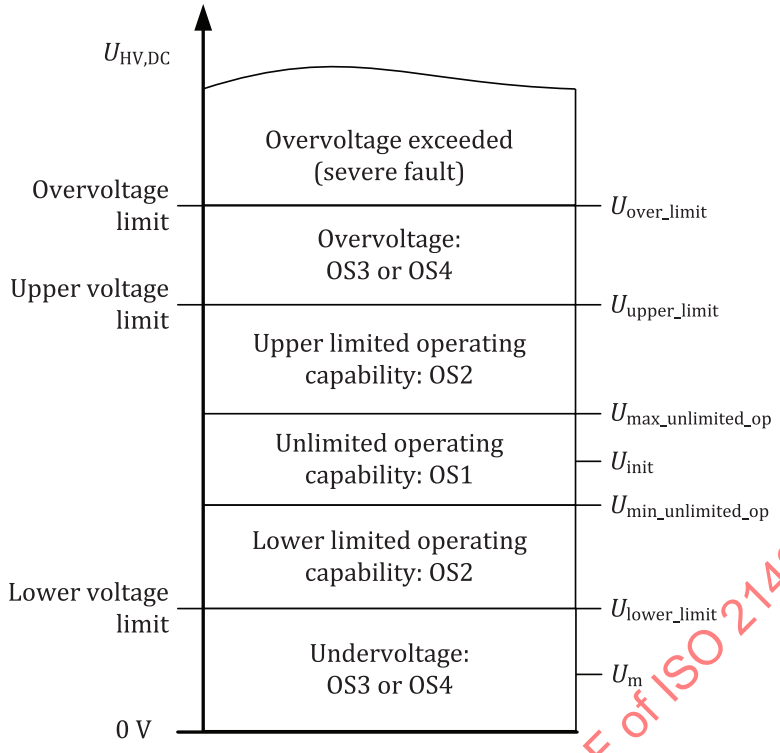


Figure 2 — Component voltage range and limits of corresponding OS

6 Tests and requirements

6.1 Test parameters and general test requirements

6.1.1 Purpose

In 6.1, the specification of test parameters are described, including tolerances and general test requirements. Frequency, time and voltage levels used for the tests are also introduced.

6.1.2 Applicability of tests

Not all tests described in this document are applicable for all voltage class B components. The customer and the supplier shall agree on the applicability of the individual tests for each component.

6.1.3 Test setup

The test setup shall provide appropriate interfaces, connections and loads to achieve representative DUT operation and characteristics. Measurement of voltages shall be performed at the DC voltage class B terminals of the DUT.

6.1.4 Voltages

Table 1 contains voltage definitions and their abbreviations.

Table 1 — Voltage definitions and abbreviations

Test parameter	Meaning
U_{over_limit}	Overvoltage limit[a]
U_{upper_limit}	Upper voltage limit[a]
U_{lower_limit}	Lower voltage limit[a]
$U_{max\_unlimited\_op}$	Maximum voltage for unlimited operating capability[b]
$U_{min\_unlimited\_op}$	Minimum voltage for unlimited operating capability[b]
U_{init}	Initial voltage for all tests
U_{VCB}	Voltage within voltage class B range
$U_{VCB,DC}$	DC part of the voltage U_{VCB} at the terminals of the DUT
$U_{VCB,AC}$	AC part of the voltage U_{VCB} at the terminals of the DUT (peak value)
U_{PP}	Peak-to-peak value of AC voltage
$U_{VCB,Pidle}$	$U_{VCB,DC}$ at no load operation
$U_{VCB,Ppeak}$	$U_{VCB,DC}$ at peak power operation
U_{m}	Voltage in the undervoltage range
[a] Voltage defined in ISO 21498-1.	
[b] See Figure 2 for illustration. The unlimited operating capability is defined in ISO 21498-1.	

6.1.5 Powers

Table 2 contains power definitions and their abbreviations.

Table 2 — Power definitions and abbreviations

Test parameter	Meaning
P_{cont}	Continuous power of the DUT
P_{max_gen}	Generated maximum power by the DUT
P_{peak}	Maximum short-term power of the DUT
P_{idle}	Power of the DUT during no load operation
$P_{request}$	Power request to the DUT[a]
[a] This value is related to the desired output power of the DUT. The actual set value may have another physical quantity (e.g. current, speed, torque) depending on the DUT.	

6.1.6 Temperatures

The tests in this document focus on the electrical behaviour of the component at the voltage class B terminals. Thermal derating is not considered. All tests shall therefore be performed at ambient temperature.

If a component needs additional liquid cooling, the cooling system shall be chosen as such that the DUT's performance is not affected by thermal derating. Flow rate and coolant temperature shall be documented.

When performing the electric tests at different temperature levels, the customer and the supplier shall agree on how these tests are to be performed, e.g. using a climate chamber or using a heat exchanger for the liquid coolant.

6.1.7 Times and durations

Table 3 contains definitions of times and durations and their abbreviations.

Table 3 — Times/duration definitions and abbreviations

Test parameter	Meaning
t_f	Fall time (e.g. of a voltage profile or a transient event)
t_h	Hold time (e.g. of a voltage profile)
t_{idle}	Duration of P_{idle}
t_{peak}	Duration of P_{peak}
t_r	Rise time (e.g. of a voltage profile or a transient event)
t_{test}	Test duration

6.1.8 Standard tolerances

Unless otherwise specified, the tolerances outlined in Table 4 apply with accuracy as shown in Table 5.

The tolerances of the test equipment shall not lead to an OS change.

Tolerances shall only be applied in a way that requirements are not weakened.

Table 4 — Standard tolerances for test equipment

Test parameter	Value
Amplitude of AC voltage	0 % to +5 % relating to the specified value [b]
Capacitance	±10 % of specified component value [a]
DC voltage	±0,2 % of U_{upper_limit}
Frequency of AC voltage	±1 % relating to the specified value [a]
Inductance	±10 % of specified component value [a]
Resistance	±10 % of specified component value [a]
Time/duration	0 % to +5 % relating to the specified value [b]
[a] The specified value is given in the test description or in Annex B and Annex C.	
[b] The specified value is given in the test description. The value may not be below the given value.	

Table 5 — Accuracy of measurement

Test parameter	Value
DC voltage measurement	±0,5 % of U_{upper_limit}
AC voltage measurement	±1 % of $U_{VCB,AC}$ [a]
DC current measurement	±1 % of measured DC current or 100 mA, whichever is higher
AC current measurement	±3 % of measured AC current or 100 mA, whichever is higher
[a] For the $U_{VCB,AC}$ level, see Annex B.	

6.1.9 Default ambient conditions

Unless otherwise specified, the parameter values of ambient conditions outlined in Table 6 shall be used.

Table 6 — Default ambient conditions

Test parameter	Value	Remark
RT	(23 ± 5) °C	Room temperature
RH	25 % to 75 %	Relative humidity
T_{amb}	RT	Ambient temperature
T_{cool}	According to specification or as agreed by the customer and the supplier	Coolant temperature

6.1.10 Wiring

The DUT shall be connected to the test setup using the following conditions. If there is an attached cable tail at the DUT or a designated wiring, the test setup shall be connected at the end of the existing wiring. If not, a cable with a maximum length of 2 m (straight and parallel if possible) shall be used to connect the DUT to the test setup. The shielding of the wiring depends on DUT target configuration.

6.1.11 Load conditions

The DUT shall be connected to an appropriate load or source. For all tests, the DUT shall be operated at continuous power, if not otherwise stated. If this condition can be reached at several operating points (e.g. speed, torque), the customer and the supplier shall agree on an appropriate operating point.

If a component can consume and deliver electrical energy (e.g. a motor or generator), the component shall be tested in both energy flow directions.

6.1.12 Sampling rates and measured value resolutions

The sampling rate, bandwidth and resolution of the measuring system shall be adapted for the respective test. This document contains tests concerning DC operation only and tests concerning AC characteristics within a frequency range from 10 Hz to 150 kHz.

6.1.13 Data acquisition and processing

Data acquisition is the measurement of electrical signals (e.g. voltage or current) and the conversion into digital signals (acquired data).

Data processing is the processing of the acquired data, e.g. filtering. The processing can be done by the measurement device or by post processing.

6.1.14 Parameter monitoring

All additional parameters to be monitored shall be defined for the relevant tests with their value ranges. During the complete test, the parameters to be monitored shall be recorded. The data resulting from the continuous parameter monitoring shall be examined for trends and drifting to detect abnormalities or malfunctions of the component. For components with fault memory, the customer and the supplier shall prior to the testing agree on which component behaviour to store during the test. The fault memory shall be monitored and all entries shall be documented.

6.1.15 Interface description

A detailed description of the states and electrical properties of all interfaces (measuring setup and component) shall be provided.

6.1.16 Documentation

For documentation, see individual requirements given during the test description.

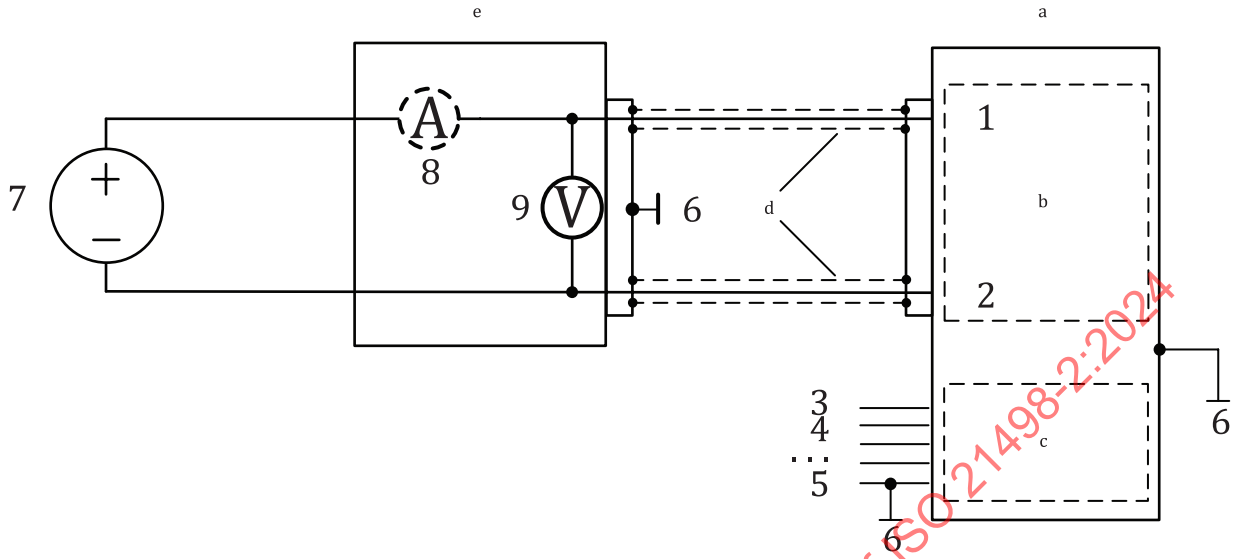
6.2 DC supply voltage variation within operational range

6.2.1 Purpose

This test verifies that the voltage class B component can perform as specified when the DC voltage varies in the range between the lower voltage limit and the upper voltage limit. The purpose is to emulate real battery operation.

