

INTERNATIONAL STANDARD

**Low-voltage switchgear and controlgear –
Part 4-3: Contactors and motor-starters – Semiconductor controllers and
semiconductor contactors for non-motor loads**

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INTERNATIONAL STANDARD

**Low-voltage switchgear and controlgear –
Part 4-3: Contactors and motor-starters – Semiconductor controllers and
semiconductor contactors for non-motor loads**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

**Part 4-3: Contactors and motor-starters –
Semiconductor controllers and semiconductor
contactors for non-motor loads**

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International Standard IEC 60947-4-3 has been prepared by subcommittee 121A: Low-voltage switchgear and controlgear, of IEC technical committee 121: Switchgear and controlgear and their assemblies for low-voltage.

This third edition cancels and replaces the second edition published in 2014. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) scope exclusions;
- b) editorial correction of notes and hanging paragraphs;

- c) safety aspects related to:
 - general aspects;
 - limited energy circuits;
 - electronic circuits;
- d) mention of dedicated wiring accessories;
- e) power consumption measurement;
- f) alignment to IEC 60947-1:2020;
- g) alignment with IEC 60947-4-2 when appropriate.

The provisions of the general rules dealt with IEC 60947-1 are applicable to this part of IEC 60947 series where specifically called for. Clauses and subclauses, tables, figures and annexes of the general rules thus applicable are identified by reference to IEC 60947-1:2020.

The text of this document is based on the following documents:

FDIS	Report on voting
121A/357/FDIS	121A/368/RVD

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

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

A list of all parts in the IEC 60947 series, published under the general title *Low-voltage switchgear and controlgear*, can be found on the IEC website.

The following differing practices of a less permanent nature exist in the countries indicated below.

5.5 USA and Canada

8.1.14.1 Canada

Table 14 USA

Table 15 USA

9.4.3.2 USA

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

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

INTRODUCTION

This document covers low-voltage semiconductor controllers and semiconductor contactors (solid-state contactors) intended for the use with non-motor loads. As semiconductor controllers, they have many capabilities beyond the simple switching on and off of non-motor loads. As semiconductor contactors, they perform the same functions as mechanical contactors, but utilize one or more semiconductor switching devices in their main poles.

The devices may be single-pole or multi-pole (see 3.5.1 of IEC 60947-1:2020). This document refers to complete devices rated as a unit incorporating all necessary heat-sinking material and terminals. It includes devices with all necessary terminals, which are supplied with or without heat-sink in knocked-down form for combination by the users, when the manufacturer gives with the device detailed information about choosing the heat-sink and mounting the device on the heat-sink.

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LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 4-3: Contactors and motor-starters – Semiconductor controllers and semiconductor contactors for non-motor loads

1 Scope

This document applies to semiconductor controllers and semiconductor contactors for non-motor load intended to be connected to circuits, the rated voltage of which does not exceed 1 000 V AC.

It covers their use:

- for operations of changing the state of AC electric circuits between the ON-state and the OFF-state;
- with or without bypass switching devices;
- as controller, for reducing the amplitude of the RMS AC voltage.

This document does not apply to:

- electromechanical contactors (see IEC 60947-4-1);
- short-circuit protective device associated with semiconductor controllers and semiconductor contactors (see IEC 60947-4-1 (MPSD), IEC 60947-2 and IEC 60947-3);
- semiconductor motor controller or soft-starter equipment (see IEC 60947-4-2);
- semiconductor converters (see IEC 60146 (all parts));
- solid-state relays (see IEC 62314);
- use of the product within explosive atmospheres (see IEC 60079 (all parts));
- software and firmware requirements (see IEC TR 63201);
- cyber security aspects (see IEC TS 63208).

Contactors and control-circuit devices used in semiconductor controllers and contactors are considered compliant with the requirements of their relevant product standard. Where mechanical switching devices are used, they are considered meeting the requirements of their own IEC product standard and the additional requirements of this document.

The object of this document is to state as follows:

- the characteristics of semiconductor controllers and semiconductor contactors;
- the conditions with which semiconductor controllers and semiconductor contactors comply with reference to:
 - a) their operation and behaviour in normal and abnormal operating conditions including overcurrent operating conditions;
 - b) their dielectric properties;
 - c) the degrees of protection provided by their enclosures, where applicable;
 - d) their construction including safety measures against electric shock, fire hazard and mechanical hazard;
- the tests intended for confirming that these conditions have been met, and the methods to be adopted for these tests;
- the information to be given with the equipment or in the manufacturer's literature.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60445, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals, conductor terminations and conductors*

IEC 60715, *Dimensions of low-voltage switchgear and controlgear – Standardized mounting on rails for mechanical support of switchgear, controlgear and accessories*

IEC 60730-1, *Automatic electrical controls – Part 1: General requirements*

IEC 60947-1:2020, *Low-voltage switchgear and controlgear – Part 1: General rules*

IEC 60947-4-1, *Low-voltage switchgear and controlgear – Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters*

IEC 61000-3-2, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-3, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

IEC 61000-3-12, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*

CISPR 11:2015, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*
CISPR 11:2015/AMD1:2016

ISO 2859-1:1999, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*
ISO 2859-1:1999/AMD1:2011

3 Terms, definitions, symbols and abbreviated terms

3.1 General

For the purposes of this document, the terms and definitions given in Clause 3 of IEC 60947-1:2020, as well as the following terms, definitions, symbols and abbreviated terms apply.

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

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

3.2 Alphabetical index of terms

Term		Reference
A	Abnormal operating condition	3.5.1
	Accessible part	3.5.2
B	Bypassed semiconductor controller	3.4.18
C	Current-limit function	3.4.1
F	FULL-ON	3.4.6
G	Galvanic opening	3.4.20
	Galvanic separation	3.4.21
H	Hazardous-live-part	3.5.3
I	Instantaneous switching	3.4.9
L	Limited energy source	3.5.4
	Load control	3.4.2
O	OFF-state	3.4.7
	OFF-state current	3.4.8
	OFF-time	3.4.17
	ON-state	3.4.5
	ON-time	3.4.16
	Operating capability	3.4.11
	Operating cycle	3.4.10
	Overcurrent protective means OCPM	3.4.15
	Overload current profile	3.4.12
P	Protective impedance	3.5.5
R	Ramp-down	3.4.4
	Ramp-up	3.4.3
	Rating index	3.4.13
	Reasonably foreseeable misuse	3.5.6
S	Semiconductor controller	3.3.1
	Semiconductor contactor	3.3.2
	Semiconductor controller power losses	3.4.19
	Single fault condition	3.5.7
T	Trip-free semiconductor controller	3.4.14

3.3 Terms and definitions concerning the types of semiconductor controllers and semiconductor contactors (see Figure 1)

3.3.1

semiconductor controller

semiconductor switching device that provides a switching function for an AC electrical load and an OFF-state

Note 1 to entry: Because hazardous levels of the OFF-state current (3.4.8) exist in a semiconductor controller, the load terminals are considered as live parts at all times.

Note 2 to entry: In a circuit where the current passes through zero (alternately or otherwise), the effect of "not making" the current following such a zero value is equivalent to breaking the current.

Note 3 to entry: See 3.4.3 of IEC 60947-1:2020 for the definition of semiconductor switching device.

3.3.2

semiconductor contactor

<solid-state contactor> semiconductor controller, in which the switching function is limited to FULL-ON

Note 1 to entry: A semiconductor contactor can also contain mechanical switching devices.

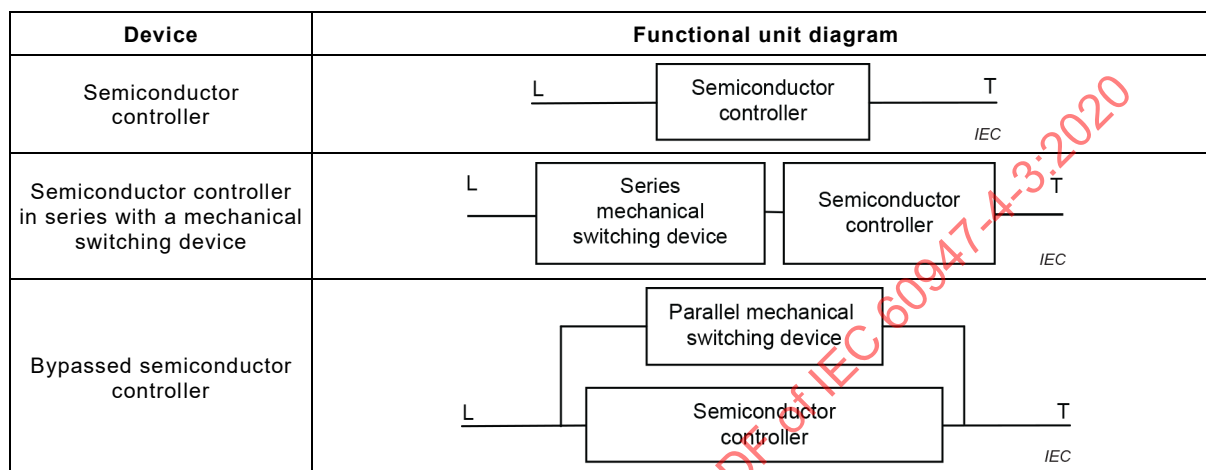


Figure 1 – Semiconductor control devices

3.4 Terms and definitions concerning characteristics of semiconductor controllers and semiconductor contactors

3.4.1

current-limit function

ability of the semiconductor controller to limit the load current to a specified value

Note 1 to entry: It does not include the ability to limit the instantaneous current under conditions of short circuit.

3.4.2

load control

any deliberate operation which causes changes in the effective power available to the load through variation of either

- an imposed operating cycle (i.e. variation of the cyclic duration factor F and/or the number of operating cycles per hour S , see 5.3.4
- or
- the load terminal voltage (for example, through phase-angle control)
- or
- a combination of these

Note 1 to entry: Switch-on is a mandatory form of load control that is recognized separately.

Note 2 to entry: Load control can be performed by semiconductor contactor, if an external switching device or control circuit causes the cyclic transition from the OFF-state to the FULL-ON state and back again (i.e. load control by operating cycle).

3.4.3

ramp-up

switching (switch-on) function which causes the transition from the OFF-state (or from the open state, in the case of a semiconductor controller in series with a mechanical switching device) to the ON-state (i.e. to the FULL-ON state or to a load control operation) over a defined period of time (the ramp-up time)

3.4.4

ramp-down

switching (switch-off) function which causes the transition from the ON-state (i.e. either from FULL-ON or from a load control operation) to the OFF-state (or the open state, in the case of a semiconductor controller in series with a mechanical switching device) over a defined period of time (ramp-down time)

3.4.5

ON-state

condition of a semiconductor controller when the conduction current can flow through its main circuit

3.4.6

FULL-ON

condition of a semiconductor controller when the controlling functions are set to provide normal full-voltage excitation to the load

3.4.7

OFF-state

condition of a semiconductor controller when no control signal is applied and no current exceeding the OFF-state current flows through the main circuit

3.4.8

OFF-state current

I_{OFF}

current which flows through the main circuit of a semiconductor contactor in the OFF-state

3.4.9

instantaneous switching

switching function which causes the instantaneous transition from the ON-state (i.e. either from FULL-ON or from a load control operation) to the OFF-state (or the open state, in the case of a semiconductor controller with mechanical switching device) or vice versa

Note 1 to entry: In the case of switch-off, the term "instantaneous" is used to mean the minimum opening time (see 3.7.39 of IEC 60947-1:2020).

Note 2 to entry: In the case of switch-on, the term "instantaneous" is used to mean make time (see 3.7.43 of IEC 60947-1:2020) plus the transient time determined only by external circuit impedance.

3.4.10

operating cycle

<of a semiconductor controller> succession of operations from one state to the other and back to the first state

Note 1 to entry: A succession of operations not forming an operating cycle is referred to as an operating series.

3.4.11

operating capability

under prescribed conditions, ability to perform a series of operating cycles without failure

3.4.12

overload current profile

current-time coordinate specifying the requirement to accommodate overload currents for a period of time (see 5.3.5.2)

3.4.13

rating index

rating information organized in a prescribed format unifying rated operational current and the corresponding utilization category, overload current profile, and the duty cycle or OFF-time (see 6.1 e))

3.4.14**trip-free semiconductor controller**

semiconductor controller which establishes and sustains an OFF-state condition which cannot be overridden in the presence of a trip condition

Note 1 to entry: In the case of semiconductor controller in series with a mechanical switching device, the term "OFF-state condition" is replaced by the term "OPEN position".

3.4.15**overcurrent protective means**

OCPM

means that cause a switching device to revert to the OFF-state or open position with or without time-delay when the current exceeds a predetermined value

3.4.16**ON-time**

period of time during which the semiconductor controller is on-load

Note 1 to entry: For example, as in Figure F.1.

3.4.17**OFF-time**

period of time during which the semiconductor controller is off-load

Note 1 to entry: For example, as in Figure F.1.

3.4.18**bypassed semiconductor controller**

equipment wherein the main circuit contacts of a mechanical switching device are connected in parallel with the main circuit terminals of a semiconductor switching device, and wherein the operating means of the two switching devices are co-ordinated

Note 1 to entry: The means of bypassing the semiconductor controller or semiconductor contactor can be integral or installed separately.

Note 2 to entry: A bypassed semiconductor controller is rated and tested as a unit.

3.4.19**semiconductor controller power losses**

power consumed by the semiconductor controller or semiconductor contactor at FULL-ON at the maximum power rating

3.4.20**galvanic opening**

<of a circuit> prevention of electric conduction within an electric circuit intended to provide power and/or signals

Note 1 to entry: Galvanic opening can be provided e.g. by a switch or a contactor.

3.4.21**galvanic separation**

prevention of electric conduction between two electric circuits intended to exchange power and/or signals

Note 1 to entry: Galvanic separation can be provided e.g. by an isolating transformer or an opto-coupler.

[SOURCE: IEC 60050-151:2001, 151-12-26]

3.5 Terms and definitions concerning safety aspects

3.5.1

abnormal operating condition

temporary operating condition that is not a normal operating condition and is not a single fault condition of the equipment itself

Note 1 to entry: An abnormal operating condition is a temporary condition which can be introduced by the equipment or by a person and can result in a failure of a component, a device or a safeguard.

Note 2 to entry: This definition is used in the context of component failure risk analysis.

3.5.2

accessible part

part which can be touched by means of the standard test finger

[SOURCE: IEC 60050-442:1998, 442-01-15]

3.5.3

hazardous-live-part

live part which, under certain conditions, can give a harmful electric shock

[SOURCE: IEC 60050-195:1998, 195-06-05]

3.5.4

limited energy source

source that is designed and protected that, under both normal operating conditions and single fault conditions, the current that can be delivered is not hazardous with respect to fire hazard

3.5.5

protective impedance

impedance connected between hazardous live parts and accessible conductive parts, of such value that the current, in normal use and under likely fault conditions, is limited to a safe value, and which is so constructed that its ability is maintained throughout the life of the equipment

[SOURCE: IEC 62477-1:2012, 3.42]

3.5.6

reasonably foreseeable misuse

use of a product or system in a way not intended by the supplier, but which can result from readily predictable human behaviour

[SOURCE: ISO/IEC Guide 51:2014, 3.7, modified – Notes to entry have been deleted]

3.5.7

single fault condition

condition in which there is a fault of a single protection (but not a reinforced protection) or of a single component or a device

Note 1 to entry: If a single fault condition results in one or more other fault conditions, all are considered as one single fault condition.

[SOURCE: IEC Guide 104:2019, 3.8, modified – Deletion of the Note 2 to entry.]

