# IEC 60947-4-2

Edition 4.1 2024-11
CONSOLIDATED VERSION

# INTERNATIONAL STANDARD

colour inside

## Low-voltage switchgear and controlgear – Part 4-2: Contactors and motor-starters – Semiconductor motor controllers, starters and soft-starters



IEC 60947-4-2:2020-06+AMD1:2024-11 CSV(en)

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# LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 4-2: Contactors and motor-starters – Semiconductor motor controllers, starters and soft-starters

## AMENDMENT 1

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**This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.**

**IEC 60947-4-2 edition 4.1 contains the fourth edition (2020-06) [documents 121A/353/FDIS and 121A/360/RVD] and its amendment 1 (2024-11) [documents 121A/615/FDIS and 121A/626/RVD].**

**In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough**

**red text. A separate Final version with all changes accepted is available in this publication.**

International Standard IEC 60947-4-2 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 fourth edition cancels and replaces the third edition published in 2011. This edition constitutes a technical revision.

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

- scope exclusions;
- editorial correction of notes and hanging paragraphs;
- reference to IEC 62683-1;
- safety aspects related to:
  - general aspects;
  - limited energy circuits;
  - electronic circuits;
- mention of dedicated wiring accessories;
- power consumption measurement;
- alignment to IEC 60947-1:2020.

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.

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

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

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

- reconfirmed,
- withdrawn, or
- revised.

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# INTRODUCTION

This document covers low-voltage semiconductor motor controllers, starters and soft-starters that have many capabilities and features beyond the simple starting and stopping of an induction motor, such as controlled starting and stopping, manoeuvring and controlled running.

The generic term “controller” is used in this document wherever reference is made to elements of power semiconductor switching devices.

The generic term “starter” is used in this document wherever reference is made to the elements of power semiconductor switching devices together with suitable overload protective devices.

# LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 4-2: Contactors and motor-starters – Semiconductor motor controllers, starters and soft-starters



## 1 Scope

This part of IEC 60947 applies to semiconductor motor controllers, starters and soft-starters which can include a series mechanical switching device, intended to be connected to circuits the rated voltage of which does not exceed 1 000 V AC.

This document characterizes semiconductor motor controllers and starters with and without bypass means.

This document does not apply to:

– semiconductor motor controllers and starters used for continuous operation of AC motors at motor speeds other than the normal speed[1];

– electromechanical contactors and external overload relays (see IEC 60947-4-1);

– short-circuit protective device associated with semiconductor motor controllers and starters (see IEC 60947-4-1 (MPSD), IEC 60947-2 and IEC 60947-3);

– semiconductor equipment, including semiconductor contactors (3.4.13 of IEC 60947-1:2020) controlling non-motor loads (see IEC 60947-4-3);

– semiconductor motor controllers and starters used for rotor circuits[1];

– adjustable speed electrical power drive systems (see IEC 61800 series);

– use of the product within explosive atmospheres (see IEC 60079 series);

– software and firmware requirements[1];

NOTE 1 Guidance on embedded software is given in IEC TR 63201.

– cyber security aspects (see IEC TS 63208).

Contactors, overload relays and control circuit devices used in semiconductor motor controllers and starters 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 motor controllers, starters and soft-starters and associated equipment;

– the conditions with which semiconductor motor controllers, starters and soft-starters 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;

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[1] For this subject, the manufacturer is responsible for taking additional safety measures.

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.

NOTE 2 For the purpose of this document, the term "controller" is used instead of "semiconductor motor controller".

## 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 60034-1:2017, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60445:2021, *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 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 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*

IEC 63404:2024, *Switchgear and controlgear and their assemblies for low voltage – Integration of radiocommunication device above 380 MHz into an equipment*

IEC TS 63058, *Environmental aspects for low-voltage switchgear and controlgear and their assemblies*

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*

# 3 Terms, definitions, symbols and abbreviated terms

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60947-1:2020, as well as the following terms, definitions, symbol and abbreviations apply.