6.2.2 Test setup

The test setup according to Figure 3 shall be used. The test setup consists of a variable voltage class B DC power supply and the DUT. A profile for the voltage U_{VCB} is given in Figure 4.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 3 — Test setup for DC supply voltage variation within operational range

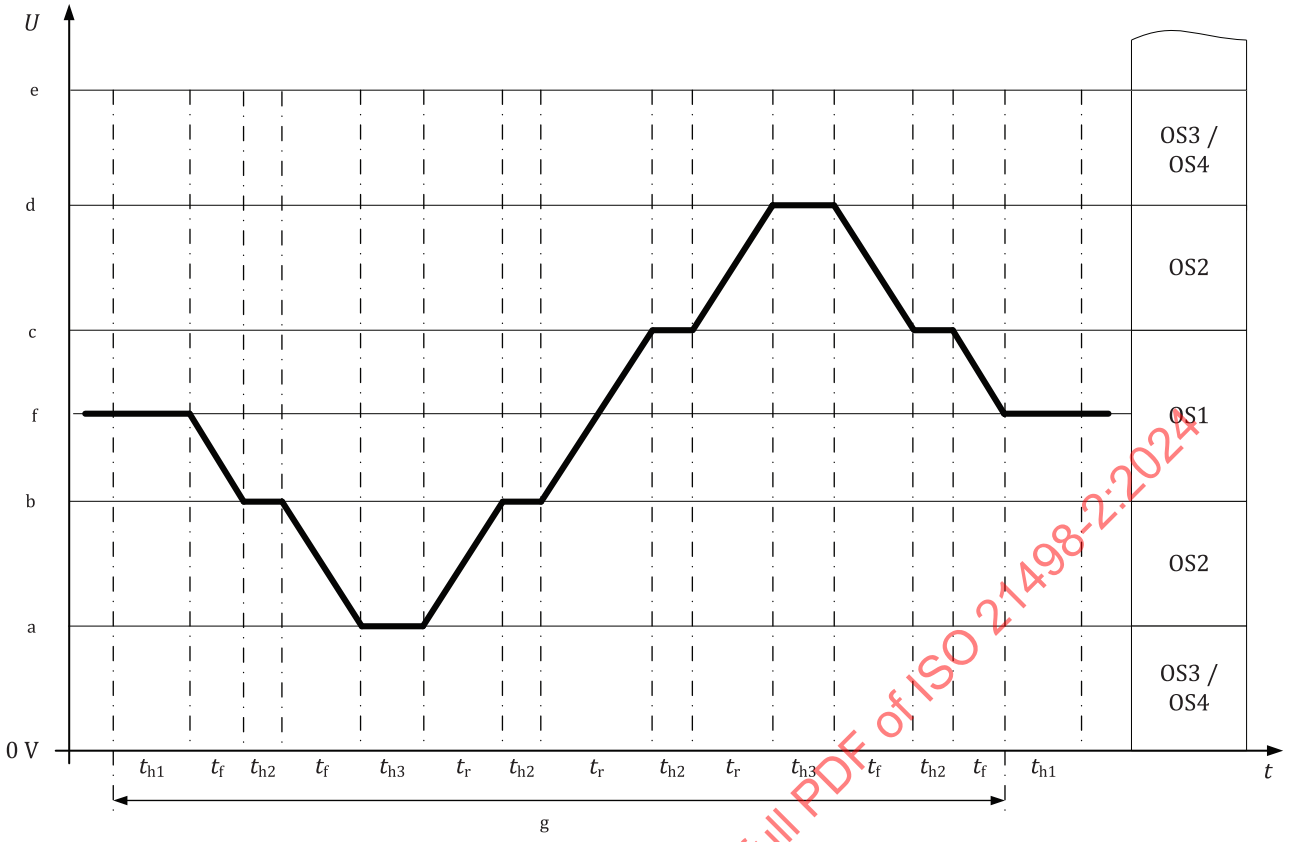
6.2.3 Test procedure

Install the DUT in a test setup according to Figure 3. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

Change the level of the voltage class B DC power supply so that U_{VCB} meets the voltage profile in Figure 4 and Table 7.

If a DUT has no OS2 (i.e. $U_{max\_unlimited\_op}$ has the same value as U_{upper_limit} and/or $U_{min\_unlimited\_op}$ has the same value as U_{lower_limit}), the respective test procedures and test profiles shall be adapted accordingly. The customer and the supplier shall agree on the adaptation.

The voltage U_{VCB} and relevant parameters to evaluate the OS shall be recorded during the test.



Key

U	voltage	b	$U_{min\_unlimited\_op.}$
t	time	c	$U_{max\_unlimited\_op.}$
t_f	fall time	d	$U_{upper\_limit.}$
t_h	hold time	e	$U_{over\_limit.}$
t_r	rise time	f	$U_{init.}$
a	$U_{lower\_limit.}$	g	One test cycle.

Figure 4 — Voltage profile for DC supply voltage variation within operational range

Table 7 — Test parameters for DC supply voltage variation within operational range

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
t_{h1}	≥30 s	Hold time
t_f	$\lvert\Delta U/\Delta t\rvert \leq 2$ V/s [b]	Fall time, to be determined with $\lvert\Delta U/\Delta t\rvert$
t_{h2}	≥5 s	Hold time
t_r	$\Delta U/\Delta t \leq 2$ V/s [b]	Rise time, to be determined with $\Delta U/\Delta t$
t_{h3}	≥10 s	Hold time
ΔU	<1 V	voltage increment of $U_{VCB,DC}$
n	1	Number of test cycles

[a] Or as agreed by the customer and the supplier.

[b] The voltage change rate may be faster if the DUT stays in stable operation.

6.2.4 Requirements

The DUT shall stay in OS1 for voltages equal to and in between $U_{min\_unlimited\_op}$ and $U_{max\_unlimited\_op}$.

The DUT shall stay in OS2 for a voltage below $U_{min\_unlimited\_op}$, but above or equal to U_{lower_limit}. After the voltage returns to a level equal to or above $U_{min\_unlimited\_op}$, the DUT shall enter OS1 and the specified performance shall be obtained again.

The DUT shall stay in OS2 for a voltage above $U_{max\_unlimited\_op}$, but below or equal to U_{upper_limit}. After the voltage returns to a level equal to or below $U_{max\_unlimited\_op}$, the DUT shall enter OS1 and the specified performance shall be obtained again.

6.3 Generated voltage slope

6.3.1 Purpose

This test evaluates the generated voltage slope and confirms that it is within a specified maximum rate.

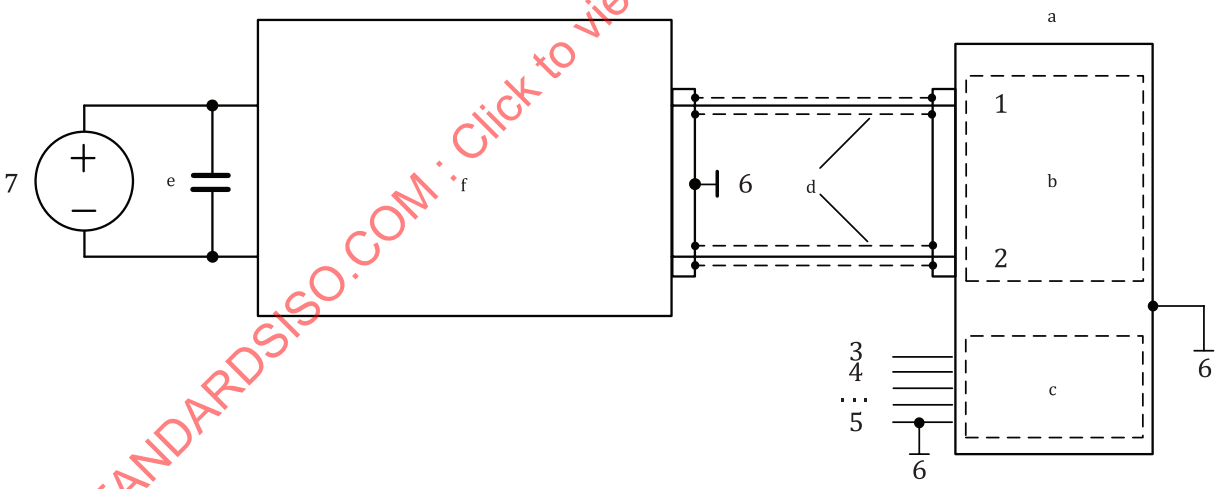
6.3.2 Test setup

For this test, a test setup according to Figure 5 shall be used. The test setup consists of the DUT, a variable voltage class B DC power supply and an artificial network.

The artificial network emulates the dynamic behaviour of a vehicle power network including the internal resistance of the battery/batteries. The setup and impedance characteristics for the artificial network given in Annex C shall be followed. The test setup may be simplified if simplifying has no influence on the result. Proof of the conformity of the artificial network is provided in Annex C.

The DUT shall be connected to a voltage class B DC power supply and shall be able to change the power on request. The capacitor C_S is used to decouple the voltage class B DC power supply and the artificial network. The capacitor C_S should be positioned as near as possible to the artificial network and its value shall be greater than or equal to 10 mF.

The voltage U_{VCB} shall be measured within the artificial network (see C.2).



Key

1	VCB positive connection: U_{VCB}+	a	DUT.
2	VCB negative connection: U_{VCB-}	b	VCB circuit.
3	VCA power	c	VCA circuit.
4	I/O and bus signals	d	Wiring.
5	VCA terminal with direct connection to the reference potential	e	Decoupling capacitor C_S.
6	reference potential	f	Artificial network (see Annex C).
7	VCB DC power supply		

Figure 5 — Test setup for generated voltage slope

6.3.3 Test procedure

Install the DUT in a test setup according to Figure 5. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

The voltage slope shall be generated by changing the power request of the DUT according to the test parameters outlined in Table 8 and Figure 6.

The voltage U_{VCB} shall be acquired from the start of a power change request until the voltage reaches a steady state.

The test cycles may be performed separately or in one sequence.

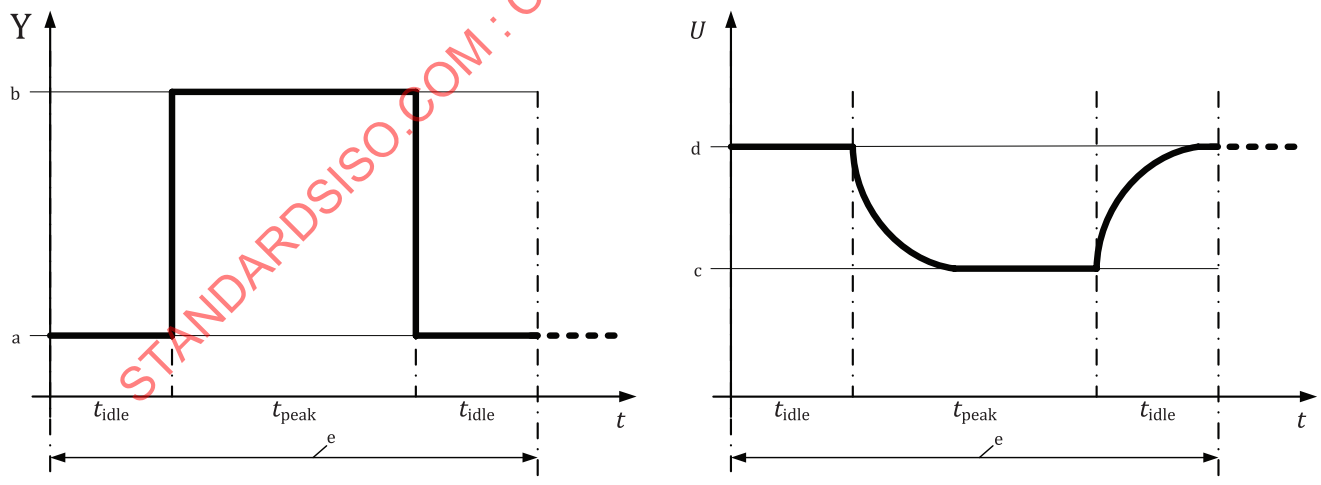
If a DUT works in a bidirectional way (i.e. can consume electrical energy or generate electrical energy), both ways shall be tested.