3.6 Symbols and abbreviated terms

A_f Final ambient temperature (9.3.3.3.4)

C_f Final case temperature (9.3.3.3.4)

EMC Electromagnetic compatibility

EUT	Equipment under test
I_c	Current made and broken (Table 7)
I_e	Rated operational current (5.3.2.3)
I_F	OFF-state current after the blocking and commutating capability test (9.3.3.6.4)
I_o	OFF-state current before the blocking and commutating capability test (9.3.3.6.4)
I_q	Maximum conditional short-circuit test current
I_{lim}	Current setting of the current-limit function
I_{OFF}	Maximum OFF-state current
I_{th}	Conventional free air thermal current (5.3.2.1)
I_{the}	Conventional enclosed thermal current (5.3.2.2)
I_u	Rated uninterrupted current (5.3.2.4)
SCPD	Short-circuit protective device
U_c	Rated control circuit voltage (5.5)
U_e	Rated operational voltage (5.3.1.1)
U_i	Rated insulation voltage (5.3.1.2)
U_{imp}	Rated impulse withstand voltage (5.3.1.3)
U_r	Power frequency recovery voltage (Table 6)
U_s	Rated control circuit supply voltage (5.5)

4 Classification

All data which could be used as criteria for classification is given in 5.2.

5 Characteristics of semiconductor controllers and semiconductor contactors

5.1 Summary of characteristics

The characteristics of semiconductor controllers and semiconductor contactors shall be stated in the following terms, where such terms are applicable:

- type of equipment (see 5.2);
- rated and limiting values for main circuits (see 5.3);
- utilization category (see 5.4);
- control circuits (see 5.5);
- auxiliary circuits (see 5.6);
- coordination with short-circuit protective devices (see 5.8).

5.2 Type of equipment

5.2.1 Kind of equipment

The type of semiconductor controller and semiconductor contactor shall be stated in the following terms:

- a) type of semiconductor switching device
 - semiconductor controller; or
 - semiconductor contactor;
- b) bypassed semiconductor controller or semiconductor contactor, if relevant;
- c) type of control (not limited to):

- FULL-ON;
- ramp-up;
- ramp-down;
- current-limit function.

5.2.2 Number of poles

- number of main poles;
- number of main poles where the operation is controlled by a semiconductor switching element.

5.2.3 Kind of current

Alternating current only.

5.2.4 Interrupting medium (air, vacuum, etc.)

Applicable only to mechanical switching devices.

5.2.5 Operating conditions of the equipment

5.2.5.1 Method of operation

For example:

- symmetrically controlled semiconductor controller (such as semiconductor valve devices with fully controlled phases);
- non-symmetrically controlled semiconductor controller (semiconductor valve devices such as thyristors and diodes).

5.2.5.2 Method of control

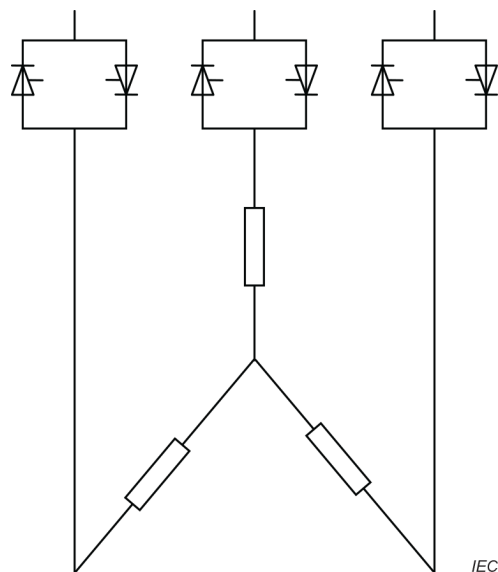
For example:

- automatic (by pilot switch or sequence control);
- non-automatic (that is push-buttons);
- semi-automatic (that is partly automatic, partly non-automatic).

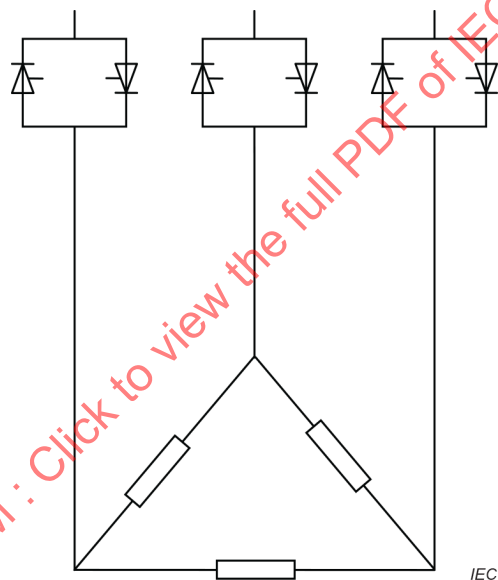
5.2.5.3 Method of connecting

For example (see Figure 2):

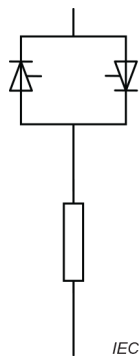
- load in star, semiconductor valve devices connected between load and supply (see for example Figure 2 a));
- load in delta, semiconductor valve devices connected between load and supply (see for example Figure 2 b));
- single-phase load, semiconductor valve devices connected between load and supply (see for example Figure 2 c)).



a) Load in star, semiconductor valve devices between load and supply



b) Load in delta, semiconductor valve devices between load and supply



c) Single-phase load, semiconductor valve devices between load and supply

Figure 2 – Methods of connecting

5.3 Rated and limiting values for main circuits

5.3.1 Rated voltages

5.3.1.1 Rated operational voltage (U_e)

Subclause 5.3.1.1 of IEC 60947-1:2020 applies with the following addition.

The rating of AC equipment shall include the number of phases except that the rating of equipment obviously intended for single-phase use only is not required to include the number of phases.

5.3.1.2 Rated insulation voltage (U_i)

Subclause 5.3.1.2 of IEC 60947-1:2020 applies.

5.3.1.3 Rated impulse withstand voltage (U_{imp})

Subclause 5.3.1.3 of IEC 60947-1:2020 applies.

5.3.2 Currents

5.3.2.1 Conventional free air thermal current (I_{th})

Subclause 5.3.2.1 of IEC 60947-1:2020 applies.

5.3.2.2 Conventional enclosed thermal current (I_{the})

Subclause 5.3.2.2 of IEC 60947-1:2020 applies.

5.3.2.3 Rated operational current (I_e)

The rated operational current, I_e , of semiconductor controllers and semiconductor contactors is the normal operating current when the device is in the FULL-ON state and takes into account the rated operational voltage (see 5.3.1.1), the rated frequency (see 5.3.3), the rated duty cycle (see 5.3.4), the utilization category (see 5.4), the overload characteristics (see 5.3.5) and the type of protective enclosure, if any.

5.3.2.4 Rated uninterrupted current (I_u)

Subclause 5.3.2.4 of IEC 60947-1:2020 applies.

5.3.2.5 Maximum OFF-state current (I_{OFF})

The maximum OFF-state current (I_{OFF}) is the maximum current flowing through the main circuit of the controller when it is in the OFF state, in the test condition of 9.3.3.6.3.

5.3.3 Rated frequency

Subclause 5.3.3 of IEC 60947-1:2020 applies.

5.3.4 Duty cycle values and symbols

For the purpose of this document, the duty cycle is expressed by two symbols, F and S . This describes the duty and also sets the time that shall be allowed for cooling.

F is the ratio of the on-load period to the total period, expressed as a percentage.

The preferred values of F are:

$F = 1\%, 5\%, 15\%, 25\%, 40\%, 50\%, 60\%, 70\%, 80\%, 90\%, 99\%$.

S is the number of operating cycles per hour. The preferred values of S are:

$S = 1, 2, 3, 4, 5, 6, 10, 20, 30, 40, 50, 60$ operating cycles per hour.

NOTE Other values of F and/or S can be declared by the manufacturer.

5.3.5 Normal load and overload characteristics

5.3.5.1 General

Subclause 5.3.5 of IEC 60947-1:2020 applies with the following additions.

5.3.5.2 Overload current profile

The overload current profile gives the current/time coordinates for the controlled overload current. It is expressed by two symbols, X and T_x .

X denotes the overload current as a multiple of I_e selected from the array of values in Table 4 and represents the maximum value of operating current under operational overload conditions.

Deliberate overcurrents not exceeding ten cycles of the power-line frequency which may exceed the stated value of $X \times I_e$ are disregarded for the overload current profile.

T_x denotes the sum of duration times for the operational overload currents during the switching function (for example pre-heater elements of metal vapour lamps), load control and steady-state operating. See Table 4.

5.3.5.3 Operating capability

Operating capability represents the combined capabilities of

- current commutation and current carrying in the ON-state; and
- establishing and sustaining the OFF-state (blocking),

at full voltage under normal load and overload conditions in accordance with utilization category, overload current profile and specified duty cycles.

Operating capability is characterized by:

- rated operational voltage (see 5.3.1.1);
- rated operational current (see 5.3.2.3);
- rated duty cycle (see 5.3.4);
- overload current profile (see 5.3.5.2);
- utilization category (see 5.4);
- the availability of a current-limiting function.

Requirements are given in 8.2.4.1.

5.3.5.4 Switch-on, ramp-up, ramp-down and load control characteristics

Typical service conditions for semiconductor controllers and semiconductor contactors are described in Annex B.

5.3.6 Rated conditional short-circuit current

Subclause 5.3.6.4 of IEC 60947-1:2020 applies.

5.3.7 Controller power losses

5.3.7.1 General

The power consumptions of the semiconductor controller or semiconductor contactor may be stated by the manufacturer.

A controller consists of power semiconductor(s) controlled phase(s) and a semiconductor controlling device. These power semiconductors are bypassed or not bypassed after switching on or ramp-up the load.

The power semiconductor losses during ramp-up (and ramp-down) occur for a very short period of time (seconds) and are therefore not considered.

The power consumptions are determined by calculating the power losses of the power semiconductor components according to 5.3.7.2 and by measuring the control device losses according to 5.3.7.3.

5.3.7.2 Power semiconductor losses (main circuit)

For continuous operation the power semiconductor losses can be calculated as follows:

- a) formula for non-bypassed operation

$$P_{vnb} = n \times I_e \times V_d$$

with

n is the number of controlled phases;

I_e is the rated operational current;

P_{vnb} is the power losses non-bypassed operation; and

V_d is the voltage drop of a power semiconductor (typically equal to 1 V).

- b) formula for bypassed operation

$$P_{vb} = 0,1 \times P_{vnb}$$

with (in addition to the key of the previous formula):

P_{vb} is the power losses in bypassed operation.

NOTE The factor of 0,1 is based on the typical voltage drop of the bypass contact in comparison to the voltage drop of the semiconductor.

5.3.7.3 Semiconductor controlling device losses

The power consumption of semiconductor controlling device, including the fans if any, is obtained by measurement according to 9.3.3.2.

5.4 Utilization category

5.4.1 General

Subclause 5.4 of IEC 60947-1:2020 applies with the following addition.

For semiconductor controllers and semiconductor contactors the utilization categories as given in Table 1 are considered standard. Any other type of utilization shall be based on agreement between manufacturer and user, but information given in the manufacturer's catalogue or tender may constitute such an agreement.

In the case of AC-5 and AC-6 respectively, the a- or b-suffix serves to define the application more closely.

NOTE As opposed to the convention used in IEC 60947-4-2 for semiconductor motor controllers and starters, these suffixes do not refer to the duty cycle sequence.

5.4.2 Assignment of ratings based on the results of tests

A designated semiconductor controller or semiconductor contactor with a rating for one utilization category which has been verified by testing can be assigned other ratings without testing, provided that:

- the rated operational current and voltage that are verified by testing shall not be less than the ratings that are to be assigned without testing;
- the utilization category and duty cycle requirements for the tested rating shall be equal to or more severe than the rating that is to be assigned without testing; the relative levels of severity are given in Table 2;
- the overload current profile for the tested rating shall be equal to or more severe than the rating that is to be assigned without testing, in accordance with the relative levels of severity in Table 2. Only values of X lower than the tested value of X may be assigned without testing.

Table 1 – Utilization categories

Specific utilization category	Harmonised utilization category ^a	Typical non-motor load
AC-51	AC-1	Non-inductive or slightly inductive loads
AC-55a	AC-5a	Discharge lamps ballast
AC-55b	AC-5b	Incandescent lamps
AC-56a	AC-6a	Transformers
AC-56b	AC-6b	Capacitor banks
^a The new utilization categories according to Annex A of IEC 60947-1:2020 are proposed to replace the specific ones but the specific utilisation categories are remaining valid.		

Table 2 – Relative levels of severity

Severity level	Utilization category	Overload current profile ^a	ON-time / OFF-time requirements ^b
Most severe	all	Highest value of $(X \times I_e)^2 \times T_x$	Highest value of $F \times S$
^a When the highest value of $(X \times I_e)^2 \times T_x$ occurs at more than one value of $X \times I_e$, then the highest value of $X \times I_e$ applies.			
^b When the highest value of $F \times S$ occurs at more than one value of S , then the highest value of S applies.			

5.5 Control circuits

Subclause 5.5.1 of IEC 60947-1:2020 applies with the following additions.

The list of characteristics given in 5.5.1 of IEC 60947-1:2020 shall be completed by:

- limited energy (if the source is in accordance with 8.1.14);
- SELV (PELV) supply (in accordance with Annex N of IEC 60947-1:2020).

NOTE In the USA and Canada, control circuits are characterised as Class 2 sources as defined in NFPA 70, National Electrical Code and CSA C22.1, Canadian Electrical Code (CE Code).

5.6 Auxiliary circuits

Subclause 5.6 of IEC 60947-1:2020 applies with the following additions.

Under normal conditions, auxiliary circuits are characterized in the same way as control circuits and are subject to the same kinds of requirements. If the auxiliary functions include unusual performance features, the manufacturer should be consulted to define the critical characteristics.

Digital inputs and/or digital outputs contained in semiconductor controllers and semiconductor contactors, and intended to be compatible with PLCs, shall fulfil the requirements of Annex S of IEC 60947-1:2020.

5.7 Vacant

5.8 Coordination with short-circuit protective devices (SCPD)

Semiconductor controllers and semiconductor contactors are characterized by the type, ratings and characteristics of the SCPD to be used to provide an adequate protection of the semiconductor controller or semiconductor contactor against short-circuit currents.

Requirements are given in 8.2.5 of this document and in 5.8 of IEC 60947-1:2020.

6 Product information

6.1 Nature of information

The following information shall be given by the manufacturer.

Identification

- a) the manufacturer's name or trademark;
- b) type designation or serial number;
- c) number of this document.

Characteristics, basic rated values and utilization

- d) rated operational voltages (see 5.3.1.1);
- e) rated operational currents, corresponding utilization category (see 5.4), overload current profile (see 5.3.5.2) and duty cycle (see 5.3.4 or OFF-time, comprising the rating index).

The prescribed format for AC-1 is shown by this example:

100 A: AC-1: $1,5 \times I_e - 46 \text{ s}$: 50 % – 30/h

This indicates 100 A current rating for general applications with non-inductive or slightly inductive loads. The device can accommodate 150 A for 46 s, 50 % on-load factor, 30 standard operating cycles per hour.

If the rated operational current only applies if the semiconductor controller is used in conjunction with a bypass, then this shall be indicated by the following prescribed form of the rating index, shown by example for AC-5a:

100 A: AC-5a: $2 \times I_e - 30 \text{ s}$: 180 s

This indicates 100 A current rating for the switching on of electric discharge lamp controls. The device can accommodate 200 A for 30 s, the OFF-time shall not be less than 180 s before any subsequent switch-on may be initiated.