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

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

### 3.1.1 Terms and definitions concerning the types of semiconductor motor controllers and starters

**3.1.1.1**
**semiconductor switching device**
switching device designed to make and/or break the current in an electric circuit by means of the controlled conductivity of a semiconductor

Note 1 to entry: This definition differs from IEC 60050-441:1984, 441-14-03 since a semiconductor switching device is also designed for breaking the current.

[SOURCE: IEC 60947-1:2020, 3.4.3, modified – Note 1 to entry added.]

**3.1.1.2**
**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 (3.1.2.12) exist in a semiconductor controller, the load terminals should be 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.

Note 4 to entry: This device can include internal electromechanical switching device(s) bypassing or in series with the semiconductor at the manufacturer's discretion.

**3.1.1.3**
**semiconductor motor controller**
semiconductor controller that provides the starting function for an AC motor and an OFF-state

Note 1 to entry: This device can include any starting method specified by the manufacturer, control functions which can have any combination of manoeuvring, controlled acceleration, running or controlled deceleration of an AC motor. A FULL-ON state can also be provided.

Note 2 to entry: See Figure 1.

**3.1.1.4**
**direct-on-line semiconductor motor controller**
**DOL semiconductor motor controller**
semiconductor motor controller, in which the starting function is limited to a full-voltage, unramped starting method only, and where the additional control function is limited to providing FULL-ON

Note 1 to entry: This device can include a very short controlled ramp time of a few cycles which contribute to limit the inrush current of the motor to the level of Table 9.

Note 2 to entry: See Figure 1.

### 3.1.1.5
**semiconductor motor-starter**
**soft-starter**
semiconductor motor controller with suitable overload protection, rated as a unit

Note 1 to entry: The term “soft-starter” is often used on the market to designate a semiconductor motor controller with or without overload protection but, in this document, it is a type of starter which by definition includes an overload protection.

### 3.1.1.6
**direct-on-line semiconductor motor-starter**
**DOL semiconductor motor-starter**
direct-on-line semiconductor motor controller with suitable overload protection, rated as a unit

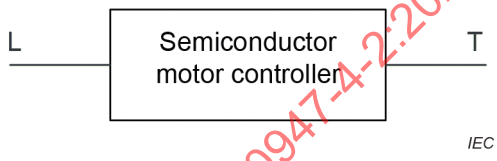
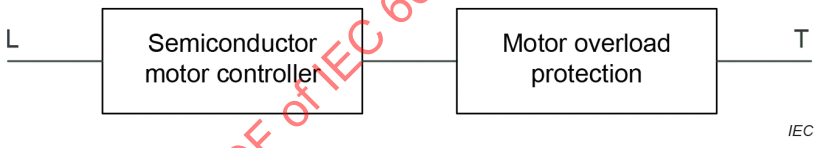
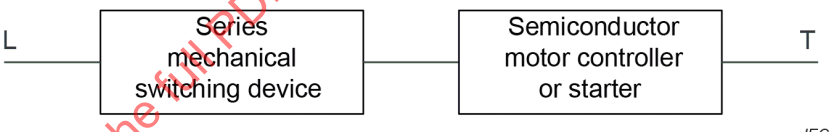
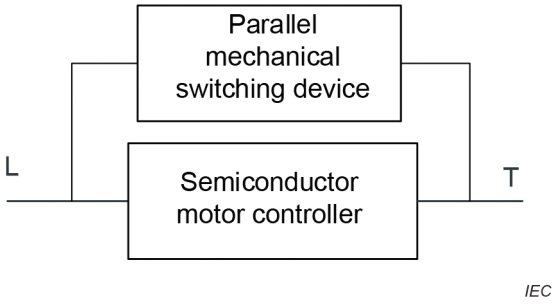
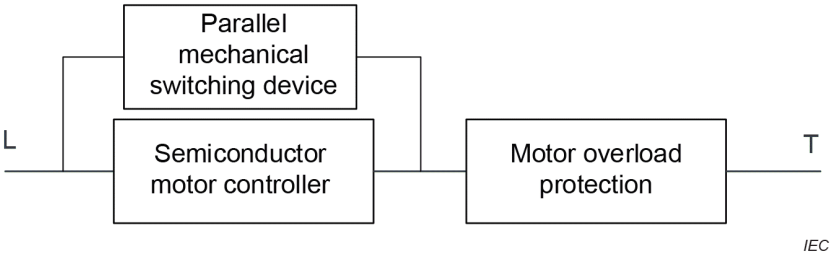
| Device | Functional unit diagram |
|---|---|
| Semiconductor motor controller |   |
| Semiconductor motor-starter |   |
| Semiconductor motor controller or starter in series with a mechanical switching device |   |
| Bypassed semiconductor motor controller |   |
| Bypassed semiconductor motor-starter |   |