The voltage U_{VCB} shall be monitored and evaluated for positive and negative slope.

Table 8 — Test parameters for generated voltage slope

Test parameter	Value	Remark
U_{VCB}[a]	Voltage within the specification for unlimited operation (e.g. U_{init})	Voltage level during P_{idle}
P_{peak}	As agreed by the customer and the supplier	Maximum short term power of the DUT
P_{idle}	As agreed by the customer and the supplier	Power of the DUT during no load operation
t_{idle}	>10 s	Duration of P_{idle}
t_{peak}	≥2 s [b]	Duration of P_{peak}
N	3	Number of test cycles
[a] U_{VCB} during P_{idle} shall be chosen accordingly to avoid an OS change to OS3/4 due to the peak power request.		
[b] For defining t_{peak}, derating of the DUT shall be considered.		

Figure 6 shows the required profile of the power request and an example of the resulting voltage curve for a DUT, which consumes electric energy.



a) Profile of $P_{request}$

b) Example of corresponding voltage U_{VCB}

Key

Y	$P_{request}$	a	$P_{idle.}$
U	voltage U_{VCB}	b	$P_{peak.}$
t	time	c	$U_{VCB,Ppeak.}$
t_{idle}	duration of P_{idle}	d	$U_{VCB,Pidle.}$
t_{peak}	duration of P_{peak}	e	One test cycle.

Figure 6 — Profile of $P_{request}$ and corresponding voltage during generated voltage slope

To ensure comparable results, a standardized evaluation method of the acquired voltage is necessary. Therefore, the acquired voltage shall be low-pass filtered to reduce the influence of voltage ripple. Afterwards, the discrete-time derivation of the filtered signal shall be calculated, using a discrete-time step. The maximum value of the resulting signal equals the maximum slope. The parameters of the low pass filter and the discrete-time evaluation are given in Table 9.

Table 9 — Data processing and evaluation for generated voltage slope

Parameter description	Value
Filter-type	Low pass: IIR (Bessel)
Filter order	2
Cut-off frequency (3 dB)	1 kHz
Discrete-time step for evaluation	1 ms

6.3.4 Requirements

All measured values shall be recorded and documented. It shall be verified that the voltage slope is within a specified rate. The customer and the supplier shall agree on this value. Example values are given in Table B.1.

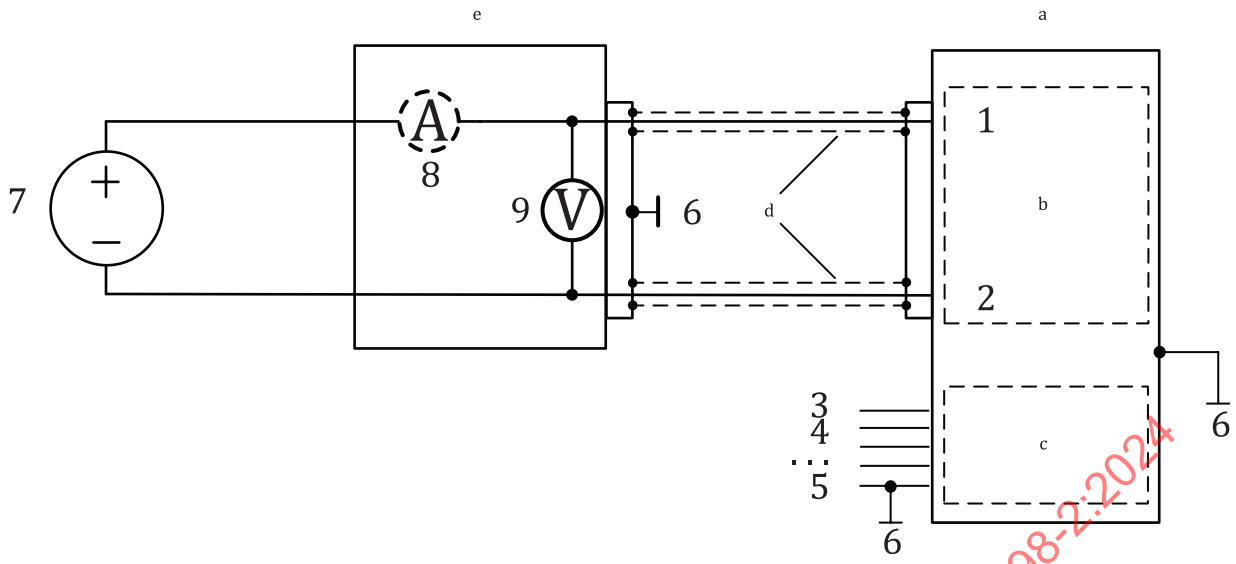
6.4 Immunity to voltage slope

6.4.1 Purpose

This test simulates a voltage slope at the DC voltage class B terminals of the component to verify its robustness. This test verifies stable electrical operation of the component, when a voltage slope is applied.

6.4.2 Test setup

For this test, a test setup according to Figure 7 shall be used. The test setup consists of a variable voltage class B power supply and the DUT. A profile for the voltage U_{VCB} is given in Figure 8.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 7 — Test setup for immunity to voltage slope

6.4.3 Test procedure

Install the DUT in a test setup according to Figure 7, Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

Change U_{VCB} as defined in Figure 8 and Table 10.

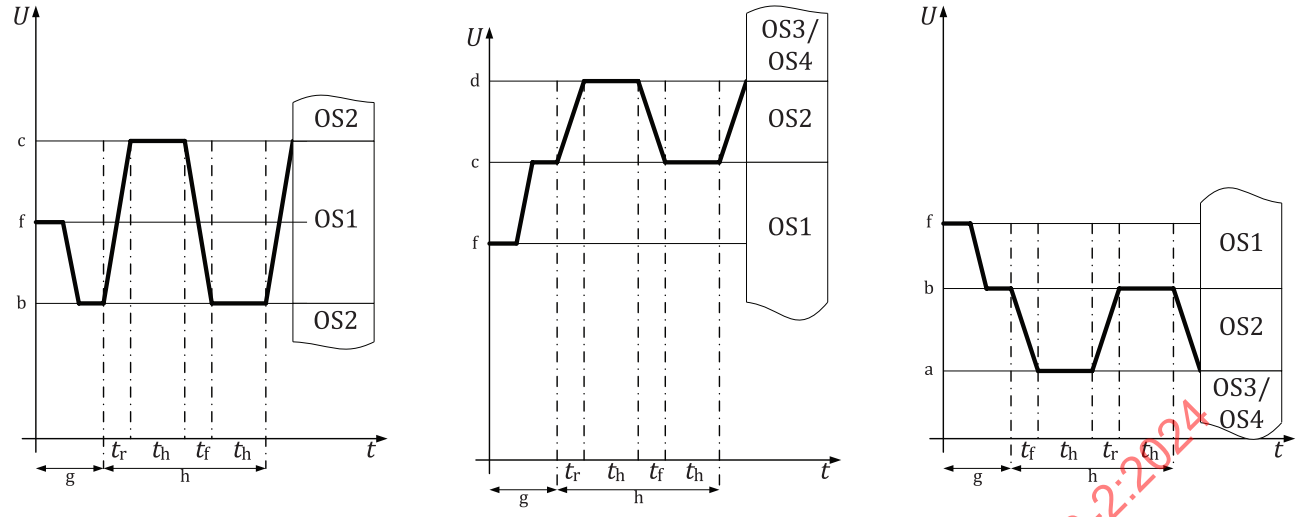
The test shall be repeated for the number of test cycles specified in Table 10 in one sequence. The test voltage U_{VCB} and relevant parameters to evaluate the OS of the DUT shall be recorded during the test.

The test shall be repeated for all operating statuses specified in Table 10.

Table 10 — Test parameters for immunity to voltage slope

Test parameter	Value	Remark
OS	OS1, OS2	Upper and lower limited operating range
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op})/2$ [a]	Voltage at start of test
t_r	$\Delta U/\Delta t \geq 1$ or 10 or 20 V/ms	Rise time, to be determined with $\Delta U/\Delta t$
t_h	≥2 s	Hold time
t_f	$\lvert\Delta U/\Delta t\rvert \geq 1$ or 10 or 20 V/ms	Fall time, to be determined with $\lvert\Delta U/\Delta t\rvert$
n	3	Number of test cycles

[a] Or as agreed by the customer and the supplier.



a) Profile for OS1 **b) Profile for upper OS2** **c) Profile for lower OS2**

Key

U	voltage	b	$U_{min\_unlimited\_op.}$
t	time	c	$U_{max\_unlimited\_op.}$
t_h	hold time	d	$U_{upper\_limit.}$
t_f	fall time	f	$U_{init.}$
t_r	rise time	g	Start-up phase.
a	$U_{lower\_limit.}$	h	One test cycle.

Figure 8 — Voltage profile for immunity to voltage slope

6.4.4 Requirements

It shall be verified that the voltage class B operating status of the DUT in the respective operating voltage range does not change due to voltage slope occurring in the voltage class B circuit. The DUT shall perform as specified.

6.5 Generated voltage ripple

6.5.1 Purpose

This test describes a standardized test setup and test method to enable comparability of the generated voltage ripple of voltage class B components. In this document, voltage ripple within a frequency range between 10 Hz and 150 kHz is considered. Voltage ripple is characterised by its peak-to-peak voltage in the time domain and its dominating frequencies.

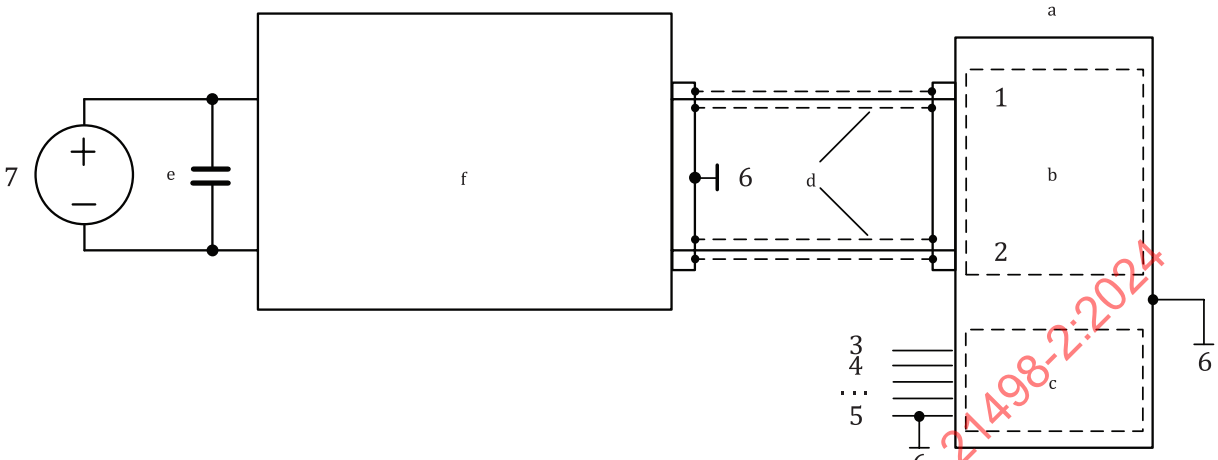
6.5.2 Test setup

For this test, a test setup according to Figure 9 shall be used. The test setup consists of the DUT, a variable voltage class B DC power supply and an artificial network.