- f) maximum OFF-state current;
- g) either the value of the rated frequency 50 Hz/60 Hz, or other rated frequencies for example 16 2/3 Hz, 400 Hz;
- h) indication of the rated duties as applicable (see 5.3.4);
- i) galvanic separation between poles if applicable;

Safety and installation

- j) rated insulation voltage (see 5.3.1.2);
- k) rated impulse withstand voltage (see 5.3.1.3);
- l) IP code according to Annex C of IEC 60947-1:2020;
- m) pollution degree (see 7.1.3.2);
- n) rated conditional short-circuit current and type of coordination of the semiconductor controller, current rating and characteristics of the associated SCPD (see 5.8) including when integrated within the product;
- o) terminal clamping unit characteristics including:
 - length of insulation to be removed before insertion of the conductor into the terminal;
 - maximum number of conductors which may be clamped.

For non-universal screwless terminals:

- "s" or "sol" for terminals declared for solid conductors;
- "r" for terminals declared for solid and stranded conductors;
- "f" for terminals declared for flexible conductors.

NOTE In the United States, "str" is used for identifying terminals declared for stranded conductors.

- p) vacant.

Control circuits

- q) rated control circuit voltage U_c , nature of current and rated frequency, and, if necessary, rated control circuit supply voltage U_s , nature of current and rated frequency and any other information (for example impedance matching requirements) necessary to ensure satisfactory operation of the control circuits (see Annex U of IEC 60947-1:2020, for examples of control circuit configurations);

Auxiliary circuits

- r) nature and ratings of auxiliary circuits (see 5.6);

EMC emission and immunity levels

- s) EMC Environment A or B according to IEC 60947-1; if an external EMC filter is required to fulfil the emission levels given in Table 12, it shall be specified in the catalogue and in the instruction manual;

Additional information

- t) reference of dedicated wiring accessories which can be used for wiring the semiconductor controller or semiconductor contactor;
- u) type of equipment according to 5.2;
- v) maximum permissible altitude of the installation site, if greater than 1 000 m;
- w) pole impedance (Z) of the parallel mechanical switching device of a bypassed semiconductor controller or semiconductor contactor according to IEC 60947-4-1;
- x) material declaration according to Annex W of IEC 60947-1:2020;
- y) semiconductor controller power losses if declared.

6.2 Marking

Subclause 6.2 of IEC 60947-1:2020 applies to semiconductor controllers and semiconductor contactors with the following addition.

Data under d) to y) in 6.1 shall be included on the nameplate, or on the equipment, or in the manufacturer's published literature.

Data under c) and l) (if the degree of protection is different than IP00) in 6.1 shall preferably be marked on the equipment.

6.3 Instructions for installation, operation, maintenance, decommissioning and dismantling

Subclause 6.3 of IEC 60947-1:2020 applies with the following addition.

The instructions shall also cover the dedicated wiring accessories.

Additional information for the decommissioning and dismantling of the device shall be maintained available to the user in case of foreseeable hazardous condition of the device, for example due to stored energy, instability or falling of objects, etc.

For products complying with this document, the following are specific items to be considered:

- in the event of a short-circuit;
- specific mode of operation, if any;
- in case of mechanical switching devices used in a semiconductor controller or a semiconductor contactor (see 8.2.1.6);
- in the event of temperature-rise above 50 K of the metallic radiator surface of the device.

If the construction requires energization by an external source that is not a limited energy source as defined in 8.1.14, the manufacturer shall provide the appropriate information for short-circuit and overcurrent protection of the ports.

For each relevant potential hazard, the manufacturer shall provide safety signs, graphical symbols or safety notes of the hazard for example by using e.g. IEC 60417-5036:2002-10. Signal words are given by ISO 3864-2.

NOTE IEC 82079-1 provides guidance for developing safety instructions.

The instruction shall also provide information about the installation of a disconnecting means where maintenance activities needs to be performed downstream to the semiconductor controller or semiconductor contactor.

6.4 Environmental information

Subclause 6.4 of IEC 60947-1:2020 applies.

Material declarations, if any, shall be provided according to Annex W of IEC 60947-1:2020.

7 Normal service, mounting and transport conditions

7.1 Normal service conditions

7.1.1 Ambient air temperature

The ambient air temperature does not exceed +40 °C and its average over a period of 24 h does not exceed +35 °C.

The lower limit of the ambient air temperature is 0 °C.

Ambient air temperature is that existing in the vicinity of the equipment if supplied without enclosure, or in the vicinity of the enclosure if supplied with an enclosure.

NOTE If the equipment is to be used at ambient air temperatures above +40 °C (e.g. within switchgear and controlgear assemblies and in forges, boiler rooms, tropical countries) or below 0 °C (e.g. –25 °C, as required by IEC 61439 (all parts) for outdoor installed low-voltage switchgear and controlgear assemblies), the manufacturer can be consulted. Information given in the manufacturer's catalogue can satisfy this requirement.

7.1.2 Altitude

When rated above 1 000 m, the manufacturer shall specify the maximum altitude taking into account:

- thermal limitation, if rated for operation above 1 000 m;
- insulation coordination considerations, if rated for operation above 2 000 m.

For equipment to be used at higher altitudes, it is necessary to take into account the reduction of the dielectric strength, and of the cooling effect of the air. Electrical equipment intended to operate in these conditions are designed or used in accordance with an agreement between manufacturer and user.

7.1.3 Atmospheric conditions

7.1.3.1 Humidity

Subclause 7.1.3.1 of IEC 60947-1:2020 applies.

7.1.3.2 Degrees of pollution

Unless otherwise stated by the manufacturer, semiconductor controllers and semiconductor contactors are intended for use in pollution degree 3 environmental conditions, as defined in 7.1.3.2 of IEC 60947-1:2020. However, other pollution degrees may be considered applicable, depending upon the micro-environment.

7.1.4 Shock and vibrations

Subclause 7.1.4 of IEC 60947-1:2020 applies with the following addition.

Standard conditions of vibration are defined in footnote b of Table Q.1 of IEC 60947-1:2020.

7.2 Conditions during transport and storage

Subclause 7.2 of IEC 60947-1:2020 applies.

7.3 Mounting

Subclause 7.3 of IEC 60947-1:2020 applies for EMC considerations, see 8.3 and 9.4 of this document.

Rail mounting shall be specified according to IEC 60715, when relevant.

7.4 Electrical system disturbances and influences

For EMC considerations, see 8.3 and 9.4.

8 Constructional and performance requirements

8.1 Constructional requirements

8.1.1 General

Subclause 8.1.1 of IEC 60947-1:2020 applies with the following addition.

Measures shall be provided to reduce the likelihood of injury and property damage, under installation, maintenance, normal operation conditions, abnormal operation conditions and reasonably foreseeable misuses. The requirements of this document are intended to provide these measures.

Protection against hazards caused by the electronic circuits shall be maintained under normal and single fault conditions, as specified in this document.

Components used in the construction of the equipment, compliant with a relevant IEC product standard, do not require separate evaluation. Components or assemblies of components, for which no relevant product standard exists, shall be tested according to the requirements of this document. Where mechanical switching devices are used, they should meet the requirements of their own IEC product standard, and the additional requirements of this document.

Where the product is intended to be used together with specific auxiliary equipment and dedicated wiring accessories, the safety evaluation and test shall include this auxiliary equipment and accessories unless it can be shown that it does not affect the safety of any equipment.

The accessible part of the device and especially the operating means shall not present sharp edges and corners which can injure the operator.

The user manual shall give details of all safety-relevant adjustments intended for the user. Clear warning shall be provided in the user manual where adjustment could lead to a hazardous situation.

Annex O of IEC 60947-1:2020 should be considered carefully especially for substitution or reduction in use of hazardous substances or if not possible for providing measures to prevent emission and contact with them.

NOTE The future publication IEC TS 63058 will give the method for assessing the environmental impact of switchgear and controlgear.

8.1.2 Materials

8.1.2.1 General materials requirements

Subclause 8.1.2.1 of IEC 60947-1:2020 applies with the following additions.

Parts of insulating materials located in electrical circuits sourced from limited energy sources according to 8.1.14 are not required to comply with the requirements of this subclause.

NOTE Fire hazard aspects are detailed in IEC TR 63054.

8.1.2.2 Glow wire testing

Subclause 8.1.2.2 of IEC 60947-1:2020 applies with the following addition.

When tests on the equipment or on sections taken from the equipment are used, parts of insulating materials necessary to retain current-carrying parts in position shall conform to the glow-wire tests in 9.2.2.1 of IEC 60947-1:2020 at a test temperature of 850 °C.

8.1.2.3 Test based on flammability category

Subclause 8.1.2.3 of IEC 60947-1:2020 applies.

8.1.3 Current-carrying parts and their connections

Subclause 8.1.3 of IEC 60947-1:2020 applies.

Wiring that is subject to movement or flexing during its intended use, or during mechanical maintenance, such as wiring from a stationary part to a part mounted on a hinged cover or door, shall be routed and secured so that the wire is not damaged during opening and closing of the door or cover.

8.1.4 Clearances and creepage distances

Subclause 8.1.4 of IEC 60947-1:2020 applies with the following additions.

Clearance and creepage distances within the circuits sourced from limited energy sources as defined in 8.1.14, including those on printed wiring boards (PWBs), are not required to comply with the requirements of the above subclause.

Where SELV and PELV circuits are accessible, they shall be separated from other hazardous-live-part according to the requirements of Annex L for protective impedance in addition to Annex N of IEC 60947-1:2020.

NOTE 1 If some circuits are only accessible under maintenance or similar conditions, they can, depending on the risk level (severity of harm and the probability of occurrence), be considered under normal service conditions (see 6.1), and use only basic insulation. Accessible parts can be determined using test probes according to IEC 61032.

NOTE 2 The nature of a semiconductor makes it unsuitable for use for isolation purposes.

8.1.5 Actuator

Vacant

8.1.6 Indication of the contact position

Vacant

8.1.7 Additional requirements for equipment suitable for isolation

Vacant

8.1.8 Terminals

8.1.8.1 General

Subclause 8.1.8 of IEC 60947-1:2020 applies with the following additional requirements.

8.1.8.2 Terminal identification and marking

Subclause 8.1.8.4 of IEC 60947-1:2020 applies with additional requirements as given in Annex A and the following.

Equipment may be provided with means for connection to earth for functional purposes only (as distinct from protective earth), shall be marked or provided with other identification in accordance with IEC 60445.

8.1.9 Additional requirements for equipment provided with a neutral pole

Vacant

8.1.10 Provisions for protective earthing

Subclause 8.1.10 of IEC 60947-1:2020 applies.

8.1.11 Enclosures for equipment

Subclause 8.1.11 of IEC 60947-1:2020 applies.

8.1.12 Degrees of protection of enclosed equipment

Subclause 8.1.12 of IEC 60947-1:2020 applies.

8.1.13 Conduit pull-out, torque and bending with metallic conduits

Subclause 8.1.13 of IEC 60947-1:2020 applies.

8.1.14 Limited energy source

8.1.14.1 General

A limited energy source can be implemented as a secondary circuit derived from circuits connected to the hazardous-live-part with the following separation means:

- a) galvanic separation;
- b) current limiting impedance.

NOTE Class 2 sources, as defined in NFPA 70, National Electrical Code and CSA C22.1 Canadian Electrical Code (CE Code), have the same electrical output characteristics as limited energy sources with galvanic separation.

8.1.14.2 Limited energy source with galvanic separation

A limited energy source with galvanic separation incorporates an isolating component such as a transformer between the primary circuit and the limited energy output. It shall comply with one of the following requirements:

- a) the output is inherently limited in compliance with Table 14; or
- b) a linear or non-linear impedance limits the output in compliance with Table 14. If a positive temperature coefficient device (e.g. PTC) is used, it shall pass the applicable tests specified in IEC 60730-1; or
- c) a regulating network limits the output in compliance with Table 14, both with and without a single fault in the regulating network; or
- d) an over-current protective device is used and the output is limited in compliance with Table 15.
- e) where an over-current protective device is used, it shall be a fuse or non-adjustable electromechanical device.

Compliance to determine the maximum available power is checked by test of 9.2.4.

In case of external power supplies without overcurrent protective devices, they shall not exceed the values given in Table 14. In case of external power supplies with over-current protective devices, they shall not exceed the values given in Table 15.

Table 14 – Limits for limited energy sources without an over-current protective device

Output voltage ^a		Output current ^{b, d}	Maximum power ^c
U_{oc}		I_{sc}	S
V AC	V DC	A	VA
≤ 30 RMS	≤ 30	≤ 8	100
-	$30 < U_{oc} \leq 60$ ^e	$\leq \frac{150}{U_{oc}}$	100

NOTE This table will be moved into the future revision of IEC 60947-1 and is therefore numbered differently to the other tables in this document.

^a U_{oc} : output voltage measured in accordance with all load circuits disconnected. Voltages are for substantially sinusoidal alternating current and ripple-free direct current. For non-sinusoidal alternating current and direct current with ripple greater than 10 % of the peak, its peak value shall not exceed 42,4 V.

^b I_{sc} : maximum output current with any non-capacitive load, including a short circuit.

^c S (VA): maximum output apparent power with any non-capacitive load as determined by 9.2.4.

^d Measurement of I_{sc} is made 5 s after application of the load if protection is by an electronic circuit or a positive temperature coefficient device (e.g. PTC), and 60 s in other cases.

^e In the USA, the limit is 60 V DC continuous or direct current switching outside of 10 Hz to 200 Hz, 24,8 V direct current switching at 10 Hz to 200 Hz.

Table 15 – Limits for limited energy sources with an over-current protective device

Output voltage ^a		Output current ^{b, d}	Maximum power ^{c, d}	Current rating of over-current protective device ^e
U_{oc}		I_{sc}	S	
V AC	V DC	A	VA	A
≤ 20	≤ 20	$\leq \frac{1\,000}{U_{oc}}$	250	≤ 5
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$ ^f			$\leq \frac{100}{U_{oc}}$
-	$30 < U_{oc} \leq 60$ ^f			$\leq \frac{100}{U_{oc}}$

NOTE 1 The reason for making measurements with over-current protective devices bypassed according to ^d is to determine the amount of energy that is available to cause possible overheating during the operating time of the over-current protective devices.

NOTE 2 This table will be moved into the future revision of IEC 60947-1 and is therefore numbered differently to the other tables in this document.

^a U_{oc} : output voltage measured with all load circuits disconnected. Voltages are for substantially sinusoidal alternating current and ripple free direct current. For non-sinusoidal alternating current and for direct current with ripple greater than 10 % of the peak, its peak value shall not exceed 42,4 V.

^b I_{sc} : maximum output current with any non-capacitive load, including a short circuit, measured 60 s after application of the load.

^c S (VA): maximum output apparent power with any non-capacitive load measured 60 s after application of the load as determined by 9.2.4.

^d Current limiting impedances remain in the circuit during measurement, but over-current protective devices are bypassed.

^e The current ratings of over-current protective devices that break the circuit within 120 s with a current equal to 210 % of the current rating specified in the table.

^f In the USA, the limit is 60 V DC continuous or direct current switching outside of 10 Hz to 200 Hz, 24,8 V DC switching at 10 Hz to 200 Hz.

8.1.14.3 Limited energy source with current limiting impedance

A limited energy source with current limiting impedance has the following characteristics:

- the output voltage is limited in compliance with Table 16, and
- a linear or non-linear impedance limits the output in compliance with Table 16, both with and without a single fault.

A limited energy source with current limiting impedance may be derived from either mains or from a galvanically separated circuit e.g. the secondary of a transformer.

Table 16 – Limits for limited energy source with current limiting impedance

Output voltage ^a		Output current ^{b, d}	Maximum power ^c
U_{oc}			
V AC	V DC	I_{sc} A	S VA
≤ 30 RMS	≤ 30	0,5	15
NOTE This table will be moved into the future revision of IEC 60947-1 and is therefore numbered differently to the other tables in this document.			
^a U_{oc}: output voltage measured in accordance with all load circuits disconnected. Voltages are for substantially sinusoidal alternating current and ripple-free direct current. For non-sinusoidal alternating current and direct current with ripple greater than 10 % of the peak, its peak value shall not exceed 42,4 V. ^b I_{sc}: maximum output current measured across the output of the limited energy source. ^c S (VA): maximum output apparent power as determined by 9.2.4. ^d Measurement of I_{sc} is made 5 s after application of the short circuit.			