**Figure 1 – Semiconductor motor control devices**

### 3.1.2 Terms and definitions concerning semiconductor motor controllers and starters

**3.1.2.1**
**current-limit function**
ability of the controller to limit the motor current to a specified value

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

**3.1.2.2**
**manoeuvre**
any deliberate operation that causes current changes which shall be characterized and controlled (for example jogging, braking)

Note 1 to entry: Starting is a mandatory manoeuvre that is recognized separately.

Note 2 to entry: Braking operations performed by the semiconductor motor controller or starter are considered to be a manoeuvre within the scope of this document.

**3.1.2.3**
**controlled acceleration**
control of motor performance while increasing motor speed by acting on the motor supply

**3.1.2.4**
**controlled deceleration**
control of motor performance while decreasing motor speed by acting on the motor supply

**3.1.2.5**
**controlled running**
control of motor performance by acting on the motor supply while the motor is running at normal speed (for example, energy saving)

**3.1.2.6**
**prospective current**
<circuit with respect to a switching device or a fuse> current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is to be specified in the relevant product standard.

[SOURCE: IEC 60947-1:2020, 3.7.5]

**3.1.2.7**
**prospective locked rotor current**
**$I_{LRP}$**
prospective current that would flow when the rated voltage is applied to the motor with a locked rotor

Note 1 to entry: The test current of $I_{LRP}$ for overload capability is given by Table 9.

**3.1.2.8**
**ON-state**
the condition of a controller when the conduction current can flow through its main circuit

**3.1.2.9**
**FULL-ON**
<state of controllers> condition of a controller when the controlling functions are set to provide normal full voltage excitation to the load

**3.1.2.10**
**minimum load current**
minimum operational current in the main circuit which is necessary for correct action of a controller in the ON-state

Note 1 to entry: The minimum load current is given as the RMS value.

**3.1.2.11**
**OFF-state**
the condition of a controller when no control signal is applied, and no current exceeding the OFF-state current flows through the main circuit

**3.1.2.12**
**OFF-state current**
the current which flows through the main circuit of a controller in the OFF-state

**3.1.2.13**
**operation**
<controller> transition from the ON-state to the OFF-state, or the reverse

**3.1.2.14**
**operating cycle**
<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.

**3.1.2.15**
**operating capability**
under prescribed conditions, the ability to perform a series of operating cycles without failure

**3.1.2.16**
**overload current profile**
current-time co-ordinate specifying the requirement to accommodate overload currents for a period of time

Note 1 to entry: See 5.3.5.2.

**3.1.2.17**
**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

Note 1 to entry: See 6.1 e).

**3.1.2.18**
**tripping operation**
<of a motor controller or starter> operation to establish and maintain an OFF-state (or open position in the case of series mechanical switching device) initiated by a control signal

**3.1.2.19**
**phase loss sensitive overload relay or release**
multipole overload relay or release which operates in case of overload and also in case of loss of phase in accordance with specified requirements

**3.1.2.20**
**under-current relay or release**
measuring relay or release which operates automatically when the current through it is reduced below a predetermined value

**3.1.2.21**
**under-voltage relay or release**
measuring relay or release which operates automatically when the voltage applied to it is reduced below a predetermined value

**3.1.2.22**
**stall sensitive electronic overload relay**
electronic overload relay which operates when the current has not decreased below a predetermined value for a specific period of time during start-up or when the relay receives the input indicating there is no rotation of the motor after a predetermined time in accordance with specified requirements

Note 1 to entry: Explanation of stall: rotor locked during start.