The artificial network emulates the dynamic behaviour of a vehicle power network and the internal resistance of the battery. A setup and impedance characteristics for the artificial network are given in Annex C and shall be followed. The test setup may be simplified if simplifying has no influence on the result. Proof of the conformity of the artificial network is provided in Annex C.

The DUT shall be connected to a voltage class B DC power supply. The capacitor C_S is used to decouple the source and the artificial network. The capacitor C_S should be positioned as near as possible to the artificial network and its value shall be greater than or equal to 10 mF.

The voltage U_{VCB} within the artificial network (see C.2) shall be monitored and evaluated.



Key

1	VCB positive connection: U_{VCB}+	a	DUT.
2	VCB negative connection: U_{VCB}-	b	VCB circuit.
3	VCA power	c	VCA circuit.
4	I/O and bus signals	d	Wiring.
5	VCA terminal with direct connection to the reference potential	e	Decoupling capacitor C_S.
6	reference potential	f	Artificial network (Annex C).
7	VCB DC power supply		

Figure 9 — Test setup for generated voltage ripple

6.5.3 Test procedure

6.5.3.1 General

Install the DUT in a test setup according to Figure 9. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. U_{init}).

The voltage U_{VCB}, within the artificial network shall be monitored and evaluated. An example is given in Figure 10.

For the test, the DUT shall be operated in OS1 at a specified operating point. To determine worst-case voltage ripple, the DUT shall work in the operating point where the highest amplitude of the generated voltage ripple is expected. If the operating point is not known, the DUT shall be operated at a DC working voltage and with an output power as defined in Table 11. The test cycles may be performed separately or in one sequence. If the highest ripple is expected to be reached with various operating points (e.g. speed and torque), the customer and the supplier shall agree on the operating points themselves as well as the number of operating points.

Table 11 — Test parameters for generated voltage ripple

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op})/2$ [a]	Voltage at start of test
U_{VCB}	U_{init}, $U_{max\_unlimited\_op}$, $U_{min\_unlimited\_op}$ [b]	DC working voltage levels
P	P_{peak} [b]	Output power of the DUT
t_{window}	1 s	Window length
t_{test}	≥1 s	Time of one test cycle
n	3	Number of test cycles

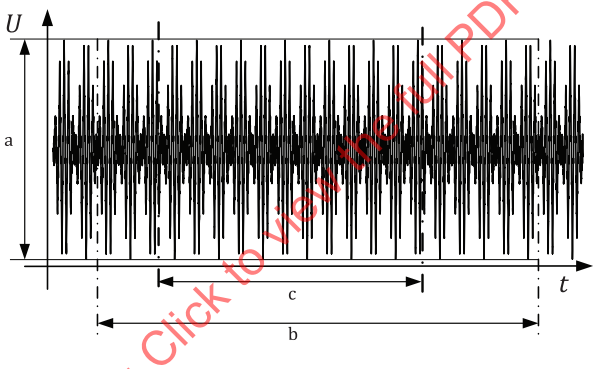
[a] Or as agreed by the customer and the supplier.

[b] Default values if the operating point with worst case ripple is not known.

The test cycles may be performed separately or in one sequence. During each test cycle the operating point shall be stable.

6.5.3.2 Evaluation in the time domain

To determine the peak-to-peak value U_{PP} of the generated voltage ripple, the maximum and minimum measured voltage values shall be used as depicted in Figure 10. For data acquisition and data processing in the time domain, the parameters in Table 12 shall be used. The measured voltage ripple in the time domain shall be documented.



Key

U voltage
t time
a $U_{pp.}$
b $t_{test.}$
c $t_{window.}$

Figure 10 — Example of the acquired voltage (U_{VCB}) in the time domain

Table 12 — Data acquisition and processing in the time domain for generated voltage ripple

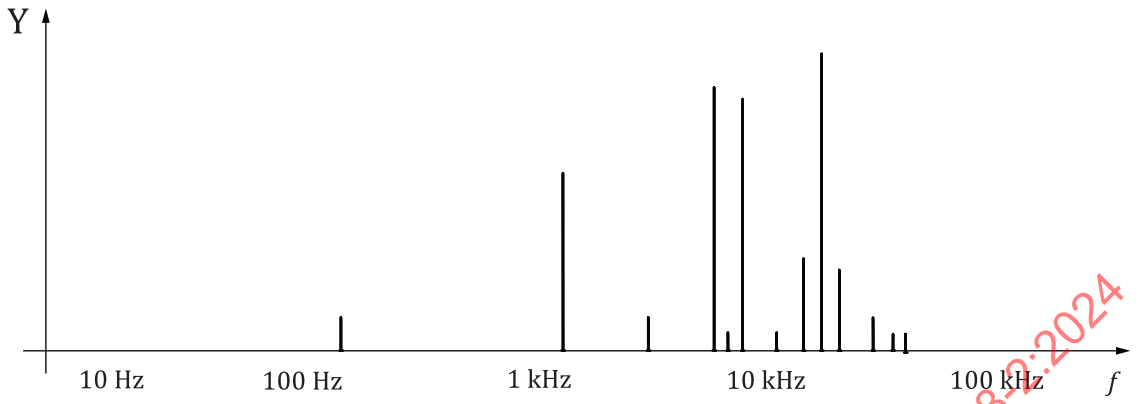
Parameter description	Value
Sampling rate for data acquisition	≥1 MS/s
Filter-type	Low pass: IIR (Bessel)
Filter order	2
Cut-off frequency (3 dB)	150 kHz

6.5.3.3 Evaluation in the frequency domain

There are different methods to process the acquired signal from the time domain to the frequency domain. The customer and the supplier shall agree on the method to be used. The chosen method shall be documented with all parameters used.

The frequency spectrum and the dominating frequencies of the measured voltage ripple shall be documented. The evaluation shall be performed for each operating point. An example of the result is given in Figure 11.

Examples for the test setups and methods are given in Annex D.



Key

Y amplitude of the voltage in the frequency domain

f frequency

Figure 11 — Example of the acquired voltage (U_{VCB}) in the frequency domain

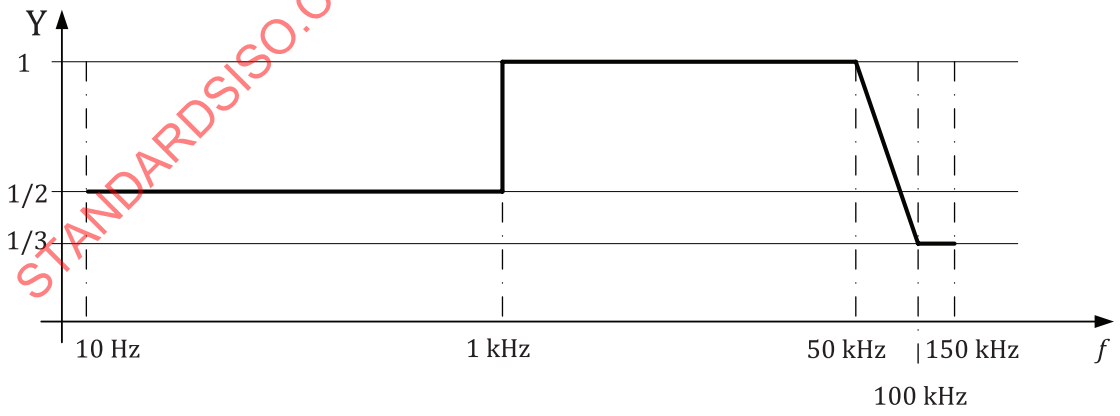
6.5.4 Requirements

6.5.4.1 Requirements in the time domain

It shall be verified that the peak-to-peak value, U_{pp}, of the generated voltage ripple is within the specified limit of the corresponding voltage class. Half of the peak-to-peak value, U_{pp}, shall be less than a given limit U_{VCB,AC_limit} ($½ \cdot U_{pp} < U_{VCB,AC\_limit}$). Example values for U_{VCB,AC_limit} are given in Table B.2.

6.5.4.2 Requirements in the frequency domain

All amplitude variations shall not exceed the maximum values according to the frequency-dependent limit shown in Figure 12.



Key

Y amplitude modification of U_{VCB,AC_limit}

f frequency

Figure 12 — Frequency-dependent amplitude modification of the limit for generated voltage ripple

6.6 Immunity to voltage ripple

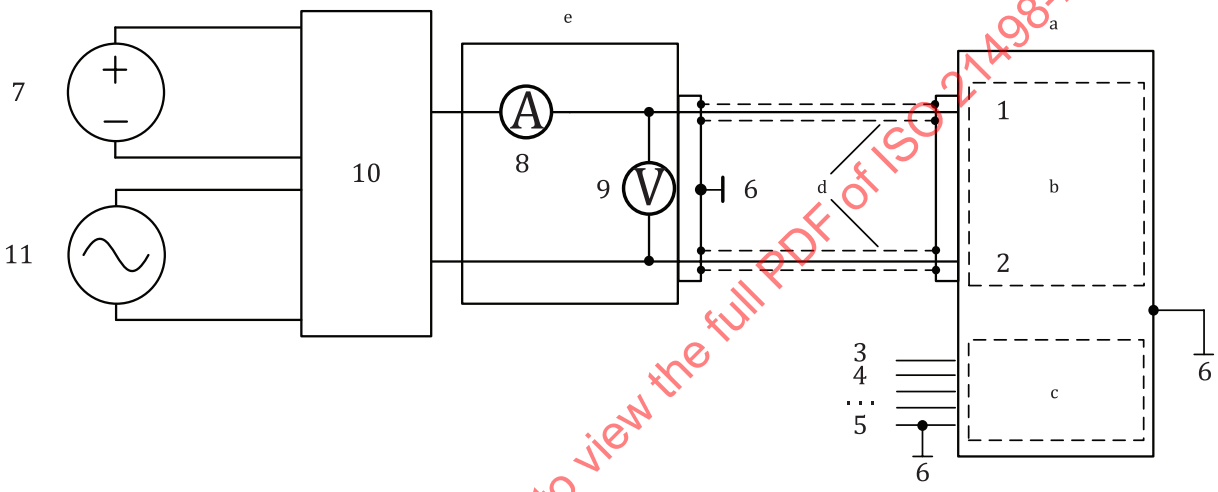
6.6.1 Purpose

This test verifies stable electrical operation of the component when a voltage ripple is present on the class B supply voltage. In this test, the behaviour of the component at frequencies between 100 Hz and 150 kHz is evaluated.

6.6.2 Test setup

For this test, a test setup according to Figure 13 shall be used. A voltage class B DC power supply provides the DC part ($U_{VCB,DC}$) of U_{VCB}. The AC part ($U_{VCB,AC}$) of U_{VCB} shall be generated by an AC voltage source. A coupling/decoupling network (e.g. a transformer) shall be used to combine the DC and AC voltages.

Due to the wide frequency range, the test setup can be changed during the test (e.g. change the coupling transformer, AC voltage source).



Key

1	VCB positive connection: U_{VCB}+	9	voltage sensor (reference for U_{VCB})
2	VCB negative connection: U_{VCB}-	10	coupling/decoupling network
3	VCA power	11	AC voltage source
4	I/O and bus signals	a	DUT.
5	VCA terminal with direct connection to the reference potential	b	VCB circuit.
6	reference potential	c	VCA circuit.
7	VCB DC power supply	d	Wiring.
8	current sensor	e	Measurement devices.

Figure 13 — Test setup for immunity to voltage ripple

6.6.3 Test procedure

Install the DUT in a test setup according to Figure 13. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. U_{init}).

The customer and the supplier shall agree on the number of operating points tested as well as the operating points themselves.