8.1.15 Stored charge energy circuit

Parts including stored charge (capacitors) that are accessible (such as coil terminals) or removable for servicing (such as coil replacement), installation, or disconnection shall present no risk of electric energy hazard after disconnection.

Capacitors connected to accessible hazardous live parts shall be discharged to an energy level less than 0,5 mJ within 5 s after the removal of power. Otherwise, a readily visible warning notice shall be provided on the product, indicating the time of discharge to the limit values or a preferable method how to discharge the capacitor before touching the connecting parts.

8.1.16 Fault and abnormal conditions

The product shall be designed to avoid operating modes or sequences that can cause a fault condition or component failure leading to a hazard, unless other measures to prevent the hazard are provided by the installation and are described in the installation information provided with the product. The requirements in this clause also apply to abnormal operating conditions as applicable.

Circuit analysis or testing shall be performed to determine whether or not failure of a particular component (including insulation systems) would result in hazard.

This analysis shall include situations where a failure of the component or the insulation (basic and supplementary) would result in:

- an impact on the risk of electric shock;
- a risk of degradation resulting in emission of flame, burning particles or molten metal of the fire;
- overheating of the power semiconductor.

The analysis or testing shall include the effect of short-circuit and open-circuit conditions of the component. Testing is necessary unless analysis can conclusively show that, in short-circuit and open circuit conditions, no electric shock and fire hazard will result from failure of the component. Compliance shall be checked by the test of 9.2.5.

Components evaluated for their reliability according to relevant product standards are considered to meet these requirements and do not need any further investigation, if tested under conditions that fulfil the conditions for which the product is designed.

8.1.17 Short-circuit and overload protection of ports

Where the power source for a signal port or power port that is external to the device does not comply with the requirements for limited energy sources in 8.1.14, the product shall not present a hazard under short-circuit or overload conditions. Instructions for the installation of external overcurrent protection shall be made available in accordance with 6.3.

Compliance shall be checked by inspection and where necessary, by simulation of single fault conditions.

8.2 Performance requirements

8.2.1 Operating conditions

8.2.1.1 General

Auxiliary devices used in semiconductor controllers and semiconductor contactors shall be operated in accordance with the manufacturer's instructions and their relevant product standard.

Semiconductor controller and semiconductor contactors shall be so constructed that they

- a) are trip-free;
- b) can be caused to return to the OPEN or OFF-state by the operating means at any time during switching from the OFF to the ON-state or while in the FULL-ON state.

Compliance is verified in accordance with 9.3.3.6.4.

Semiconductor controllers and semiconductor contactors shall not malfunction due to mechanical shock or electromagnetic interference caused by operation of their internal devices.

Compliance is verified in accordance with 9.3.3.6.4.

The moving contacts of the series mechanical switching device shall be mechanically coupled so that all poles make and break substantially together whether operated manually or automatically.

8.2.1.2 Limits of operation of semiconductor controllers

Semiconductor controllers and semiconductor contactors shall function satisfactorily at any voltage between 85 % and 110 % of their rated operational voltage U_e , and rated control circuit supply voltage U_s , when tested in accordance with 9.3.3.6.4. Where a range is declared, 85 % shall apply to the lower value and 110 % to the higher.

8.2.1.3 Relays and releases associated with semiconductor controllers and semiconductor contactors

An under-voltage relay or release can be associated with a semiconductor controller or semiconductor contactor. In addition to the test requirements of 9.3.3.6.5, the limits of operation of the under-voltage relays and releases shall be defined by the manufacturer if applicable.

8.2.1.4 Vacant

8.2.1.5 Vacant

8.2.1.6 Mechanical switching devices used in semiconductor controllers and semiconductor contactors

The switching devices shall be verified as a part of the semiconductor controller or semiconductor contactor. The making and breaking capacity test according to 8.2.4.2 need not to be performed when the mechanical switching devices is interlocked such that it is not required to make or break overload currents without direct intervention of the semiconductor switching device. Consequently, the semiconductor switching device shall take over the control of the current flowing in the main circuit whenever it is necessary to make or break currents up to and including overload currents.

8.2.2 Temperature-rise

8.2.2.1 General

The requirements of 8.2.2 of IEC 60947-1:2020 apply to semiconductor controllers and semiconductor contactors in a clean, new condition.

In the case of conducting the test at a voltage below 100 V, mechanical switching devices may have the contacts cleaned either by any nonabrasive method or by carrying out operating cycles with or without load several times prior to initiating the test at any voltage.

NOTE Contact resistance due to oxidation can impact the temperature-rise test at test voltages below 100 V.

Temperature-rise deviations on the metallic radiator surface of semiconductor devices are permitted: 50 K in the case where they need not be touched during normal operation.

If the limit of 50 K is exceeded, the manufacturer shall provide a suitable warning (e.g. symbol IEC 60417-5041:2002-10) in accordance with 6.3. Provision of suitable guarding and location to prevent danger is the responsibility of the installer.

8.2.2.2 Vacant

8.2.2.3 Vacant

8.2.2.4 Vacant

8.2.2.5 Main circuit

8.2.2.5.1 General

The main circuit of a controller or semiconductor contactor, which carries current in the FULL-ON state, shall be capable of carrying, without the temperature-rises exceeding the limits specified in 8.2.2.2 of IEC 60947-1:2020 when tested in accordance with 9.3.3.3.4, its conventional thermal current (see 5.3.2.1 and/or 5.3.2.2) and the relevant rated operational current (see 5.3.2.3).

8.2.2.5.2 Mechanical switching devices in semiconductor controllers and semiconductor contactors

The temperature-rise shall be verified by the procedures given in 9.3.3.3.4 and 9.3.3.6.2 (including Table 5 and Table 10). The device shall be tested as an integral part of a unit with a sequence of operations which is the same as intended in normal service.

8.2.2.5.3 Semiconductor devices connected in the main circuit

The temperature-rise of the semiconductor devices connected in the main circuit shall be verified by the procedures given in 9.3.3.3.4 and 9.3.3.6.2 (thermal stability test).

8.2.2.6 Control circuits

Subclause 8.2.2.6 of IEC 60947-1:2020 applies.

8.2.2.7 Windings of coils and electromagnets

Subclause 8.2.2.7 of IEC 60947-1:2020 applies. The temperature-rise limits for insulated coils in air and in oil are given in Table 3.

Table 3 – Temperature-rise limits for insulated coils in air and in oil

Class of insulating material (according to IEC 60085)	Temperature-rise limit (measured by resistance variation)	
	Coils in air	Coils in oil
A	85	60
E	100	60
B	110	60
F	135	–
H	160	–

8.2.2.8 Auxiliary circuits

Subclause 8.2.2.8 of IEC 60947-1:2020 applies.

8.2.2.9 Other parts

Subclause 8.2.2.1 of IEC 60947-1:2020 applies.

8.2.3 Dielectric properties

8.2.3.1 General

The following requirements are based on the principles of the IEC 60664 (all parts) and provide the means of achieving coordination of insulation of equipment with the conditions within the installation.

The equipment shall be capable of withstanding

- the rated impulse withstand voltage (see 5.3.1.3) in accordance with the overvoltage category given in Annex H of IEC 60947-1:2020;
- the impulse withstand voltage across the contact gaps of devices suitable for isolation as given in Table 14 of IEC 60947-1:2020;
- the power-frequency withstand voltage.

NOTE 1 A direct voltage can be used instead, provided its value is not less than the projected alternating test voltage crest value.

NOTE 2 The correlation between the nominal voltage of the supply system and the rated impulse withstand voltage of the equipment is given in Annex H of IEC 60947-1:2020.

The rated impulse withstand voltage for a given rated operational voltage (see Notes 1 and 2 of 5.3.1.1 of IEC 60947-1:2020) shall be not less than that corresponding in Annex H of IEC 60947-1:2020 to the nominal voltage of the supply system of the circuit at the point where the equipment is to be used, and the appropriate overvoltage category.

The requirements of this subclause shall be verified by the tests of 9.3.3.4.

8.2.3.2 Impulse withstand voltage

1) Main circuit

Subclause 8.2.3.2 1) of IEC 60947-1:2020 applies.

2) Auxiliary and control circuits

Subclause 8.2.3.2 2) of IEC 60947-1:2020 applies with 2) a) modified as follows:

- a) For auxiliary and control circuits which operate directly from the main circuit at the rated operational voltage, clearances from live parts to parts intended to be earthed and between poles shall withstand the test voltage given in Table 12 of IEC 60947-1:2020 appropriate to the rated impulse withstand voltage.

8.2.3.3 Power-frequency withstand voltage of the main, auxiliary and control circuits

Subclause 8.2.3.3 of IEC 60947-1:2020 applies.

8.2.3.4 Clearances

Subclause 8.2.3.4 of IEC 60947-1:2020 applies.

8.2.3.5 Creepage distances

Subclause 8.2.3.5 of IEC 60947-1:2020 applies.

8.2.3.6 Solid insulation

Subclause 8.2.3.6 of IEC 60947-1:2020 applies.

8.2.3.7 Spacing between separate circuits

Subclause 8.2.3.7 of IEC 60947-1:2020 applies.

8.2.4 Normal load and overload performance requirements

8.2.4.1 Operating capability requirements

Semiconductor controllers and semiconductor contactors shall be required to establish an ON-state, to commute, to carry designated levels of overload currents, and to establish and sustain an OFF-state condition without failure or any type of damage, when tested in accordance with 9.3.3.6.

Ratings shall be verified under the conditions stated in Table 5 and Table 6 and in the relevant parts of 9.3.3.5.2 and 9.3.3.5.3 of IEC 60947-1:2020.

Where $X \times I_e$ is greater than 1 000 A, verification of the overload capability shall be subject to agreement between manufacturer and user (for example by computer modelling).

In Table 5 and Table 6, the ON-time and OFF-time should be in accordance with Table 2 for the most severe duty cycle. If a controller is rated and tested for a duty cycle that is more severe than the standard duty cycle, the manufacturer may assign the same rating for a standard duty cycle without further testing.

**Table 4 – Minimum overload current withstand time (T_x)
in relation to overload current ratio (X)**

	$T_x = 20 \text{ ms}$	$T_x = 200 \text{ ms}$	$T_x = 1 \text{ s}$	$T_x = 10 \text{ s}$	$T_x = 60 \text{ s}$	$T_x = 300 \text{ s}$	Continuous
AC-1	$X = 1,4$	$X = 1,4$	$X = 1,4$	$X = 1,2$	$X = 1,1$	$X = 1$	$X = 1$
AC-5a	$X = 10$	$X = 6$	$X = 4$	$X = 3$	$X = 2$	$X = 1,8$	$X = 1$
AC-5b	$X = 10$	$X = 6$	$X = 1,2$	$X = 1,1$	$X = 1$	$X = 1$	$X = 1$
AC-6a	$X = 30$	$X = 6$	$X = 1,2$	$X = 1,1$	$X = 1$	$X = 1$	$X = 1$
AC-6b	$X = 30$	$X = 1,4$	$X = 1,1$	$X = 1$	$X = 1$	$X = 1$	$X = 1$

Table 5 – Minimum requirements for thermal stability test conditions

Utilization category	Current-limit function	Test current I_T	ON-time ^a s	OFF-time ^b s
all	Yes	I_{lim}^c	T_x	3 600/S- T_x
	No	$X \times I_e$		
Parameters of the test circuit:				
I_e = rated operational current				
I_{lim} = current setting of the current-limit function				
I_T = test current				
U_T = test voltage (may be any value)				
$\text{Cos } \varphi$ = test circuit power factor (may be any value)				
^a T_x is selected from Table 4 according to $X = I_T/I_e$.				
^b The number of operating cycles will depend upon the length of time required for the controller to reach thermal equilibrium.				
^c I_{lim} is the current limiting value declared by the manufacturer according to the overload current profile according to 5.3.5.2.				

Table 6 – Minimum requirements for overload current withstand test conditions

Utilization category	Parameters of the test circuit			Operating cycle ON-time s	Operating cycle OFF-time s	Number of operating cycles
	I_T/I_e	U_r/U_e^a	$\cos \varphi^b$			
AC-1	X	1,05	0,8	T_x^c	$\leq 3600/S - T_x$	5
AC-5a	3,0		0,45			5
AC-5b	1,5		^d			50
AC-6a	30		≤ 1			5
AC-6b	^f		^e			1 000
I_T = test current I_e = rated operational current U_e = rated operational voltage U_r = power-frequency recovery voltage						
Temperature conditions The initial case temperature C_i , for each test shall be not less than 40 °C plus the maximum case temperature-rise during the temperature-rise test (9.3.3.3). During the test, the ambient air temperature shall be between +10 °C and +40 °C.						
a $U_r/U_e = 1,05$ for the last three full periods of power frequency of the ON-time, plus the first 1 s of the OFF-time (full voltage period). U_r/U_e may be any value during the time when the full voltage period is not in effect (reduced voltage period). b The characteristics of the circuit ($\cos \varphi$ and maximum possible current) are mandatory during the full voltage period. During the reduced voltage period, the characteristics of the circuit are not mandatory provided the load circuit permits a current higher than I_T. c T_x is selected from Table 4 according to $X = I_T/I_e$. d Tests to be carried out with an incandescent light load. e Tests to be carried out with a capacitive load. f Capacitive ratings may be derived by capacitor switching tests or assigned on the basis of established practice and experience. As a guide, reference may be made to the formula: $I_{pmax} \leq I_{TSM} \sqrt{2}$ where I_{pmax} is the peak inrush current of capacitor and I_{TSM} is the non-repetitive surge on-state current.						

8.2.4.2 Making and breaking capacities for switching devices in the main circuit

8.2.4.2.1 General

The semiconductor controller or semiconductor contactor, including the mechanical switching devices associated with it, shall be capable of operating without failure in the presence of overload current.

The capability of making and breaking currents without failure, shall be verified under the conditions stated in both Table 7 and Table 8, for the required utilization categories, and the number of operations indicated.

Table 7 – Making and breaking capacity test – Making and breaking conditions according to utilization categories for the mechanical switching device

Utilization category	Make and break conditions					
	I_c/I_e	U_r/U_e	Cos φ	ON-time s	OFF-time s	Number of operating cycles
AC-1	1,5	1,05	0,80	0,05	a	50
AC-5a	3,0		0,45			
AC-5b	1,5 ^b		b			
AC-6a	30		c			
AC-6b	d		d			
I_c = current made and broken, expressed in AC RMS symmetrical values I_e = rated operational current U_e = rated operational voltage U_r = power-frequency recovery voltage			Current I_c A		OFF-time s	
^a OFF-time shall not be greater than the values given in the chart. ^b Tests to be carried out with incandescent light load. ^c $I_{c\text{ peak}} = 30 \times I_e \sqrt{2}$ Cos φ preferred: ≤ 0,45 ^d Capacitive ratings may be derived by capacitor switching tests or assigned on the basis of established practice and experience.			$I_c \leq 100$		10	
			100 < $I_c \leq 200$		20	
			200 < $I_c \leq 300$		30	
			300 < $I_c \leq 400$		40	
			400 < $I_c \leq 600$		60	
			600 < $I_c \leq 800$		80	
			800 < $I_c \leq 1\,000$		100	
			1\,000 < $I_c \leq 1\,300$		140	
			1\,300 < $I_c \leq 1\,600$		180	
			1\,600 < $I_c \leq$		240	

Table 8 – Conventional operational performance – Making and breaking conditions according to utilization categories for the mechanical switching device

Utilization category	Make and break conditions					
	I_c/I_e	U_r/U_e	Cos φ	ON-time s	OFF-time s	Number of operating cycles
AC-1	1,0	1,05	0,80	0,05	a	6 000 ^d
AC-5a	2,0		0,45		a	
AC-5b	1,0 ^b		b		60	
AC-6a	c		c			
AC-6b	c		c			
I_c = current made and broken, expressed in AC RMS symmetrical values I_e = rated operational current U_e = rated operational voltage U_r = power-frequency recovery voltage						
^a OFF-times shall not be greater than the values given in Table 7. ^b Tests to be carried out with incandescent light load. ^c Under consideration. ^d For manually operated switching devices, the number of operating cycles shall be 1 000 on-load, followed by 5 000 off-load.						