Adjust the operation voltage $U_{VCB,DC}$ according to Table 13 and $U_{VCB,AC}$, as agreed by the customer and the supplier. The frequency of the sinusoidal test voltage shall vary according to the parameters outlined in Table 13. The frequency sweep may be separated into several sequences.

The amplitude of the sinusoidal test voltage shall be verified at all frequency points. The hold time at each frequency step shall be long enough to record all values, at least 2 s.

The maximum amplitude of the voltage ripple is expected in the frequency range between 1 kHz and 50 kHz due to the switching frequency of power electronic devices and their included harmonics. Beyond this frequency range, the given amplitude can be modified according to Figure 14. All variations that are higher than the amplitude modification given in Figure 14 are also valid.

If the AC current exceeds a limit agreed upon by the customer and the supplier (e.g. due to resonant effects), a deviation of the applied sinusoidal test voltage is allowed for that specific frequency. The deviation shall be recorded. The current amplitude limit depends on specific vehicle components and system topology. Example values for current amplitude limits at the respective frequency are given in Table B.4. Depending on the frequency, the current amplitude limit can be modified according to Figure 14.

The superimposed alternating test voltage and current at the voltage class B terminals shall be recorded during the test. Relevant parameters to evaluate the OS of the DUT shall also be recorded.

The test shall be repeated for the number of test cycles and for all voltages $U_{VCB,DC}$ specified in Table 13. The test cycles may be performed separately or in one sequence.

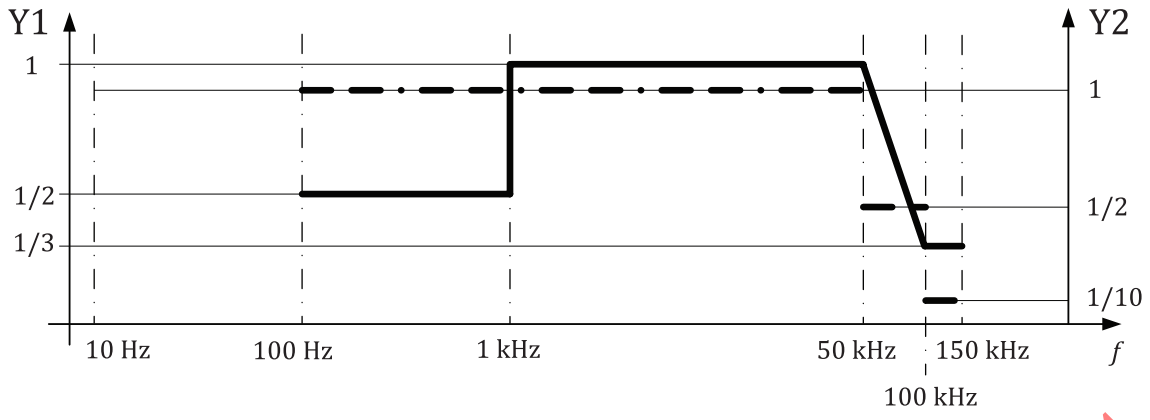
Table 13 — Test parameters for immunity to voltage ripple

Test parameter	Value	Remark
OS	OS1, OS2	Operating status
$U_{VCB,DC}$	U_{upper_limit}, $U_{max\_unlimited\_op}$, U_{init}, $U_{min\_unlimited\_op}$, U_{lower_limit}	DC part of U_{VCB}
$U_{VCB,AC}$	As agreed by the customer and the supplier [a]	Peak value of the overlaid sinusoidal test voltage
f	100 Hz – 150 kHz [b]	Frequency range of the overlaid sinusoidal test voltage $U_{VCB,AC}$
Δf	E12[c] series. Smaller increments may be used if necessary	Frequency increment within one decade
t_h	≥2 s	Hold time at each frequency
n	3	Number of test cycles

[a] Example values are given in Table B.3.

[b] If necessary, the customer and the supplier shall agree on deviations.

[c] See IEC 60063.



Key

Y_1 amplitude modification of $U_{VCB,AC}$ (solid line)

Y_2 amplitude modification of current amplitude limit (dashed line)

f frequency

Figure 14 — Frequency-dependent amplitude modification for immunity to voltage ripple

6.6.4 Requirements

Evidence shall be provided that the voltage class B operating status of the DUT in the respective operating range does not change due to the overlaid sinusoidal test voltage. The DUT shall perform as specified.

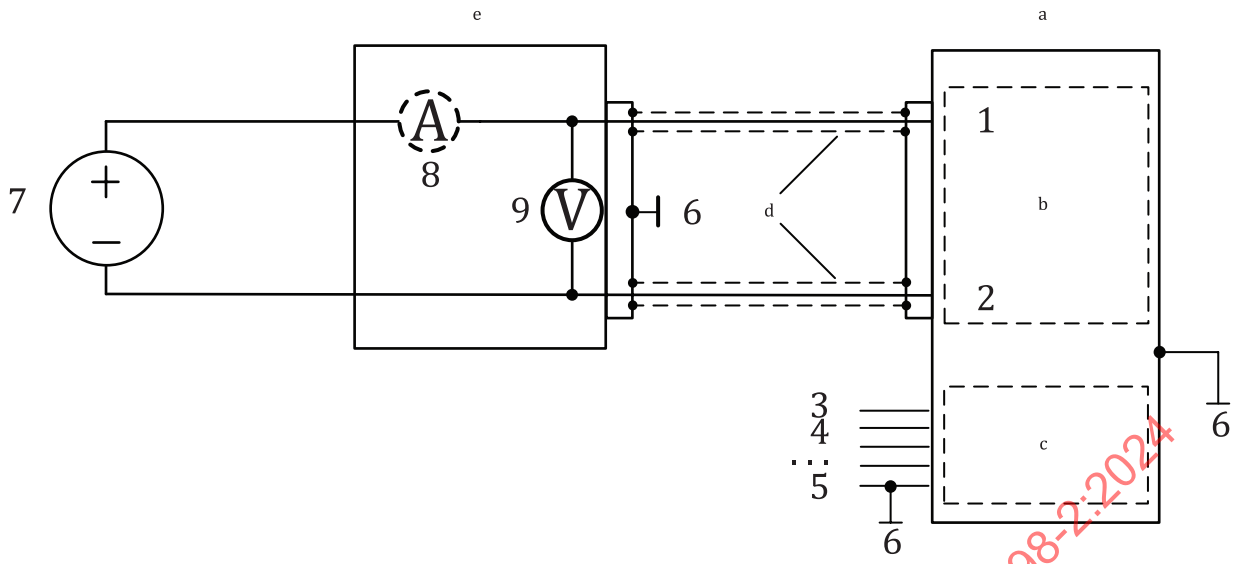
6.7 Overvoltage

6.7.1 Purpose

This test evaluates the robustness of the component in case the DC voltage rises above the upper voltage limit. The test verifies whether the component can protect itself or withstand a specified maximum voltage limit within the overvoltage limit. The behaviour of the component may differ depending on the power request.

6.7.2 Test setup

For this test, a test setup according to Figure 15 shall be used. The test setup consists of a variable voltage class B DC power supply and the DUT. A profile for the required voltage U_{VCB} is given in Figure 16.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 15 — Test setup for overvoltage

6.7.3 Test procedure

Install the DUT in a test setup according to Figure 15. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. U_{init}).

The DUT shall be ready to operate but no power request is applied (no power is consumed or provided).

Apply the voltage profile according to Figure 16, with the parameters in Table 14, while recording the voltage U_{VCB}.

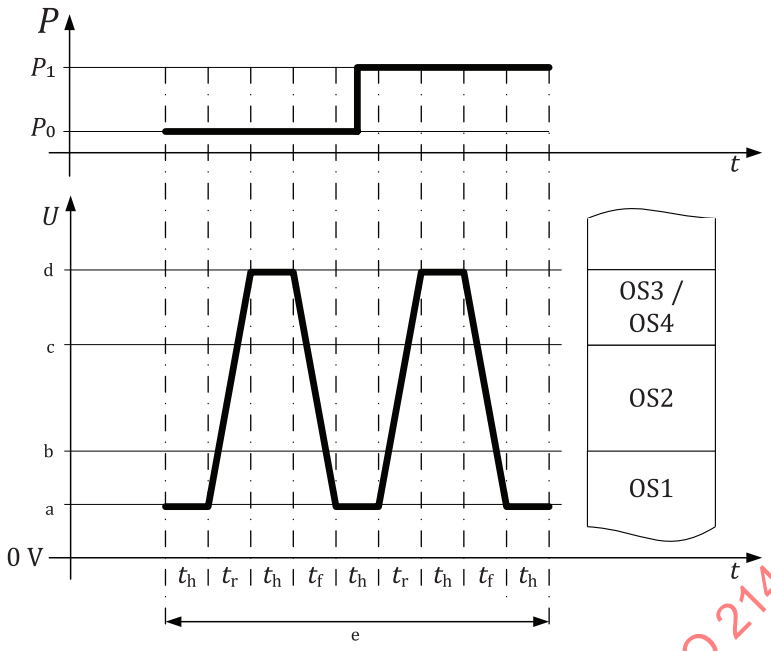
The test cycles may be performed separately or in one sequence.

Table 14 — Test parameters for overvoltage

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
t_h	20 s	Hold time
t_r	$\Delta U/\Delta t \leq 2$ V/s [b]	Rise time, to be determined with $\Delta U/\Delta t$
t_f	$\lvert\Delta U/\Delta t\rvert \leq 2$ V/s [b]	Fall time, to be determined with $\lvert\Delta U/\Delta t\rvert$
n	3	Number of test cycles

[a] Or as agreed by the customer and the supplier.

[b] Voltage change rate may be faster if the DUT stays in stable operation.



Key

P	$P_{request}$
P_0	P_{idle}
P_1	P_{cont}
t	time
t_f	fall time
t_h	hold time
t_r	rise time
U	voltage
a	$U_{init.}$
b	$U_{max\_unlimited\_op.}$
c	$U_{upper\_limit.}$
d	$U_{over\_limit.}$
e	One test cycle.

Figure 16 — Voltage profile for overvoltage

6.7.4 Requirements

The DUT shall be operational according to the component specification for OS3 or OS4. Depending on the DUT, a reset of the DUT may be necessary after the test voltage falls below U_{upper_limit}.

After testing with the overvoltage pulse, verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation.

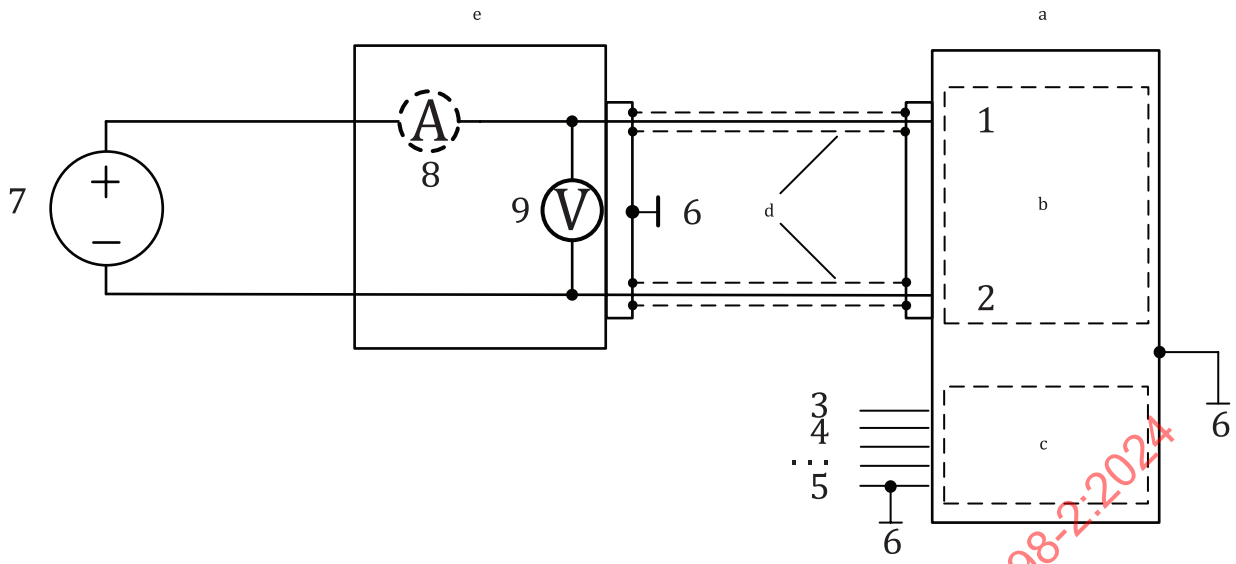
6.8 Undervoltage

6.8.1 Purpose

This test evaluates the robustness of the component in case the DC voltage drops below the lower voltage limit. The test verifies whether the voltage class B component can perform as specified during an undervoltage event. The behaviour of the component may differ depending on the power request.