8.2.4.2.2 Mechanical switching devices of semiconductor controllers and semiconductor contactors

The making and breaking capacity shall be verified when tested as a combined unit in accordance with the procedure of 9.3.3.5.2.

8.2.4.2.3 Semiconductor switching devices

The capability to control overload currents shall be verified by the procedures of 9.3.3.6.3 and 9.3.3.6.4.

8.2.4.3 Requirements for an initiating load

The initiating load for short-circuit testing (see Figure I.1) shall be any convenient passive load with the following characteristics:

- the rated voltage shall be equal to or greater than U_e for the device to be tested;
- the power factor shall be between 0,8 and 1,0;
- with voltage U_e applied to the initiating load, the current flow may be any value greater than 1 A.

8.2.4.4 Semiconductor controller and semiconductor contactor power losses

Where the power losses of the semiconductor controller or semiconductor contactor is given, the power semiconductor losses shall be calculated according to 5.3.7.2 and the semiconductor controlling device losses shall be measured according to 9.3.3.2.

8.2.5 Coordination with short-circuit protective devices

8.2.5.1 Performance under short-circuit conditions

The rated conditional short-circuit of semiconductor controllers and semiconductor contactors backed up by short-circuit device(s) (SCPDs) shall be verified by short-circuit tests as specified in 9.3.4. These tests are mandatory.

The rating of the SCPD shall be adequate for any given rated operational current, rated operational voltage and the corresponding utilization category.

The SCPD may be integrated within the semiconductor controller or semiconductor contactor.

Two types of coordination are permissible, type 1 or type 2. Test conditions for both are given in 9.3.4.3.

Type 1 coordination requires that, under short-circuit conditions, the device shall cause no danger to persons or to the installation and may not be suitable for further service without repair and replacement of parts.

Type 2 coordination requires that, under short-circuit conditions, the device shall cause no danger to persons or to the installation and shall be suitable for further use. For series mechanical switching devices of semiconductor controllers and semiconductor contactors, the risk of contact welding is recognized, in which case the manufacturer shall indicate the measures to be taken as regards the maintenance of the equipment.

NOTE Use of an SCPD not in compliance with the manufacturer's recommendations can invalidate the coordination.

8.2.5.2 Vacant

8.3 EMC requirements

8.3.1 General

Subclause 8.3.1 of IEC 60947-1:2020 applies with the following addition.

All phenomena, whether immunity or emission, are considered individually: the limits given are for conditions which are not considered to have cumulative effects.

For EMC tests, the minimum system to be considered is the semiconductor controller or semiconductor contactor interconnected with a load and cables.

8.3.2 Immunity

8.3.2.1 General

The test results are specified using the performance criteria given in Table 9.

Table 9 – Specific performance criteria when EM disturbances are present

Item	Performance criteria during tests		
	1	2	3
A. Overall performance	No noticeable changes of the operating characteristic. Operating as intended.	Noticeable changes (visual or audible) of the operating characteristic. Self-recoverable.	Changes in operating characteristic. Triggering of protective devices. Not self-recoverable.
B. Operation of power and driving circuits	No maloperation.	Temporary maloperation which can cause changes in current or voltage. Self-recoverable.	Shut down. Not self-recoverable.
C. Operation of displays and control panels	No changes to visible display information. Only slight light intensity fluctuation of LED's, or slight movement of characters.	Temporary visible changes or loss of information. Undesired LED illumination.	Shut-down. Permanent loss or display of wrong information. Unpermitted operating mode. Not self-recoverable.
D. Information processing and sensing functions	Undisturbed communication and data interchange to external devices.	Temporarily disturbed communication with possible error reports of the internal and external devices.	Erroneous processing of information. Loss of data and/or information. Errors in communication. Not self-recoverable.

8.3.2.2 Electrostatic discharges

The test values and procedures are given in 9.4.2.1.

8.3.2.3 Radio-frequency electromagnetic fields

The test values and procedures are given in 9.4.2.2.

8.3.2.4 Fast transients (5/50 ns)

The test values and procedures are given in 9.4.2.3.

8.3.2.5 Surges (1,2/50 µs – 8/20 µs)

The test values and procedures are given in 9.4.2.4.

8.3.2.6 Harmonics and commutation notches

The test values and procedures are given in 9.4.2.5.

8.3.2.7 Voltage dips and short-time interruptions

The test values and procedures are given in 9.4.2.6.

8.3.2.8 Power-frequency magnetic field

Tests are not required. Immunity is demonstrated by the successful completion of the operating capability test (see 9.3.3.6).

8.3.3 Emission

8.3.3.1 Low-frequency emission with reference to main power frequency

8.3.3.1.1 Harmonics

Because no significant harmonic emissions are produced in the FULL-ON state, tests are not required on those semiconductor controllers or semiconductor contactors which run only in the FULL-ON state or which are by-passed by a mechanical switching device after completing a start.

Devices intended to be connected to public low-voltage distribution systems and which can operate continuously in a state different than FULL-ON state shall comply, if applicable, with IEC 61000-3-2 when rated less or equal to 16 A per phase and with IEC 61000-3-12 when rated above 16 A and below or equal to 75 A.

8.3.3.1.2 Voltage fluctuation

Devices intended to be connected to public low-voltage distribution systems and which can operate continuously in a state different than FULL-ON state shall comply, if applicable, with IEC 61000-3-3 when rated less or equal to 16 A per phase and with IEC 61000-3-11 when rated below or equal to 75 A.

8.3.3.2 High-frequency emission

8.3.3.2.1 Conducted radio-frequency (RF) emission

The limits given in Table 12 shall be verified in accordance with the procedures of 9.4.3.1.

8.3.3.2.2 Radiated emissions

The limits given in Table 13 shall be verified in accordance with the procedures of 9.4.3.2.

9 Tests

9.1 Kinds of tests

9.1.1 General

Subclause 9.1.1 of IEC 60947-1:2020 applies.

9.1.2 Type tests

Type tests are intended to verify compliance of the design of semiconductor controllers and semiconductor contactors of all types and their dedicated wiring accessories with this document. They comprise the verification of:

- a) temperature-rise limits (see 9.3.3.3);
- b) dielectric properties (see 9.3.3.4);
- c) operating capability (see 9.3.3.6);
- d) operation and operating limits (see 9.3.3.6.4);
- e) rated making and breaking capacity and conventional operational performance of series mechanical switching devices (see 9.3.3.5);
- f) performance under short-circuit conditions (see 9.3.4);
- g) mechanical properties of terminals (9.2.5 of IEC 60947-1:2020 applies);
- h) degrees of protection of enclosed semiconductor controllers and semiconductor contactors (Annex C of IEC 60947-1:2020 applies);

i) EMC tests (see 9.4).

9.1.3 Routine tests

Subclause 9.1.3 of IEC 60947-1:2020 applies where sampling tests (see 9.1.4) are not made instead.

For dedicated wiring purpose accessories delivered separately, only dielectric test applies.

Routine tests for semiconductor controllers and semiconductor contactors comprises:

- operation and operating limits according to 9.5.2 but only for AC-1;
- dielectric tests (see 9.5.3).

9.1.4 Sampling tests

Sampling tests for semiconductor controllers and semiconductor contactors comprise:

- operation and operating limits according to 9.5.2 but only for AC-1;
- dielectric tests (see 9.5.3).

Subclause 9.1.4 of IEC 60947-1:2020 applies with the following amplification.

A manufacturer may use sampling tests instead of routine tests at his own discretion. Sampling shall meet or exceed the following requirements as specified in Table 2-A of ISO 2859-1:1999.

Sampling is based on $AQL \leq 1$:

- acceptance number $A_c = 0$ (no defect accepted);
- rejection number $R_e = 1$ (if one defect, the entire lot shall be tested).

Sampling shall be made at regular intervals for each specific lot.

Alternative statistical methods that ensure compliance with ISO 2859-1:1999 requirements can be used, for example statistical methods controlling continuous manufacturing or process control with capability index.

Sampling tests for clearance verification according to 9.3.3.4.3 of IEC 60947-1:2020 are under consideration.

9.1.5 Special tests

The conducting of special test is at the discretion of the manufacturer.

Special tests include damp heat, salt mist, vibration and shock tests.

For these special tests, Annex Q of IEC 60947-1:2020 applies.

Where Table Q.1 of IEC 60947-1:2020 calls for verification of operational capability, this shall be done according to 9.5.2 of this document.

The vibration tests shall be done on the equipment with the mechanical switching device in the open and closed positions, if any. To check the behavior of main and auxiliary contacts, tests can be done under any current / voltage value.

The shock test on the equipment shall be done in the open position of the mechanical switching device(s).

For the dry heat test, the mechanical switching device shall be in the closed position during the conditioning period (see 5.3.3 of IEC 60068-2-2:2007). For categories A, B and C, the test may be done without current in the poles and for categories D, E and F, the test shall be done under the maximum rated current but may be limited to 100 A for practical reasons. During the last hour, the controller shall be operated 5 times.

For the low temperature test, the test Ad is to be chosen instead of the test Ab and the mechanical switching device shall be in the open position during the cooling period. It shall then be energized for the last hour. For categories A, B and C, the test may be done without current in the poles and for categories D, E and F, the test is done under the maximum rated current which may be limited to 100 A for practical reasons. During this last hour the controller shall be operated 5 times.

For the damp heat test, for categories A, B and C, the test may be done without current in the poles. For categories D, E and F the equipment shall be energized under the maximum rated current for the first cycle and de-energized for the second cycle. The current may be limited to 100 A for practical reasons. After stabilization of the temperature, during the first 2 h of the first cycle and during the last 2 h of the second cycle, the controller shall be operated 5 times.

With the agreement of the manufacturer, the duration of the recovery periods may be reduced.

After the salt mist test, the product may be washed with the manufacturer's agreement.

9.2 Compliance with constructional requirements

9.2.1 General

Subclause 9.2 of IEC 60947-1:2020 applies with the following additions.

9.2.2 Electrical performance of screwless-type clamping units

Subclause 9.2.5.7 of IEC 60947-1:2020 applies with the following additions.

The insertion and disconnection of the conductors shall be made in accordance with the manufacturer's instructions.

The measurement methods and the results shall be documented in the test report. The test current is I_{th} .

NOTE The device sample can be provided with holes or equivalent arrangements which provide measurement access points for the voltage drop on the terminal.

9.2.3 Ageing test for screwless-type clamping units

Subclause 9.2.5.8 of IEC 60947-1:2020 applies with the following change.

The test shall be done on the device equipped with the clamping units.

The test current is I_{th} .

NOTE The device sample can be provided with holes or equivalent arrangements which provide measurement access points for the voltage drop on the terminal.

9.2.4 Limited energy source test

A limited energy source circuit shall be tested as follows, with the equipment operating under normal operating conditions.

In case the limited energy source requirement depends on over-current protective device(s), the device(s) shall be short-circuited.

With the equipment operating under normal operating conditions, a variable resistive load is connected to the parts under consideration and adjusted to obtain a level of required limited apparent power (VA). Further adjustment is made, if necessary, to maintain the limited apparent power (VA) for a period specified in 8.1.14.

A variable resistive load is connected to the circuit under consideration and adjusted to obtain the limit of apparent power as indicated in Table 14, Table 15, or Table 16, as applicable. Further adjustment is made, if necessary, to maintain the limit of apparent energy for the time period indicated in Table 14, Table 15, or Table 16, as applicable.

The test is passed, if after the test period the available apparent power does not exceed the limits indicated in Table 14, Table 15, or Table 16, as applicable.

In case the limited energy source requirement depends on over-current protective device(s), the current rating of at least one of the protective device(s) in the current path shall not exceed the limit in Table 15.

These tests shall be conducted under the most unfavourable combination within the manufacturer's operating specifications of the parameters as listed in 5.5.

9.2.5 Breakdown of components

9.2.5.1 General

The breakdown of a component, identified as a result of the circuit analysis of 8.1.16, shall be tested with the product operating with the load creating the more severe condition.

NOTE As described in 8.1.16, this test is intended to verify it does not result in hazardous situation, but it is not intended to verify the continuity of the functions of the equipment.

The test is not required:

- when circuit analysis indicates that no other component or portion of the circuit will be overloaded as a result of open- or short-circuit failure mode of another component;
- for components in circuits supplied by limited energy sources in compliance with 8.1.14;
- on power semiconductor devices when equivalent testing is accomplished during short-circuit tests;
- for components that have previously been positively evaluated considering the failure modes and the circuit conditions in which the component is used within the device.

9.2.5.2 Breakdown of components test

Each identified component shall be subjected to a breakdown of components test in open- and/or short-circuit failure modes, whichever is most severe.

The breakdown of component test may be done with only those circuits of the device that can affect the result of the test, being fully energized and in operation.

During the test, there shall be no emission of flame or molten metal, nor ignition of cotton. The fusible element shall not open.

Components, such as capacitors or diodes, are short- or open-circuited. For device without a dedicated enclosure, an outer metal enclosure or a wire mesh cage (with surrounded cotton on the cage) that is 1,5 times the size of the device (or different, according to manufacturer declarations) shall be provided to simulate the potential grounded parts around the device. In case of dedicated enclosure, the cotton shall be placed over all openings. The outer dedicated enclosure or wire mesh cage (when provided) and any grounded or exposed dead-metal part shall be connected through a fusible element F, according to subclause 9.3.4.1.2 d) of IEC 60947-1:2020, to the supply circuit.

NOTE The definition of enclosed equipment is given in Annex C of IEC 60947-1:2020.

9.2.6 Wire flexing test

Following the requirements of 8.1.3, the wiring to components mounted on a door or cover is to be tested by opening the door or cover as far as possible – restraints such as a chain are to remain in place – and then closing it for 500 cycles of operation. Following this test, the equipment is to be subjected to the dielectric voltage withstand test described in 9.3.3.4.1 applied between conductors and between conductors and ground.

9.3 Compliance with performance requirements

9.3.1 Test sequences

Each test sequence is made on a new sample.

For convenience of testing and by agreement with the manufacturer, these tests may be conducted on separate new samples and omitted from the relevant sequence.

This only applies to the following tests upon request:

- 9.3.3.4.1 item 7) of IEC 60947-1:2020: Verification of creepage distance;
- 9.2.5 of IEC 60947-1:2020: Mechanical properties of terminals;
- Annex C of IEC 60947-1:2020: Degrees of protection of enclosed equipment.

For convenience of testing, compliance with 8.2.4.2 is omitted from the following test sequence. Nonetheless, the manufacturer is obliged to verify compliance by other convenient means.

The test sequence shall be as follows:

- a) Test sequence I
 - 1) verification of temperature-rise (see 9.3.3.3);
 - 2) verification of dielectric properties (see 9.3.3.4).
- b) Test sequence II: operating capability verification (see 9.3.3.6)
 - 1) thermal stability test (see 9.3.3.6.2);
 - 2) overload capability test (see 9.3.3.6.3);
 - 3) blocking and commutating capability test (see 9.3.3.6.4) including verification of operation and operating limits.
- c) Test sequence III
Performance under short-circuit conditions (see 9.3.4).
- d) Test sequence IV
 - 1) verification of mechanical properties of terminals (9.2.5 of IEC 60947-1:2020, 9.2.2 and 9.2.3 of this document);
 - 2) verification of degrees of protection of enclosed equipment (see Annex C of IEC 60947-1:2020).