6.8.2 Test setup

For this test, a test setup according to Figure 17 is used. The test setup consists of a variable voltage class B DC power supply and the DUT. A profile for the voltage U_{VCB} is given in Figure 18.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 17 — Test setup for undervoltage

6.8.3 Test procedure

Install the DUT in a test setup according to Figure 17. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

The DUT shall be ready to operate but no power request is applied (no power is consumed or provided).

Apply the voltage profile according to Figure 18, with the parameters in Table 15, while recording the voltage U_{VCB}.

Between the first and the second voltage drop, a power request shall be applied and the DUT shall consume or provide power corresponding to OS1.

In the event of undervoltage, operation with the performance specified for the voltage class B operating status OS3 or OS4 shall be verified.

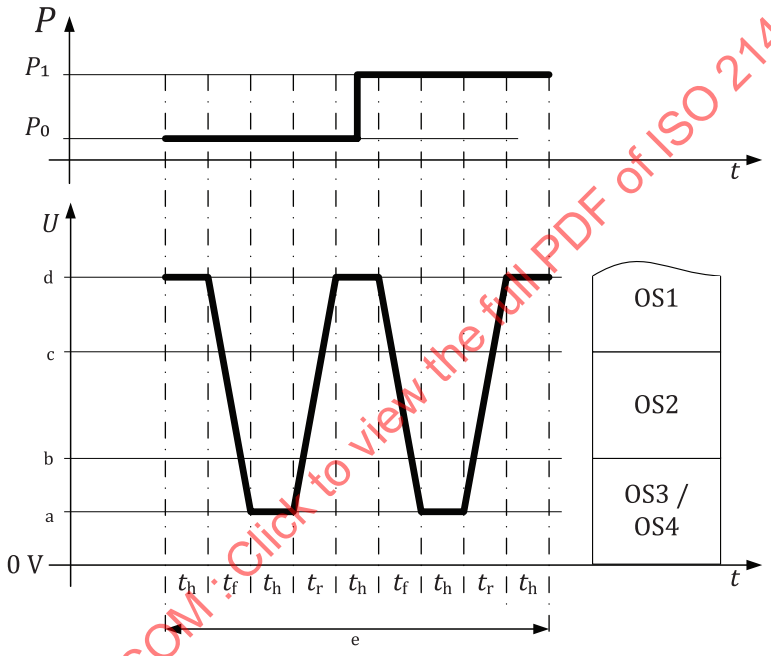
The test cycles may be performed separately or in one sequence.

Table 15 — Test parameters for undervoltage

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
U_m	$U_{lower\_limit} / 2$ [a]	Voltage in the undervoltage range
t_h	20 s	Hold time
t_f	$\lvert\Delta U/\Delta t\rvert \leq 2$ V/s[b]	Fall time, to be calculated with $\lvert\Delta U/\Delta t\rvert$
t_r	$\Delta U/\Delta t \leq 2$ V/s[b]	Rise time, to be calculated with $\Delta U/\Delta t$
P	P_{cont}	Continuous power
n	3	Number of test cycles

[a] Or as agreed by the customer and the supplier.

[b] Voltage change rate can be faster if the DUT stays in stable operation.



Key

P	$P_{request}$	U	voltage
P_0	P_{idle}	a	$U_{m.}$
P_1	P_{cont}	b	$U_{lower\_limit.}$
t	time	c	$U_{min\_unlimited\_op.}$
t_f	fall time	d	$U_{init.}$
t_h	hold time	e	One test cycle.
t_r	rise time		

Figure 18 — Voltage profile for undervoltage

6.8.4 Requirements

The DUT shall be operational according to the component specification for OS3 or OS4. Depending on the DUT, a reset of the DUT may be necessary after the test voltage rises above U_{lower_limit}.

After testing with the undervoltage pulse, verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation.

6.9 Voltage offset

6.9.1 Purpose

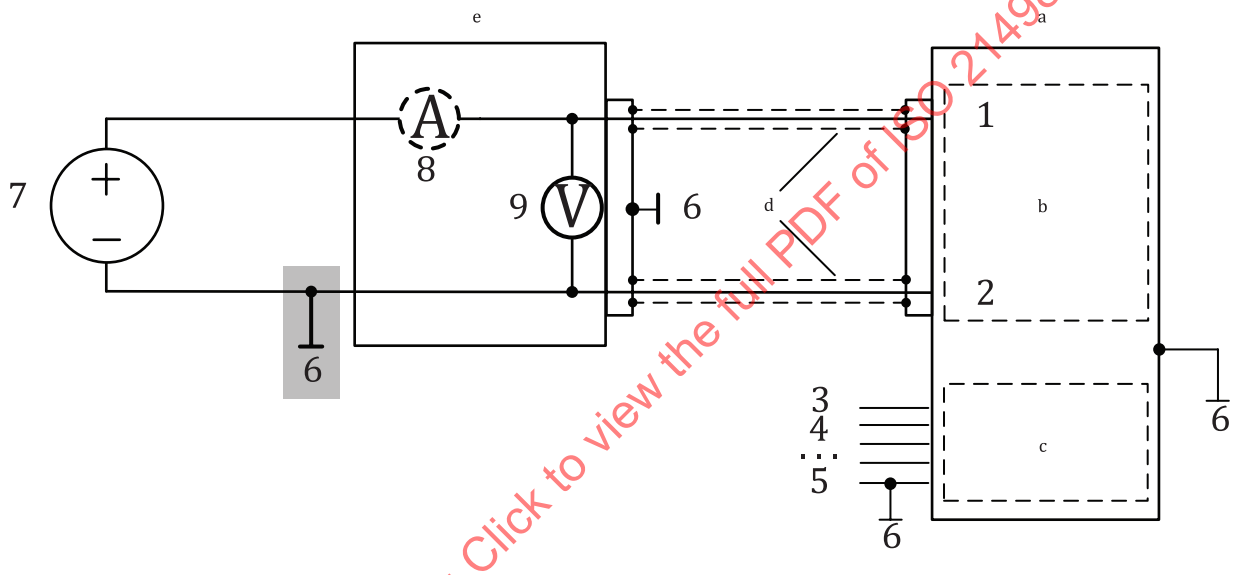
This test evaluates the robustness of the voltage class B component in case the insulation resistance decreases.

This test covers the worst-case condition, which is the electrical connection of one of the two power lines to the reference potential.

6.9.2 Test setup

For this test, a test setup according to Figure 19 and Figure 20 is used. The test setup consists of a voltage class B DC power supply and the DUT. A connection between the voltage class B DC power supply, the conductive housing of the DUT and/or reference potential shall be installed.

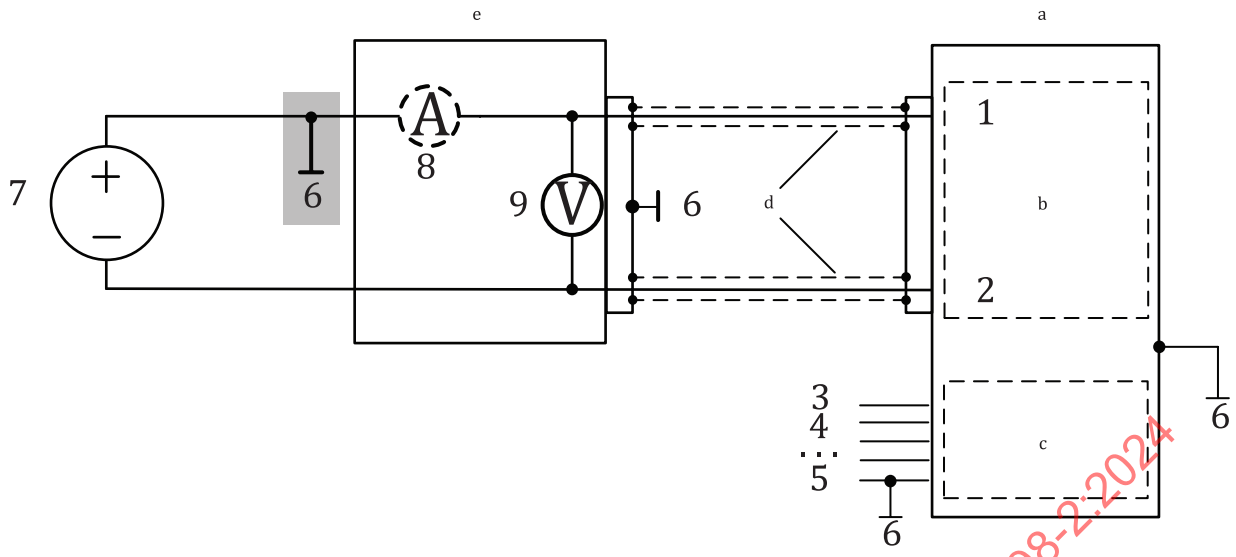
A profile for the voltage U_{VCB} is given in Figure 21.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 19 — Test setup for voltage offset with VCB negative connection shorted to reference potential



Key

1	VCB positive connection: U_{VCB}+	8	current sensor (optional)
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.

Figure 20 — Test setup for voltage offset with VCB positive connection shorted to reference potential

6.9.3 Test procedure

a) Install the DUT in a test setup according to Figure 19. Connect the following to a common reference potential:

- negative voltage class B connection (U_{VCB}-) of the DUT (Figure 19, key reference 2);
- voltage class A terminal with direct connection to the reference potential (Figure 19, key reference 5);
- conductive housing (Figure 19, key references a and e).

Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

The DUT shall operate in an operating point corresponding to OS1. The customer and the supplier shall agree on this operating point.

Change U_{VCB} as defined in Figure 21 and Table 16 and verify that the DUT behaves as specified for the respective OS.

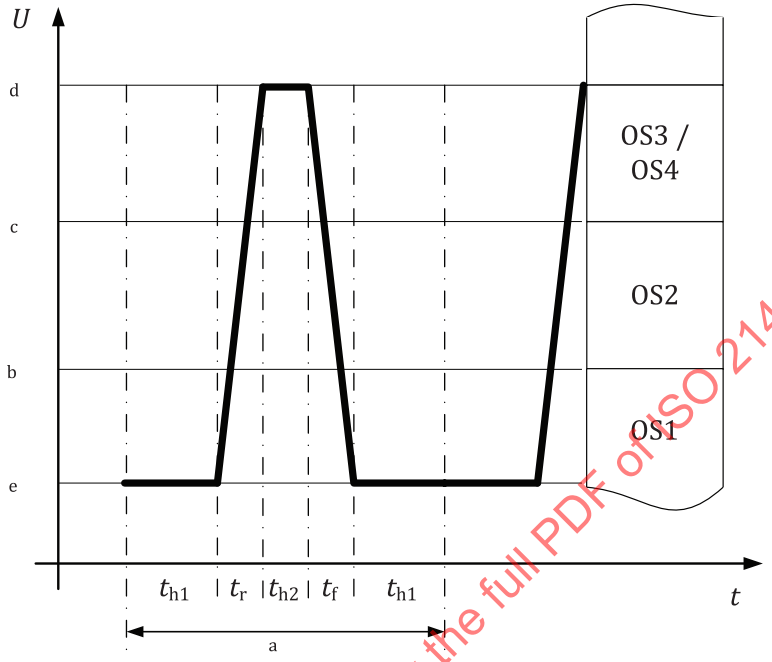
b) Install the DUT in a test setup according to Figure 20 connecting the following to a common reference potential:

- positive voltage class B connection (U_{VCB}+) of the DUT (Figure 20, key reference 1);
- voltage class A terminal with direct connection to the reference potential (Figure 20, key reference 5);
- conductive housing (Figure 20, key references a and e).

Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

The DUT shall operate in an operating point corresponding to OS1. The customer and the supplier shall agree on this operating point.

Change U_{VCB} as defined in Figure 21 and Table 16 and verify that the DUT behaves as specified for the respective OS.



Key

U	voltage	a	One test cycle.
t	time	b	$U_{max\_unlimited\_op}$.
t_f	fall time	c	U_{upper_limit}.
t_h	hold time	d	U_{over_limit}.
t_r	rise time	e	U_{init}.

Figure 21 — Voltage profile for voltage offset

Table 16 — Test parameters for voltage offset

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
t_{h1}	30 s	Hold time
t_f	$\lvert\Delta U/\Delta t\rvert \leq 2$ V/s [b]	Fall time, to be calculated with $\lvert\Delta U/\Delta t\rvert$
t_{h2}	10 s	Hold time
t_r	$\Delta U/\Delta t \leq 2$ V/s [b]	Rise time, to be calculated with $\Delta U/\Delta t$
n	2	One cycle with positive and one cycle with negative potential shorted to reference potential

[a] Or as agreed by the customer and the supplier.

[b] Voltage change rate can be faster if the DUT stays in stable operation.

6.9.4 Requirements

If the DUT operates according to OS4, a reset may be necessary at the beginning of the next cycle and no operation is required during fall time.

Evidence shall be provided that the DUT behaves as specified for the respective OS relevant for the DC voltages in the voltage profile.

6.10 Generated load dump voltage

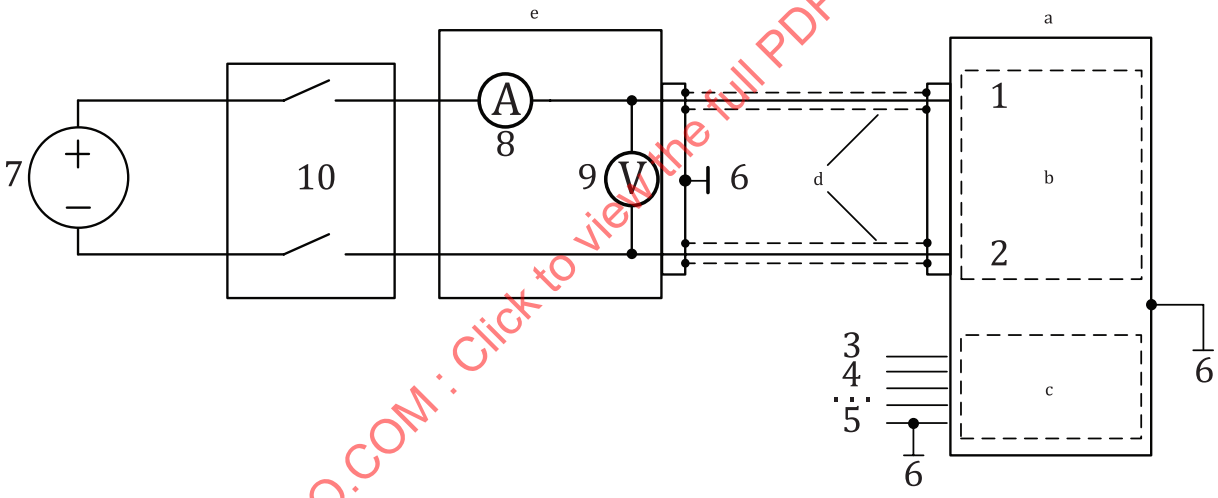
6.10.1 Purpose

This test verifies whether a voltage class B component can limit the overvoltage during a load dump.

The resulting voltage change rate that occurs during a load dump is one of the main subjects of this test and needs to be documented because it may affect other components connected to the voltage class B system.

6.10.2 Test setup

For this test, a test setup according to Figure 22 is used. The test setup consists of a variable voltage class B DC power supply operating as a power sink and switches. The customer may request extra circuit components to be added to the test setup between the switches (see Figure 22, key reference 10) and the measurement devices (see Figure 22, key reference e) to represent a certain power network of interest.



Key

1	VCB positive connection: U_{VCB}+	8	current sensor
2	VCB negative connection: U_{VCB}-	9	voltage sensor (reference for U_{VCB})
3	VCA power	10	switches (e.g. mechanical or semiconductor)
4	I/O and bus signals	a	DUT.
5	VCA terminal with direct connection to the reference potential	b	VCB circuit.
6	reference potential	c	VCA circuit.
7	VCB DC power supply (sink)	d	Wiring.
		e	Measurement devices.

Figure 22 — Test setup for generated load dump voltage

6.10.3 Test procedure

Install the DUT in a test setup according to Figure 22 with closed switches. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}). The DUT shall

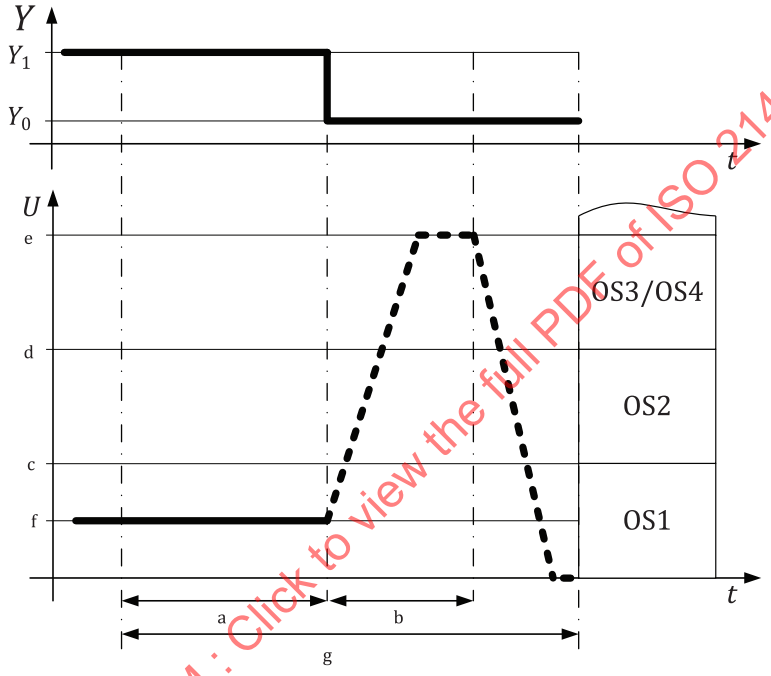
be operated at an operating point corresponding to OS1, providing electrical energy to the sink. Adjust the working voltage U_{VCB} and the delivered power P_{DUT} according to Table 17 during the time interval, key reference a in Figure 23, and wait until steady state is reached.

Open the switches while recording the voltage U_{VCB} and current in the time domain.

Opening the switches during the test will lead to an electric arc (in case of using mechanical switches). Due to the switch-specific influence of the electric arc, the U_{VCB} and the current shall be documented, and the customer and the supplier shall agree on the test results.

Figure 23 gives an example of an acquired voltage profile U_{VCB}, neglecting electric arc effects. This may vary according to the DUT.

The test shall be repeated n times for each voltage specified in Table 17. The test cycles shall be performed separately.



Key

t	time	b	Voltage characteristic to evaluate.
U	voltage	c	$U_{max\_unlimited\_op.}$
Y	VCB switch status	d	$U_{upper\_limit.}$
Y_0	switches open	e	$U_{over\_limit.}$
Y_1	switches closed	f	$U_{VCB.}$
a	Start-up phase.	g	One test cycle.

NOTE The pulse shape after the switches are opened is shown as a dotted line as an example. The pulse shape is not be defined before the test takes place because it depends on the characteristics of the DUT.

Figure 23 — Profile for switch status and example for acquired voltage for generated load dump voltage

Table 17 — Test parameters for generated load dump voltage

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
U_{VCB}	U_{init}, $U_{max\_unlimited\_op}$, $U_{min\_unlimited\_op}$	Voltage level before the switches are opened
P_{DUT}	P_{max_gen}	Delivered DC VCB power by the DUT before the switches are opened
n	3	Number of test cycles

[a] Or as agreed by the customer and the supplier.

6.10.4 Requirements

Evidence shall be provided to show that the voltage U_{VCB} does not exceed the overvoltage limit during the time interval, key reference b in Figure 23.

The generated overvoltage, including the rise time (using 10 % and 90 % of the voltage rise from key references c to e in Figure 23), shall be recorded and evaluated.

In addition, evidence shall be provided that the DUT meets its specifications after the test.

6.11 Immunity to load dump voltage

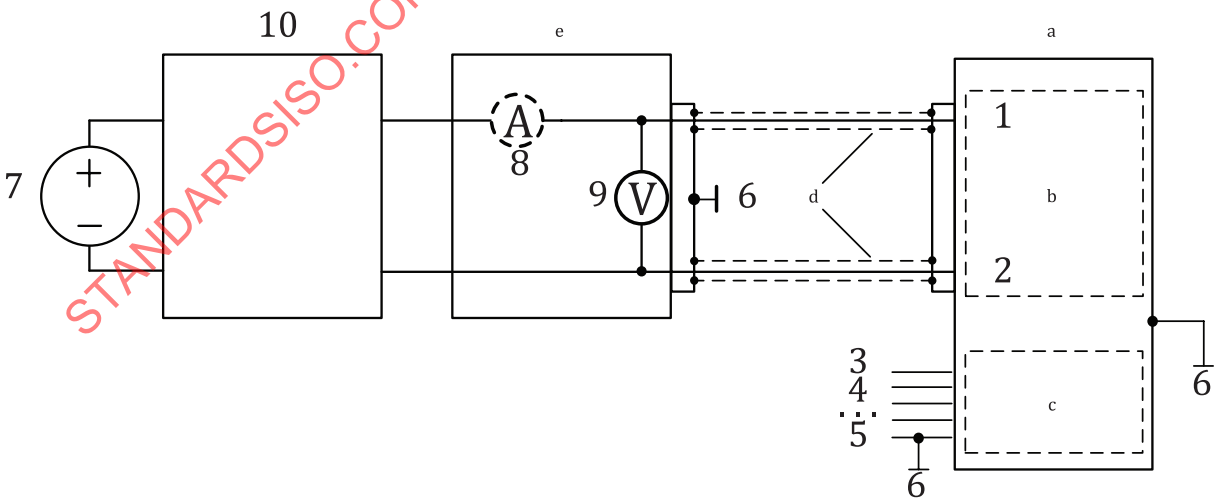
6.11.1 Purpose

This test verifies if a voltage class B component can withstand the fast voltage rise and the overvoltage caused by a load dump.