- e) Test sequence V
EMC tests (see 9.4).

9.3.2 General test conditions

Subclause 9.3.2 of IEC 60947-1:2020 applies with the following additions.

Except for devices specifically rated for only one frequency, tests performed at 50 Hz cover 60 Hz applications and vice-versa.

The selection of samples to be tested for a series of devices with the same fundamental design and without a significant difference in construction shall be based on engineering judgement.

Unless otherwise specified in the relevant test clause, the clamping torque for connections shall be that specified by the manufacturer or, if not specified, the torque given in Table 4 of IEC 60947-1:2020.

In the case where several heat-sinks are specified, the one which has the highest thermal resistance shall be used.

True RMS voltage and current measuring means shall be used.

9.3.3 Performance under no load, normal load and overload conditions

9.3.3.1 Vacant

9.3.3.2 Power consumption

The power consumption of the semiconductor controlling device is measured with a wattmeter on the terminals of the control supply voltage in FULL-ON operation during a typical duty cycle.

9.3.3.3 Temperature-rise

9.3.3.3.1 Ambient air temperature

Subclause 9.3.3.3.1 of IEC 60947-1:2020 applies.

9.3.3.3.2 Measurement of the temperature of parts

Subclause 9.3.3.3.2 of IEC 60947-1:2020 applies.

9.3.3.3.3 Temperature-rise of a part

Subclause 9.3.3.3.3 of IEC 60947-1:2020.

9.3.3.3.4 Temperature-rise of the main circuit

Subclause 9.3.3.3.4 of IEC 60947-1:2020 applies with the exception that a single-phase test shall be conducted with all poles in the main circuit loaded at their individual maximum rated currents and as stated in 8.2.2.5, and with the following additions.

For semiconductor switching devices connected in the main circuit (see 8.2.2.5), temperature sensing means shall be attached to the outer surface of the case of the semiconductor switching device that is most likely to produce the highest temperature-rise during this test. The final case temperature, C_f , and the final ambient temperature, A_f , shall be recorded for use in the test of 9.3.3.6.3.

For mechanical switching devices (see 8.2.2.5.2 and 8.2.2.5.3), temperature sensing means shall be attached in accordance with the requirements of 9.3.3.3 of IEC 60947-1:2020.

All auxiliary circuits which normally carry current shall be loaded at their maximum rated operational current (see 5.6) and the control circuits shall be energized at their rated voltages.

9.3.3.3.5 Temperature-rise of control circuits

Subclause 9.3.3.3.5 of IEC 60947-1:2020 applies, with the following addition.

The temperature-rise shall be measured during the test of 9.3.3.3.4.

9.3.3.3.6 Temperature-rise of coils and electromagnets

Subclause 9.3.3.3.6 of IEC 60947-1:2020 applies with the following addition.

Electromagnets of mechanical switching devices intended for duty within semiconductor controllers or for mechanical bypass switching means shall comply with 8.2.2.7 with rated current flowing through the main circuit for the duration of the test. The temperature-rise shall be measured during the test of 9.3.3.3.4.

9.3.3.3.7 Temperature-rise of auxiliary circuits

Subclause 9.3.3.3.7 of IEC 60947-1:2020 applies with the following addition.

The temperature-rise shall be measured during the test of 9.3.3.3.4.

9.3.3.4 Dielectric properties

9.3.3.4.1 Type tests

1) General conditions for withstand voltage tests

Subclause 9.3.3.4.1 1) of IEC 60947-1:2020 applies.

2) Verification of impulse withstand voltage

a) General

Subclause 9.3.3.4.1 2) a) of IEC 60947-1:2020 applies.

b) Test voltage

Subclause 9.3.3.4.1 2) b) of IEC 60947-1:2020 applies with the following sentence added:

For any part for which the dielectric properties are not sensitive to altitude (e.g. optocoupler, potted parts, etc.) the correction factor for altitude is not applicable.

c) Application of test voltage

With the equipment mounted and prepared as specified in item 1) above, the test voltage is applied as follows:

- i) between all the terminals of the main circuit connected together (including the control and auxiliary circuits connected to the main circuit) and the enclosure or mounting plate, with the contacts, if any, in all normal positions of operation;
- ii) for poles of the main circuit declared galvanically separated (3.4.21) from the other poles: between each pole and the other poles connected together and to the enclosure or mounting plate, with the contacts, if any, in all normal positions of operation;
- iii) between each control and auxiliary circuit not normally connected to the main circuit and
 - the main circuit;

- the other circuits;
 - the exposed conductive parts;
 - the enclosure or mounting plate, which, wherever appropriate, may be connected together;
- iv) for equipment suitable for isolation, across the poles of the main circuit, the line terminals being connected together and the load terminals connected together. The test voltage shall be applied between the line and load terminals of the equipment with the contacts in the isolated open position and its value shall be as specified in item 1) b) of 8.2.3.2 of IEC 60947-1:2020.
- d) Acceptance criteria
Subclause 9.3.3.4.1 2) d) of IEC 60947-1:2020 applies.
- 3) Power-frequency withstand verification of solid insulation
- a) General
Subclause 9.3.3.4.1 3) a) of IEC 60947-1:2020 applies.
- b) Test voltage
Subclause 9.3.3.4.1 3) b) of IEC 60947-1:2020 applies with the following sentence added at the end of the first paragraph.
If an alternating test voltage cannot be applied due to the EMC filter components, which cannot easily be disconnected, a direct test voltage may be used having the same value as the crest value of the projected alternating test voltage.
- c) Application of test voltage
Subclause 9.3.3.4.1 3) c) of IEC 60947-1:2020 applies with the following additional condition :
For semiconductor controllers and semiconductor contactors with series mechanical switching devices, across the poles of the main circuit, the line terminals being connected together, and the load terminals connected together.
The test voltage shall be applied for 5 s, with the following conditions:
- in accordance with items i), ii) and iii) of 2) c) above;
 - for semiconductor controllers and semiconductor contactors with series mechanical switching devices, across the poles of the main circuit, the line terminals being connected together and the load terminals connected together.
- d) Acceptance criteria
Subclause 9.3.3.4.1 3) d) of IEC 60947-1:2020 applies.
- 4) Power-frequency withstand verification after switching and short-circuit tests
- a) General
Subclause 9.3.3.4.1 4) a) of IEC 60947-1:2020 applies.
- b) Test voltage
Subclause 9.3.3.4.1 4) b) of IEC 60947-1:2020 applies.
- c) Application of test voltage
Subclause 9.3.3.4.1 4) c) of IEC 60947-1:2020 applies with the following sentence added at the end of the paragraph:
The use of a metal foil, as mentioned in 9.3.3.4.1 1) of IEC 60947-1:2020, is not required.
- d) Acceptance criteria
Subclause 9.3.3.4.1 4) d) of IEC 60947-1:2020 applies.
- 5) Vacant
- 6) Verification of DC withstand voltage
Subclause 9.3.3.4.1 4) of IEC 60947-1:2020 applies.

7) Verification of creepage distances

Subclause 9.3.3.4.1 7) of IEC 60947-1:2020 applies (see also 8.1.4).

8) Verification of leakage current of equipment suitable for isolation.

The maximum leakage current shall not exceed the values of 8.2.7 of IEC 60947-1:2020.

9.3.3.4.2 Vacant**9.3.3.4.3 Verification of clearances**

1) General

Subclause 9.3.3.4.3 1) of IEC 60947-1:2020 applies.

2) Test voltage

The test voltage shall be that corresponding to the rated impulse withstand voltage.

3) Application of test voltage

Subclause 9.3.3.4.3 3) of IEC 60947-1:2020 applies.

4) Acceptance criteria

Subclause 9.3.3.4.3 4) of IEC 60947-1:2020 applies.

9.3.3.5 Making and breaking capacity of mechanical switching devices**9.3.3.5.1 General**

The making and breaking capacity shall be verified in accordance with 9.3.3.5 of IEC 60947-1:2020.

This test shall cover the conditions of maximum interrupted values of voltage, power, and current.

9.3.3.5.2 Mechanical switching devices of semiconductor controllers and semiconductor contactors

The complete unit with bypass installed shall be tested as in normal service. The operational sequence, to simulate switching (ON and OFF), shall be the same as in normal service.

If the mechanical switching devices has already fulfilled the requirements according to Table 7 and Table 8, it is not required to repeat the test.

9.3.3.6 Operating capability**9.3.3.6.1 General**

Compliance with the operating capability requirements of 8.2.4.1 shall be verified by the following three tests.

- a) thermal stability tests;
- b) overload capability tests;
- c) blocking and commutation capability test.

The tests simulate an 8 h duty.

Connections to the main circuit shall be similar to those intended to be used when the equipment is in service. The control voltage shall be fixed at 110 % of the rated control circuit supply voltage U_s .

Table 10 – Thermal stability test specifications

Test details	Level	Instructions
Test objective	To verify that the temperature variation between successive identical operating cycles in a sequence reduces to less than 5 % within an 8 h period To verify that the temperature-rise of the accessible terminals of the mechanical switching device in the main circuit does not exceed the limit prescribed by Table 2 of IEC 60947-1:2020	
Test duration	Run test until $\Delta_n \leq 0,05$ or 8 h have elapsed $\Delta_n = (C_n - C_{n-1} - A_n + A_{n-1})/(C_{n-1})$	
Test conditions	Table 5	
EUT ^a temperature	C_n , case temperature	Temperature sensing means attached to the outer surface of one semiconductor switching device (see 9.3.3.3.4) Monitor the semiconductor switching device that is likely to be the hottest
Ambient temperature	A_n , any level convenient	Temperature sensing means to monitor changes in ambient temperature (9.3.3.3.1 of IEC 60947-1:2020 applies)
Results to be obtained	1) $\Delta_n \leq 0,05$ within 8 h 2) No visual evidence of damage (such as smoke, discoloration) 3) The temperature-rise of the accessible terminals of the mechanical switching device in the main circuit shall not exceed the limit prescribed by Table 2 of IEC 60947-1:2020 4) When the terminals are not accessible, the values of Table 2 of IEC 60947-1:2020 may be exceeded provided that adjacent parts are not impaired	
^a Equipment under test.		

9.3.3.6.2 Thermal stability test procedure

Test specifications and acceptance criteria are given in Table 10. The test profiles are illustrated in Figure F.1.

- 1) Assign a sequence number, n , to each on-load period in the test series (i.e. $n = 0, 1, 2, \dots, n-1, N$).
- 2) Record initial case temperature C_0 . Record initial ambient temperature A_0 .
- 3) Set test current, I_T (see Table 5). Change n to a new value where $n = n + 1$.
- 4) Apply test voltage U_T , to the input main circuit terminals of the EUT (equipment under test). U_T may remain applied for the duration of the test or, may be switched ON-OFF in synchronism with the operation of control voltage U_C .

Switch EUT to ON-state (EUT control voltage, U_C , is ON).

NOTE The time span of ON-time commences at the instant when the test current reaches the value of I_T . Therefore, the time for the test current ramp to reach the value of I_T increases the total test time.

- 5) After ON-time (Table 5), switch EUT to OFF-state.
- 6) Record case temperature C_n . Record ambient temperature A_n .
- 7) Decision to terminate (or continue) test:
 - a) Calculate case temperature-rise change factor:

$$\Delta_n = (C_n - C_{n-1} - A_n + A_{n-1})/(C_{n-1})$$
 - b) Check compliance with results to be obtained (see Table 10)
 If $\Delta_n > 0,05$, and total test time is less than 8 h and results to be obtained 1) and 2) of Table 10) are not violated, repeat steps 3) through 7).
 If $\Delta_n > 0,05$, and total test time is greater than 8 h or results to be obtained are violated, end test. This is a failure.

If $\Delta_n \leq 0,05$, and total test time is less than 8 h, and results 1), 2), 3) and 4) of Table 10 are not violated, end test. This is successful compliance.

9.3.3.6.3 Overload withstand current test procedure

1) Test conditions

- a) Refer to Table 6. The test profile is represented in Figure F.2.
- b) Semiconductor controllers and semiconductor contactors utilizing a current-controlled cut-out device in addition to an overcurrent protective means that provides protection against overload conditions during running in the FULL-ON state, shall be tested with the cut-out device in place. In this test, it is acceptable for the cut-out device to switch the EUT to the OFF-state in a time shorter than the specified ON-time.

2) EUT adjustments

- a) EUT shall be adjusted to minimize the time to establish the test current level I_T .
- b) EUT fitted with a current-limit function shall be set to the maximum setting of I_{Lim} .

NOTE The time span of T_x commences at the instant when the test current reaches the value I_T . Therefore, the time for the test current ramp to reach I_T increases the total test time.

3) Test

- a) Establish initial conditions.
- b) Apply test voltage to the input main circuit terminals of the EUT.
With semiconductor controller or semiconductor contactor in series with a mechanical switching device, the series mechanical switching device contact is closed.
The test voltage shall be applied for the duration of the test.
- c) Switch the EUT to ON-state.
- d) After the ON-time (Table 6), switch the EUT to the OFF-state.
- e) Repeat steps c) and d) for the number of cycles of Table 6. End test.
The initial case temperature conditions for these required operating cycles shall be as stated in Table 6.

9.3.3.6.4 Blocking and commutating capability test

Test specifications are given in Table 11. The test profiles are shown in Figure F.3.

Table 11 – Blocking and commutating capability test specifications

Utilization category	Test load parameters of the test circuit			Test cycles	
	U/U_e	Power	$\cos \varphi$	ON-time s	OFF-time s
AC-1	1,0	a	0,8 1,0	0,5	0,5
AC-5a	1,0	b	0,45	0,5	0,5
AC-5b	1,0	c	c	f	0,5
AC-6a	1,0	d	$\leq 0,45$	f	g
AC-6b	1,0	e	e	f	h
a The test load shall be any convenient slightly inductive load. b The test load shall be any convenient inductive load. c The test load shall be any convenient incandescent lamp. d The test load shall be any convenient transformer. e The test load shall be any convenient capacitor or capacitor bank. f The on-time shall be greater than that time required to reach the steady-state nominal current. g The off-time is that time required for the current to become less than 10 % of the nominal ON-state current value. h The off-time is that time required for the voltage on the capacitor to become less than 10 % of the nominal voltage due to the discharge of the capacitor through any convenient discharge resistor.					

The following tests are to be carried out:

- test 1: 100 operating cycles with 85 % U_e and 85 % U_s ;
- test 2: 1 000 operating cycles with 110 % U_e and 110 % U_s .

During the tests:

- the load and the ambient air may be at any temperature between 10 °C and 40 °C;
- a true RMS current measuring means shall be connected between the test load terminals and the load side terminals on each pole of the EUT. The means shall be capable of measuring currents in the range of milliamperes;
- settings are limited to only those external adjusting means provided by the manufacturer in the normal product offerings. Controllers fitted with ramp-up functions shall be set at the maximum ramping time or 10 s, whichever is less;
- controllers fitted with a current-limit function will be set at the lowest value of X that will allow to start the test load (as defined in Table 11).

Results to be obtained:

a) a1) or a2) shall be fulfilled

a1) $I_O < 1 \text{ mA}$ and $I_F < 1 \text{ mA}$

a2) if $I_O > 1 \text{ mA}$ or $I_F > 1 \text{ mA}$, then

- $\Delta I < 1$ for each pole where $\Delta I = (I_F - I_O) / I_O$ and
- I_O and I_F shall be within the limits of I_{Lm} given in the documentation of the controller.

No visual evidence of damage (such as smoke, discoloration).

b) No loss of functionality as specified by the manufacturer.