6.11.2 Test setup

For this test, a test setup according to Figure 24 is used. The test setup consists of a variable voltage class B DC power supply and the DUT. If the voltage class B DC power supply cannot provide the required slope, a load dump generator shall be added.

A voltage profile for the voltage U_{VCB} is given in Figure 25.



Key

1 VCB positive connection: U_{VCB}+
2 VCB negative connection: U_{VCB}-
3 VCA power
4 I/O and bus signals
9 voltage sensor (reference for U_{VCB})
10 load dump generator (optional, if needed)
a DUT.
b VCB circuit.

5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Wiring.
7	VCB DC power supply	e	Measurement devices.
8	current sensor (optional)		

Figure 24 — Test setup for immunity to load dump voltage

6.11.3 Test procedure

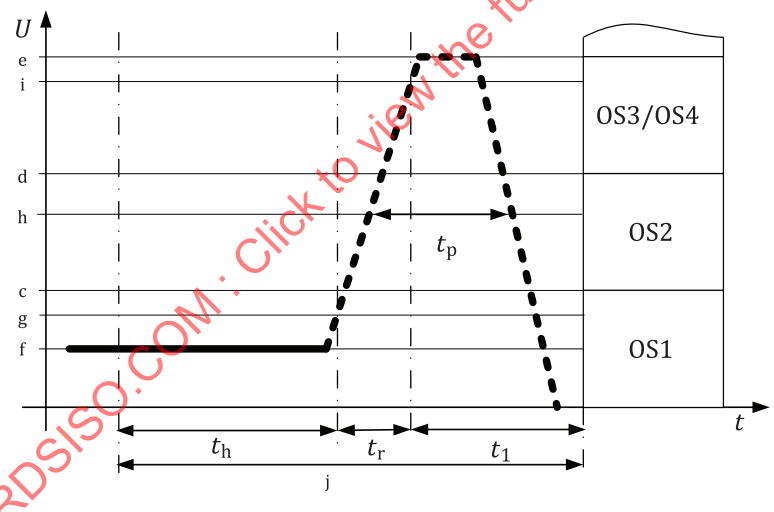
Install the DUT in a test setup according to Figure 24. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. at U_{init}).

The DUT shall operate in an operating point corresponding to OS1. The customer and the supplier shall agree on this operating point.

The test starts with the voltage U_{init} as indicated in Table 18 and Figure 25. After the hold time, t_h, the voltage is rapidly increased to its end value U_{over_limit} as indicated in Table 18 and Figure 25. After the voltage has reached its end value, the voltage class B DC power supply may hold the voltage and decrease the voltage afterwards as indicated in Figure 25. The entire resulting voltage profile indicated in Figure 25 shall be documented.

If the DUT enters OS4, the DUT shall be reset between test cycles.

The test cycles may be performed separately or in one sequence.



Key

t	time	d	$U_{upper\_limit.}$
t_h	hold time	e	$U_{over\_limit.}$
t_p	pulse width	f	$U_{init.}$
t_r	rise time	g	$U_{10.}$
U	voltage	h	$U_{50.}$
c	$U_{max\_unlimited\_op.}$	i	$U_{90.}$
		j	One test cycle.

Figure 25 — Voltage profile for immunity to load dump voltage

Table 18 — Test parameters for immunity to load dump voltage

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
t_h	30 s	Hold time
t_p	≥10 ms [a]	Pulse width
t_r	e.g. $\Delta U/\Delta t \geq 250$ V/ms [b]	Rise time, to be calculated with $\Delta U/\Delta t$ [a]
U_{10}	10 % of ΔU ($\Delta U = U_{over\_limit} - U_{init}$)	Voltage level at the start of t_r
U_{50}	50 % of ΔU ($\Delta U = U_{over\_limit} - U_{init}$)	Voltage level to evaluate t_p
U_{90}	90 % of ΔU ($\Delta U = U_{over\_limit} - U_{init}$)	Voltage level at the end of t_r
a	≤2 min	Duration of one test cycle
n	3	Number of test cycles

[a] Or as agreed by the customer and the supplier.

[b] An example for calculation is given in B.3.

6.11.4 Requirements

Evidence shall be provided that the DUT behaves as specified for the respective OS after the test. Any abnormalities during the test shall be documented.

6.12 Short circuit

6.12.1 Purpose

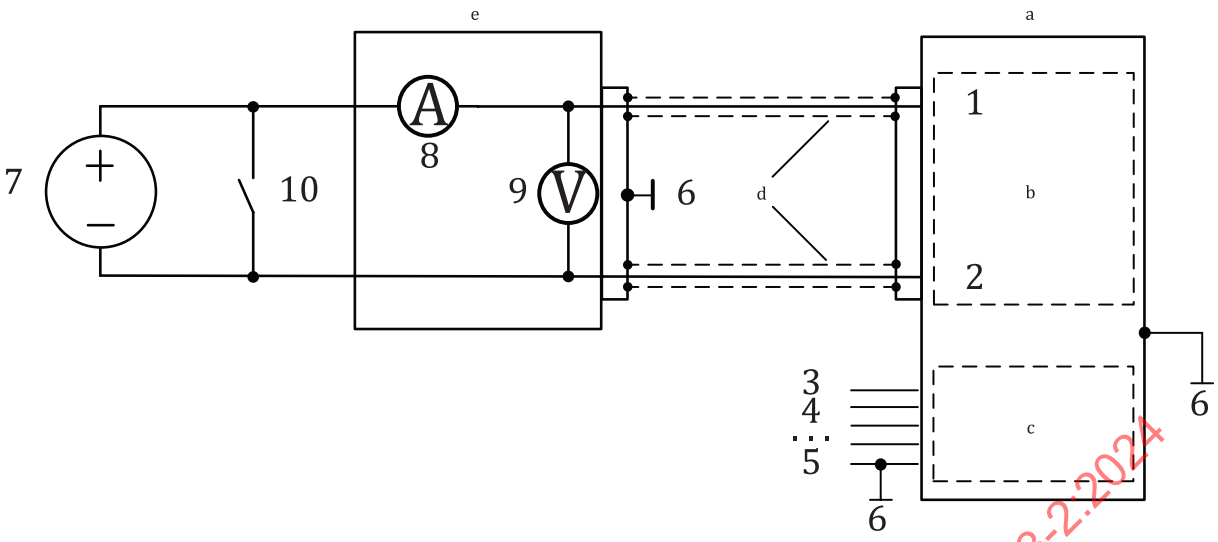
This test verifies whether a voltage class B component can withstand a short circuit, external to the component, between voltage class B positive and negative connection.

Note For rechargeable energy storage systems (RESS), see ISO 6469-1:2019 chapter 6.5.1.

6.12.2 Test setup

The test setup, including the equipment, procedure and requirements, are to be aligned carefully by the customer and the supplier.

For this test, a test setup according to Figure 26 is used. The test setup consists of a voltage class B DC power supply, a switch and the DUT. The maximum short circuit resistance between the terminals of the measurement device (Figure 26, key reference e), which are connected to the DUT, including the closed switch, shall be less than or equal to 5 mΩ. To represent an intended vehicle topology, the customer may define a different cable length compared to 6.1.10.



Key

1	VCB positive connection: U_{VCB}+	9	voltage sensor (reference for U_{VCB})
2	VCB negative connection: U_{VCB}-	10	switch (e.g. mechanical or semiconductor)
3	VCA power	a	DUT.
4	I/O and bus signals	b	VCB circuit.
5	VCA terminal with direct connection to the reference potential	c	VCA circuit.
6	reference potential	d	Cables (shielding optional).
7	VCB DC power supply	e	Measurement devices.
8	current sensor		

Figure 26 — Test setup for short circuit

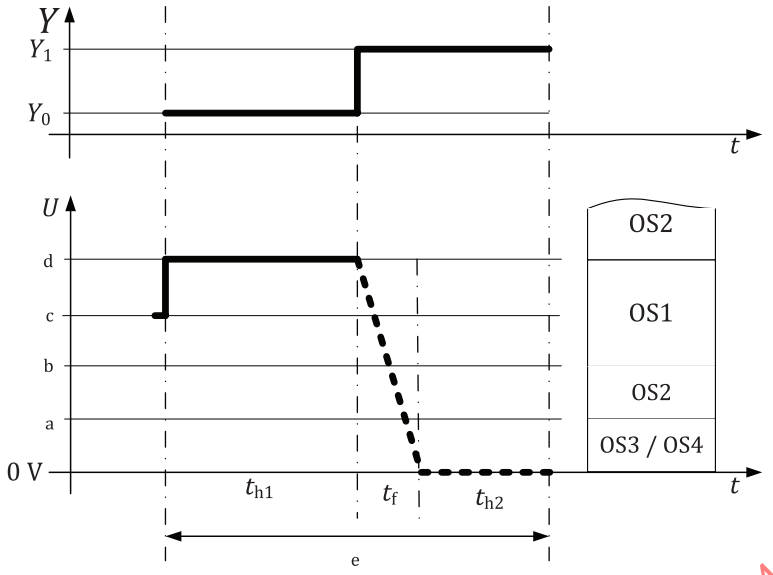
6.12.3 Test procedure

Install the DUT in a test setup according to Figure 26 with open switch. Verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation (e.g. U_{init}).

For the test, the DUT shall be operated in OS1 at an operating point where the worst case is expected. If the worst case is expected to be reached with various operating points (e.g. speed and torque), the customer and the supplier shall agree on the operating points themselves as well as the number of operating points. Typically, the DUT shall be operated at the highest voltage within OS1. Default values for the voltage and power are given in Table 19.

Adjust the voltage U_{VCB} and the delivered power P_{DUT} according to Table 19. Close the switch while recording the voltage U_{VCB} in the time domain. The switch may chatter or have a transition phase. The voltage U_{VCB} and the current shall be documented and the customer and the supplier shall agree on the results. Figure 27 shows an example for the acquired voltage profile U_{VCB}. This may vary depending on the DUT.

The test cycles may be performed separately.



Key

Y	VCB switch status	U	voltage
Y_0	switch open	a	$U_{lower\_limit.}$
Y_1	switch closed	b	$U_{min\_unlimited\_op.}$
t	time	c	$U_{init.}$
t_f	fall time	d	$U_{max\_unlimited\_op.}$
t_h	hold time	e	One test cycle.

Figure 27 — Example for recorded voltage for short circuit

Table 19 — Test parameters for short circuit

Test parameter	Value	Remark
U_{init}	$(U_{max\_unlimited\_op} + U_{min\_unlimited\_op}) / 2$ [a]	Voltage at start of test
U_{VCB}	$U_{max\_unlimited\_op}$ [a,b]	Voltage level before the switch is closed
P_{DUT}	P_{idle} [a], P_{peak} [a,b] and/or P_{max_gen} [a,b]	Delivered DC VCB power by the DUT before the switch is closed
t_{h1}	10 s	Hold time
t_{h2}	60 s [a]	Hold time during short circuit
t_f	Depending on test equipment and DUT	Fall time
n	3	Number of test cycles
[a] Or as agreed by the customer and the supplier.		
[b] Default value, where worst case is expected.		

6.12.4 Requirements

The DUT shall operate according to the component specification for the respective OS during the test.

After the test, verify that all functions operate according to OS1 at a voltage within the specification for unlimited operation.

If the customer and supplier agree, the actions in the service concept of the customer shall be followed before verification of all functions according to OS1. This may include the change or reset of short circuit protection devices (e.g. fuses).