For semiconductor controller or semiconductor contactor in series with a mechanical switching device, the contacts of the series mechanical switching device shall be maintained in the closed position for the duration of the test.

- 1) The EUT shall be mounted and connected as in normal use with cable length between the EUT and test load not greater than 10 m.
- 2) The current measuring means shall be installed in a manner that is appropriate for recording the values of the OFF-state current through the semiconductor controller in steps 3) and 7).

If other auxiliary circuits or devices are connected in parallel with the semiconductor elements, care shall be taken in order to avoid measuring the parallel currents; only the OFF-state current of the semiconductor elements shall be measured and the means for obtaining those measures shall be installed accordingly.

- 3) With the voltages (see Table 11) applied to the EUT, and with the control voltage U_c OFF, measure the current through each pole of the EUT and record these measurements as a set of initial data points, I_o .

The test circuit shall remain closed from the start of step 4) through the completion of step 7). The current measuring means may be shorted by remote control means during steps 5) and 6), but it may not be removed by opening the circuit.

- 4) To start the test, the test voltages (as specified in Table 11) are applied to the EUT and maintained for the duration of the test through the completion of step 7).
- 5) By means of the control voltage U_c , cycle the EUT between the ON-time and the OFF-time as specified in Table 11. If the semiconductor controller does not perform as intended, or if evidence of damage develops, the test is discontinued, and considered a failure.
- 6) After the required number of operating cycles, turn U_c to OFF with the test voltages remaining ON, allow the EUT to return to the initial ambient temperature.
- 7) Repeat the current measurement procedure of step 3) and record as a set of final data points, I_F , corresponding to the set of initial data points, I_o .
- 8) Determine the values regarding the OFF-state currents through each pole as specified under item 1) of the results to be obtained given after Table 11.

To obtain successful compliance, the criteria given under items 1), 2) and 3) of the results to be obtained given after Table 11 shall be fulfilled.

9.3.3.6.5 Behaviour of the semiconductor controller during, and condition after, the operating capability tests

- a) Commutating capability

If semiconductor devices do not commute properly, the early stage of the failure mode is evidenced by degraded performance. Continued operation in this mode will cause thermal runaway. The ultimate result will be excessive heating and loss of blocking capability.

- b) Thermal stability

Semiconductor devices subject to rapid operating cycles may not cool properly. The early effects may initiate a thermal runaway condition leading to loss of blocking capability.

- c) Blocking capability

Blocking capability is the ability to turn OFF and remain OFF whenever required. Excessive thermal stress will degrade blocking capability. The failure mode is evidenced by a partial or total loss of control.

- d) Functionality

Some failure modes may not be catastrophic in the early stages. These failures are evident from gradual loss of function. Early detection and correction may prevent permanent damage.

- e) Visual inspection

Ultimately, excessive thermal stresses due to elevated temperatures may cause permanent damage. Visual evidence (smoke or discoloration) provides early warning of ultimate failure.

9.3.4 Performance under short-circuit conditions

9.3.4.1 General conditions for short-circuit tests

9.3.4.1.1 General requirements for short-circuit tests

General conditions for short-circuit tests are as follows:

- "O" operation: as a pre-test condition, the semiconductor contactor/semiconductor controller shall be sustained in the ON-state by an initiating load. The pre-test current may be held at any arbitrary low level of current that is greater than the minimum load current of the semiconductor contactor/semiconductor controller. The short-circuit current is applied to the semiconductor contactor/ semiconductor controller by closing the shorting switch. The SCPD shall interrupt the short-circuit current and the semiconductor contactor/semiconductor controller shall withstand the let-through current;
- "CO" operation for direct on-line equipment.

Initial case temperature shall not be less than 40 °C. In some cases, it may be impossible to pre-heat the EUT and maintain the initial case temperature at a test site that is fitted for short-circuit testing only. In these cases, the manufacturer and user may agree to test the EUT at ambient temperature. If used, the lower temperature shall be recorded in the test report.

The general requirements of 9.3.4.1.1 of IEC 60947-1:2020 apply with the following modification.

The enclosure shall be in accordance with the manufacturer's specifications. In the case where multiple enclosure options are provided, the enclosure with the smallest volume shall be taken.

If devices tested in free air may also be used in enclosures, they shall be additionally tested in the smallest of such enclosures stated by the manufacturer. For devices tested only in free air, information shall be provided to indicate that they are not suitable for use in an individual enclosure.

9.3.4.1.2 Test circuit for the verification of short-circuit ratings

The test circuit of 9.3.4.1.2 of IEC 60947-1:2020 applies except that for type 1 coordination, the fusible element F and the resistance R_L are replaced by a solid 6 mm² wire 1,2 m to 1,8 m in length, connected to the neutral, or with the agreement of the manufacturer, to one of the poles.

NOTE This larger size of wire is not used as a detector but to establish an earth condition allowing the damage to be evaluated.

In addition, the method for achieving a FULL-ON state of the EUT shall be selected among the following possibilities:

- a) a remote circuit applied to each controller pole such that the output devices are actuated to a FULL-ON state independent of any loading;
- b) an initiating load with the characteristics that are given in 8.2.4.3 as a dummy load.

For b), the test circuit of 9.3.4.1.2 of IEC 60947-1:2020 shall be modified and wired as shown in Figure I.1. The shorting switch (not a part of the EUT) shall be capable of making and carrying the short-circuit current with no tendency to interfere with the process of applying the short-circuit current (for example bounce or other intermittent openings of the contacts).

9.3.4.1.3 Power factor of the test circuit

Subclause 9.3.4.1.3 of IEC 60947-1:2020 applies.

9.3.4.1.4 Vacant**9.3.4.1.5 Calibration of the test circuit**

Subclause 9.3.4.1.5 of IEC 60947-1:2020 applies.

9.3.4.1.6 Test procedure

Subclause 9.3.4.1.6 of IEC 60947-1:2020 applies with the following additions.

The cables length may exceed 2,4 m when they are in the circuit during calibration.

The semiconductor controller or semiconductor contactor and its associated SCPD shall be mounted and connected as in normal use. They shall be connected in the circuit using a maximum of 2,4 m of cable (corresponding to the operational current of the semiconductor controller or semiconductor contactor) for each main circuit.

If the SCPD is separate from the semiconductor controller or semiconductor contactor, it shall be connected using the cable specified above (the total length of cable shall not exceed 2,4 m).

Three-phase tests are considered to cover single-phase applications.

If the test is done according to method b) in 9.3.4.1.2, the time-line for the test sequence is shown in Figure I.2.

- a) The test is started with the shorting switch in the open position (time T_0);
- b) The test voltage is then applied and the initiating load shall limit the current to a level that is, at least, sufficient to maintain the semiconductor controller in the ON-state (time T_1);
- c) At any arbitrary time after the current through the semiconductor contactor/ semiconductor controller has stabilized, the shorting switch may then be closed at random and thereby establish a short-circuit current path through the EUT (time T_2) which shall be cleared by the SCPD (time T_3).

9.3.4.1.7 Vacant**9.3.4.1.8 Interpretation of records**

Subclause 9.3.4.1.8 of IEC 60947-1:2020 applies.

9.3.4.2 Vacant**9.3.4.3 Conditional short-circuit current of semiconductor controllers and semiconductor contactors****9.3.4.3.1 General**

The semiconductor controller or semiconductor contactor with or without a type-tested bypassed component, and the associated SCPD shall be subjected to the tests given in 9.3.4.3.2.

Bypassed semiconductor controllers shall be submitted to two separate short-circuit tests in accordance with 9.3.4. Test 2 is not required for bypassed semiconductor controllers and semiconductor contactors using external mechanical switching devices which have been already tested according to 9.3.4.3.2.

- a) Test 1: The test is conducted with the semiconductors in the conducting mode and with the bypass contacts open. This is intended to simulate short-circuit conditions occurring while starting in a mode that is controlled by the semiconductors.

- b) Test 2: The test is conducted with the semiconductors bypassed with the bypass contacts closed. This is intended to simulate short-circuit conditions occurring while the semiconductors of the EUT are bypassed.

The tests shall be conducted under conditions corresponding to the maximum I_e and the maximum U_e .

When the same semiconductor component is used for several ratings, the test shall be performed under the conditions corresponding to the highest rated current I_e .

The controls shall be energized by a separate electrical supply at the specified control voltage. The SCPD used shall be as stated in 8.2.5.1.

If the SCPD has an adjustable short-circuit current setting, the test shall be carried out with the short-circuit current setting adjusted to the maximum setting for type 1 co-ordination and to the maximum declared setting for type 2 co-ordination.

During the test, all openings of the enclosure shall be closed as in normal service and the door or cover secured by the means provided.

A semiconductor controller or semiconductor contactor covering a range of load ratings and equipped with interchangeable overcurrent protective means shall be tested with the overcurrent protective means with the highest impedance and the overcurrent protective means with the lowest impedance together with the corresponding SCPDs.

The O or CO operation shall be performed with one sample at I_q .

9.3.4.3.2 Test at the rated conditional short-circuit current at I_q

The circuit shall be adjusted to the prospective short-circuit current I_q equal to the rated conditional short-circuit current.

If the SCPD is a fuse and the test current is within the current-limiting range of the fuse then, if possible, the fuse shall be selected to allow the maximum value of cut-off current I_c (according to Figure 4 of IEC 60269-1:2006) and the maximum let-through I^2t values.

Except for direct on-line semiconductor contactors, one breaking operation of the SCPD shall be performed with the semiconductor contactor in the FULL-ON state and the SCPD closed; the short-circuit current shall be switched on by a separate switching device.

For direct on-line semiconductor contactors, one breaking operation of the SCPD shall be performed by closing the semiconductor contactor on to the short circuit.

9.3.4.3.3 Results to be obtained

The semiconductor controller or semiconductor contactor shall be considered to have passed the tests at the prospective current I_q if the following conditions are met for the claimed type of coordination.

For both types of coordination,

- a) the fault current has been successfully interrupted by the SCPD or the semiconductor contactor. In addition, the fusible element or solid connection between the enclosure and supply shall not have melted;
- b) the door or cover of the enclosure has not been blown open, and it is possible to open the door or cover. Deformation of enclosure is considered acceptable, provided the degree of protection by the enclosure is not less than IP2X;

- c) there is no damage to the conductors or terminals and the conductors have not been separated from the terminals;
- d) there is no cracking or breaking of an insulating base to the extent that the integrity of mounting of a live part is impaired;

Type 1 coordination:

- e) there has been no discharge of parts beyond the enclosure. Damage to the semiconductor controller and overcurrent protective means is acceptable. The semiconductor contactor or the semiconductor controller may be inoperative after the test;

Type 2 coordination:

- f) no damage to the overcurrent protective means or other parts has occurred and no replacement of parts is permitted during the test. No damage to any parts has occurred and no replacement of parts is permitted during the test with the exception of the fuse element of the SCPD if any. For semiconductor controllers and semiconductor contactors with series mechanical switching device, welding of contacts is permitted if they are easily separated (e.g. by energizing several times the coil of the mechanical switching device or moving the operating means or using a tool such as screwdriver for separating the welded contacts) without significant deformation (without impairing the insulation of the mechanical switching device). In the case of welded contacts as described above, the functionality of the device shall be verified under the conditions of Table 6 for the declared utilization category by carrying out 10 operating cycles (instead of five);
- g) the tripping of the overcurrent protective means shall be verified at a multiple of the current setting and shall conform to the published tripping characteristics both before and after the short-circuit test;
- h) the adequacy of the insulation shall be verified by a dielectric test on the semiconductor controller or semiconductor contactor. The test voltage shall be applied as specified in 9.3.3.4.1 4).

9.4 EMC tests

9.4.1 General

Subclause 9.4 of IEC 60947-1:2020 applies.

To ensure the EMC compliance of the equipment during its useful life based on this type test, the manufacturer shall consider how to maintain the expected characteristic variations of the equipment within appropriate margins.

EMC shall be verified on a representative sample of the production series. Where a range of semiconductor controller or semiconductor contactor comprise similar control electronics and sensors, within similar frame sizes, it is only necessary to test a single representative sample of the semiconductor controller or semiconductor contactor.

The test report and the instruction manual shall include any special measures that have been taken to achieve compliance, for example the use of shielded or special cables. If auxiliary equipment is used with the semiconductor controller or semiconductor contactor in order to comply with immunity or emission requirements, it shall be included in the report and the instruction manual.

An incandescent light load and a capacitive load are required for the purpose of testing in the case of AC-5b and AC-6b, respectively. However, for a device intended to be used for several utilization categories, the tests shall be made only with a load corresponding to AC-1. If the device is not intended for AC-1 category use, the tests shall be made for the utilization category defined by agreement between manufacturer and user. Except for the harmonic emission test, it is not necessary to load the lighting circuit or capacitor. If the load used in any test is of lower power than the intended power range of the semiconductor controller, it shall be stated in the test report. For category AC-1, the equipment under test shall be tested

at the rated operational current and with a $\cos \varphi = 1^{-0,05}$. For devices of current $I_e \leq 16$ A, the test current shall be I_e . For devices of current $I_e > 16$ A, the test current shall be the object of an agreement between the manufacturer and the user, provided this current is more than 16 A. This value shall be stated in the test report. Tests are not required on the power output port. Unless otherwise specified by the manufacturer, the length of the connections to the test load shall be 3 m.

NOTE The scanning time for frequency analysis is often much longer than the transition time. According to the current IEC 61000-4 series, relevant result of measurement can only be obtained in steady-state conditions.

The tests shall be carried out in a reproducible manner.

Semiconductor controllers, in which the power switching elements, for example thyristors, are not fully conducting during some or all steady-state modes of operation, shall be tested under conditions of minimum conduction to represent the operation of the semiconductor controller at the points of sustained maximum emission or susceptibility (see 9.4.2).

9.4.2 EMC immunity tests

9.4.2.1 Electrostatic discharge

Subclause 9.4.2.2 of IEC 60947-1:2020 applies with the following addition.

The performance criterion 2 of Table 9 of this document applies.

Tests are not required on power terminals. Discharges shall be applied only to points which are accessible during normal usage.

Tests are not possible if the semiconductor controller is an open frame or chassis unit or of degree of protection IP00. In this case, the manufacturer shall attach a label to the unit advising of the possibility of damage due to static discharge.

9.4.2.2 Radio-frequency electromagnetic field

For conducted immunity tests, 9.4.2.4 of IEC 60947-1:2020 applies with the following addition.

The performance criterion 1 of Table 9 of this document applies.

For radio-frequency electromagnetic field strength, 9.4.2.3 of IEC 60947-1:2020 applies with the following addition.

The performance criterion 1 of Table 9 of this document applies.

9.4.2.3 Fast transients (5/50 ns)

Subclause 9.4.2.5 of IEC 60947-1:2020 applies with the following additions.

Terminals for control and auxiliary circuits intended for the connection of conductors which extend more than 3 m shall be tested.

The semiconductor controller shall comply with performance criterion 2 of Table 9 of this document.

9.4.2.4 Surges (1,2/50 μ s – 8/20 μ s)

Subclause 9.4.2.6 of IEC 60947-1:2020 applies.

The preferred phase angle is 90° or 270°. Other phase angles according to IEC 61000-4-5 shall be also tested if they correspond to the worst case.

NOTE By principle, 90° and 270° are the worst testing cases for the power semiconductor valve devices.

The semiconductor controller shall comply with performance criterion 2 of Table 9 of this document.

9.4.2.5 Harmonics and commutation notches

No requirements, the test levels are under study for the future.

9.4.2.6 Voltage dips and short time interruptions

Subclause 9.4.2.8 of IEC 60947-1:2020 applies with the performance criterion 3 of Table 9 of this document, except for 0,5 cycle and 1 cycle for which the performance criterion 2 of Table 9 of this document applies.

9.4.3 EMC emission tests

9.4.3.1 Conducted radio-frequency emission test

The description of the test, the test method and the test set-up are given in Clause 7 of CISPR 11:2015 and CISPR 11:2015/AMD1:2016.

All emission tests shall be performed under steady-state conditions.

If an EMC filter is required to fulfil the emission levels given in Table 12, it has to be specified.

NOTE 1 Emission measurements during the starting time with the existing measuring equipment is not possible, because the scanning time for frequency analysis is often much longer than the starting time. According to the current IEC 61000-4 series of standards, relevant result of measurement can only be obtained in steady-state conditions.

**Table 12 – Terminal disturbance voltage limits
for conducted radio-frequency emission (AC mains power port)**

Environment ^e	A		A		A		B	
Frequency range MHz	Rated power ≤ 20 kVA ^c		Rated power > 20 kVA ^{a, c}		Rated power > 75 kVA ^{b, c}		All rated power	
	Quasi-peak dB(μV)	Average dB(μV)	Quasi-peak dB(μV)	Average dB(μV)	Quasi-peak dB(μV)	Average dB(μV)	Quasi-peak dB(μV)	Average dB(μV)
0,15 to 0,50	79	66	100	90	130	120	66 to 56 ^d	56 to 46 ^d
0,50 to 5	73	60	86	76	125	115	56	46
5 to 30	73	60	90 to 73 ^d	80 to 60 ^d	115	105	60	50

NOTE 1 At the transition frequency, the more stringent limit applies.

NOTE 2 For semiconductor controller and semiconductor contactor for class A environment intended to be connected solely to isolated neutral or high impedance earthed (IT) industrial power distribution networks (see IEC 60364-1) the limits defined for group 2 equipment with a rated power > 75 kVA in Table 8 of CISPR 11:2015 can be applied.

^a These limits apply to semiconductor controller and semiconductor contactor with a rated power > 20 kVA and intended to be connected to a dedicated power transformer or generator, and which is not connected to low voltage (LV) overhead power lines. For semiconductor controller and semiconductor contactor not intended to be connected to a user specific power transformer the limits for ≤ 20 kVA apply. The manufacturer, and/or supplier shall provide information on installation measures that can be used to reduce emissions from the installed semiconductor controller and semiconductor contactor. In particular it shall be indicated that this semiconductor controller or semiconductor contactor is intended to be connected to a dedicated power transformer or generator and not to LV overhead power lines.

^b These limits apply only to high power electronic semiconductor controller and semiconductor contactor with a rated power greater than 75 kVA when intended to be installed as follows:

- installation is supplied from a dedicated power transformer or generator, and which is not connected to Low Voltage (LV) overhead power lines,
- installation is physically separated from residential environments by distance greater than 30 m or by a structure which acts as a barrier to radiated phenomena,
- the manufacturer and/or supplier shall indicate that this semiconductor controller or semiconductor contactor meets the disturbance voltage limits for high power electronic controller and semiconductor contactor of rated input power > 75 kVA and provide information on installation measures to be applied by the installer. In particular, it shall be indicated that this semiconductor controller or semiconductor contactor is intended to be used in an installation which is powered by a dedicated power transformer or generator and not by LV overhead power lines.

^c Selection of the appropriate set of limits shall be based on the rated AC power stated by the manufacturer.

^d Decreasing linearly with logarithm of frequency.

^e Environment A and B are defined by IEC 60947-1.

NOTE 2 A rated input or output power of 20 kVA corresponds for example to a current of approximately 29 A per phase in case of 400 V three-phase power supply networks, and to a current of approximately 58 A per phase in case of 200 V three phase power supply networks.

9.4.3.2 Radiated radio-frequency emission test

The description of the test, the test method and the test set-up are given in CISPR 11.

NOTE In the USA, digital devices with power consumption less than 6 nW are exempt from RF emission tests.

It shall be sufficient to test a single representative sample from a range of semiconductor controllers and semiconductor contactors of different power ratings.

The emission shall not exceed the levels given in Table 13.

Table 13 – Radiated emissions test limits

Frequency range MHz	Environment A ^a Quasi-peak dB (µV)			Environment B ^a Quasi-peak dB (µV)	
	at 30 m	at 10 m	at 3 m	at 10 m	at 3 m
30 to 230	30	40	50	30	40
230 to 1 000	37	47	57	37	47

At the transition frequency, the more stringent limit shall apply.

^a Tests may be carried out at 3 m distance only to small equipment (equipment, either positioned on a table top or standing on the floor which, including its cables fits in a cylindrical test volume of 1,2 m in diameter and 1,5 m above the ground plane).

9.4.3.3 Low frequency emission test

Where applicable, the tests of the referred standards in 8.3.3.1.1 and 8.3.3.1.2 apply.

Where a range of semiconductor controllers comprise similarly configured control electronics, within similar frame sizes, it is only necessary to test a single representative sample of the semiconductor controller or semiconductor contactor.

9.5 Routine and sampling tests

9.5.1 General

Routine tests are tests to which each individual semiconductor controller or semiconductor contactor is subjected during or after manufacture to verify that it complies with the stated requirements.

Routine or sampling tests shall be carried out under the same or equivalent conditions to those specified for type tests in the relevant parts of 9.1.2. However, the limits of operation in 9.5.2 may be verified at the prevailing ambient air temperature and on the overcurrent protective means alone but a correction may be necessary to allow for the normal ambient conditions.

If devices are tested separately, their combination shall be tested with the dielectric test and other relevant operational tests. However, if the combination is built up with already tested connection systems or auxiliaries, an additional dielectric test is not necessary.

9.5.2 Operation and operating limits

It shall be verified that the equipment operates according to the requirements of 8.2.1.2.

The 2 following tests shall be made.

- a) Functionality shall be verified by a blocking and commutating capability test according to Table 11 and 9.3.3.6.4.

Two operating cycles are required, one at 85 % U_e with 85 % U_s , and one at 110 % U_e with 110 % U_s . No loss of functionality as specified by the manufacturer is permitted.

- b) It shall be verified that the equipment operates according to the requirements of 8.2.1.2.

9.5.3 Dielectric tests

Subclause 9.3.3.4.2 of IEC 60947-1:2020 applies with the following addition.

Verification of dielectric withstand may be performed before final assembly of the device (that is, before connecting sensitive devices such as filter capacitors).

The impulse and power frequency withstand voltage test may be replaced by a single power-frequency withstand test where the peak value of the sinusoidal wave corresponds to the value of the impulse- or power frequency withstand voltage, whichever is the higher.

At the discretion of the manufacturer, the device incorporating voltage limiting components are to be tested with the following sequence a) to b):

a) Application of the test voltage

The test shall be performed in accordance with 9.3.3.4.2 2) of IEC 60947-1:2020. The value of the test voltage shall be the U_V RMS value (max. operational voltage of the voltage limiting components) or the maximum U_V DC value of the voltage limiting components with a tolerance of –10 %.

Acceptance criteria: the over-current relay of the test apparatus shall not trip (lower tripping limit).

b) Verification of the proper function of the voltage limiting components

The test shall be performed in accordance with 9.3.3.4.2 2) of IEC 60947-1:2020. The value of the test voltage shall be chosen so that a current is generated between the upper tripping limit and the lower tripping limit of the test apparatus.

Acceptance criteria: the current shall be between a) and b) and the voltage limiting component shall not be damaged.

NOTE The main purpose of this test is to check the proper operation of the voltage limiting component.

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Annex A

(normative)

Marking and identification of terminals

A.1 General

L.1 of IEC 60947-1:2020 applies with the following additions.

A.2 Marking and identification of terminals of semiconductor controllers and semiconductor contactors

A.2.1 Marking and identification of terminals of main circuits

The terminals of the main circuits shall be marked by single figure numbers and an alphanumeric system.

Table A.1 – Main circuit terminal markings

Terminals	Markings
Main circuit	1/L1-2/T1 3/L2-4/T2 5-L3-6/T3 7/L4-8/T4

For particular types of semiconductor controllers and semiconductor contactors (see 5.2.5.3) the manufacturer shall provide the wiring diagram.

A.2.2 Marking and identification of terminals of control circuits

A.2.2.1 Control-circuit power supply terminals

L.2.1 of IEC 60947-1:2020 applies.

A.2.2.2 Auxiliary circuits and input/output signal terminals

L.3.2 of IEC 60947-1:2020 applies.

Annex B (informative)

Typical service conditions for semiconductor controllers and semiconductor contactors

B.1 Control of resistive heating elements

Three typical methods of control a), b) and c) are described:

- a) simple semiconductor contactor function of switching on and off. Single-pole semiconductor contactors with zero-point switching may be used to minimize the switching-on transient (AC-1);
- b) in the case of wire-wound resistor elements, the switch-on current may be as high as 1,4 times the rated current. Ramp-up switch-on of such heating elements by means of a gradual increase in the terminal voltage can minimize mechanical and electrical stressing;
- c) load control of resistance-heating elements by adjusting the load terminal voltage (voltage control) and the ratio of ON to OFF time (full voltage switching), or a combination of these. The load control may be achieved by means of a feed-back signal from the load to a comparator circuit or device which determines the operating cycle and/or output voltage of the semiconductor controller. This comparator or control device may be incorporated in the semiconductor controller or be used merely to generate the switching signal (for example in the case of a semiconductor contactor).

B.2 Switching of electric discharge lamp controls

The relevant utilization category should be selected with the following items a) to d) into account;

- a) During the normal switch-on phase, fluorescent lamps without power factor correction or those in a twin lamp lead-lag connection, draw pre-heating currents which may attain values of about twice the rated current for a short period of time (AC-5a).
In the case of parallel compensated fluorescent lamps, transient inrush currents of 20 times the capacitor rated current can occur (AC-6b).
In the case of fluorescent lamps with electronic ballast units, inrush currents of 10 times the lamp rated current can occur for short periods of time.
- b) High-pressure mercury-vapour and metal halide lamps (with or without power-factor correction) are switched on via ballast units in the form of series inductors and, in the case of the metal halide lamps, with the aid of ignition devices. During the initial 3 min to 5 min after switch-on, and before the lamps achieve their normal operating condition at rated current, a predominantly inductive current is drawn. This current may be as high as twice the rated current of the lamp. The over-current profile of the semiconductor contactor shall permit this value of current (AC-5a).
- c) High-pressure sodium vapour lamps (without power-factor correction) draw an inductive current of approximately 1,7 to 2,2 times their rated current for 5 min to 10 min before achieving their operational condition. The over-current profile of the semiconductor contactor shall permit this value of current (AC-5a).
- d) High-pressure mercury vapour, metal halide and sodium vapour lamps with power-factor correction, draw high transient capacitive inrush currents. These should be taken into account when selecting semiconductor contactors for such loads (AC-6b).

B.3 Switching of incandescent lamps

Semiconductor contactors can be used to switch incandescent lighting circuits often associated with high switch-on transient currents (AC-5b).

Short circuits between filament turns in incandescent lamps can cause extreme overcurrents to flow through the series connected switching device. This phenomena is classified as a short-circuit condition. The coordination between the semiconductor contactor and the short-circuit protection device (possibly incorporated in the lamp) is covered by 8.2.5.

B.4 Switching of transformers

Semiconductor contactors with defined point switching and special ramp-up switching function may be used to optimize the switching of transformer loads (surge limitation), since the high transient inrush currents associated with the switching-on of transformers is strongly dependent on the phase angle of the applied voltage at the instant current begins to flow.

B.5 Switching of capacitor banks

The amplitude and frequency of transient switch-on currents are not only determined by the capacitance of the load but also by the reactances in the associated circuit and supply lines as well as the point on the wave form of the applied AC voltage at which current begins to flow. In the case of capacitor banks (for example of a power-factor correction system), capacitors already in circuit present an additional energy source and can discharge into the switched capacitive load via low inductance linking conductors and the item of switchgear (for example semiconductor contactor). These high-inrush currents shall be taken into account when selecting the switching device (AC-6b).

Moreover, care should be taken regarding the overvoltage (difference between the capacitor voltage and the supply voltage).

Annex C

Vacant

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Annex D

Vacant

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Annex E

Vacant

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Annex F (informative)

Operating capability

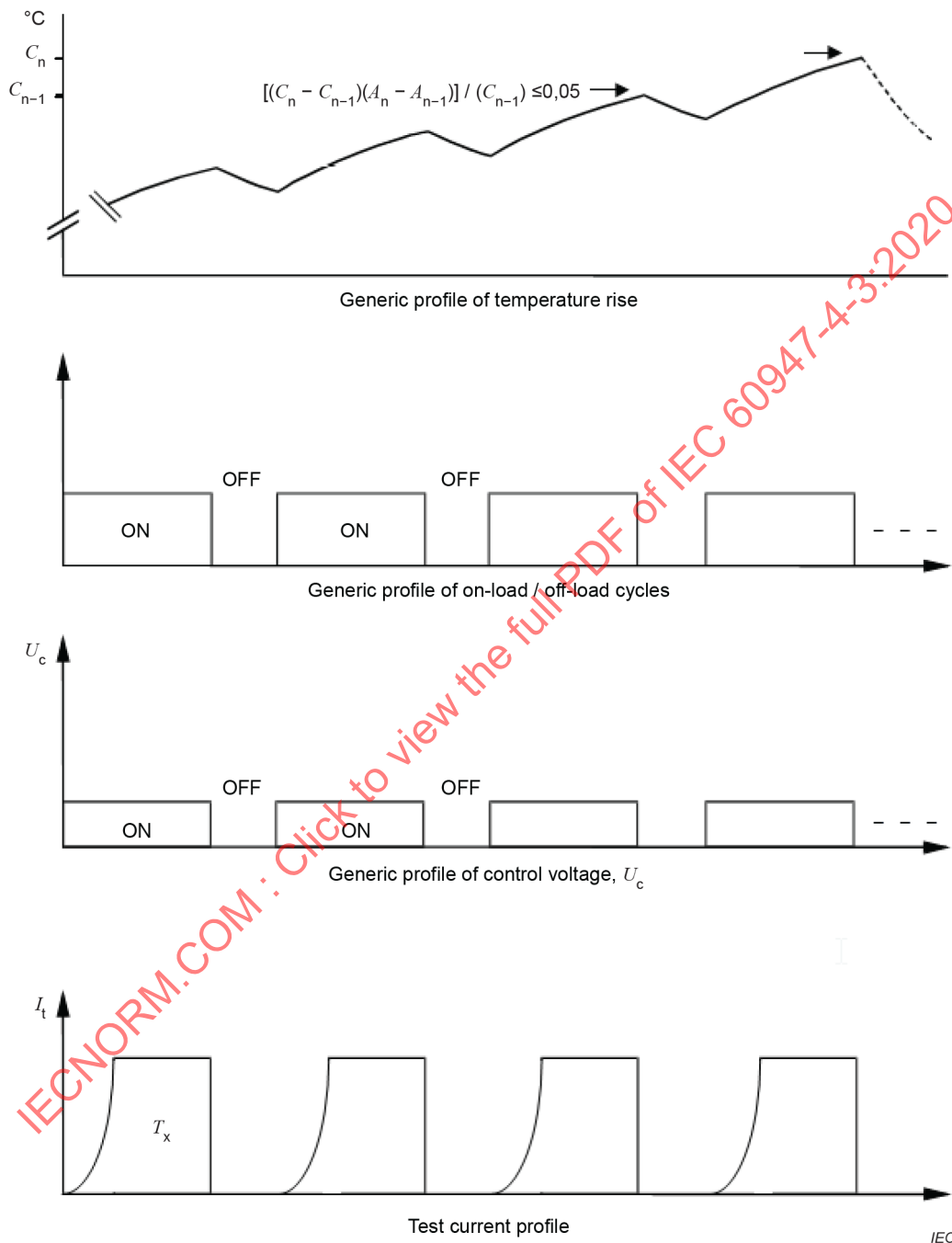


Figure F.1 – Thermal stability test profile