**3.1.2.23**
**jam sensitive electronic overload relay**
electronic overload relay which operates in the case of overload and also when the current has increased above a predetermined value for a specific period of time during run in accordance with specified requirements

Note 1 to entry: Explanation of jam: high overload occurring after the completion of starting which causes the current to reach the locked rotor current value of the motor being controlled.

**3.1.2.24**
**inhibit time**
time-delay period during which the tripping function of the relay is inhibited (may be adjustable)

**3.1.2.25**
**ON-time**
period of time during which the controller is on-load

Note 1 to entry: See the example in Figure F.1.

**3.1.2.26**
**OFF-time**
period of time during which the controller is off-load

Note 1 to entry: See the example in Figure F.1.

**3.1.2.27**
**bypassed semiconductor motor controller**
**bypassed semiconductor motor-starter**
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, tested and rated as a unit

Note 1 to entry: See rows 4 and 5 of Figure 1.

**3.1.2.28**
**CO operation**
breaking of the circuit by the SCPD resulting from closing the circuit by the equipment under test

**3.1.2.29**
**O operation**
breaking of the circuit by the SCPD resulting from closing the circuit on the equipment under test which is in the closed position

**3.1.2.30**
**semiconductor motor controller power losses**
power consumed by the semiconductor motor controller or starter at FULL-ON at the maximum power rating

**3.1.2.31**
**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 a opto-coupler.

[SOURCE: IEC 60050-151:2001-07, 151-12-26]

### 3.1.3 Terms and definitions concerning safety aspects

**3.1.3.1**
**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.

**3.1.3.2**
**accessible part**
part which can be touched by means of the standard test finger

[SOURCE: IEC 60050-442:1998-11, 442-01-15, modified – removal of “a” at the beginning]

**3.1.3.3**
**hazardous-live-part**
live part which, under certain conditions, can give a harmful electric shock

[SOURCE: IEC 60050-195:1998-08, 195-06-05]

**3.1.3.4**
**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

**3.1.3.5**
**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]

**3.1.3.6**
**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 – Deletion of Notes to entry]

**3.1.3.7**
**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.

Note 2 to entry: Reinforced protection is defined in IEC 60050-903:2013, 903-02-08.

[SOURCE: IEC Guide 104:2019-07, 3.8]

### 3.1.4 Alphabetical index of terms

O



P



R



S



T



U

### 3.2 Symbols and abbreviated terms

| Symbol and abbreviated term | Description | Definition or occurrence |
|---|---|---|
| $A_f$ | Final ambient temperature | 9.3.3.3.4 |
| $C_f$ | Final case temperature | 9.3.3.3.4 |
| $I_c$ | Current made and broken | Table 11 |
| $I_e$ | Rated operational current | 5.3.2.3 |
| $I_F$ | OFF-state current after the blocking and commutating capability test | 9.3.3.6.4 |
| $I_{init}$ | Initial test current | 9.3.3.6.3 |
| $I_{LRP}$ | Prospective locked rotor current | 3.1.2.7 |
| $I_O$ | OFF-state current before the blocking and commutating capability test | 9.3.3.6.4 |
| $I_{Lm}$ | Maximum OFF-state current | 5.3.2.5 |
| $I_q$ | Maximum conditional short-circuit test current | 9.3.4.3.2 |
| $I_{lim}$ | Current setting of the current-limit function | 8.2.4.1 |
| $I_{th}$ | Conventional free air thermal current | 5.3.2 |
| $I_{the}$ | Conventional enclosed thermal current | 5.3.2.2 |
| $I_u$ | Rated uninterrupted current | 5.3.2.4 |
| SCPD | Short-circuit protective device | 5.8 |
| $U_c$ | Rated control circuit voltage | 6.1 |
| $U_e$ | 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 10 |
| $U_s$ | Rated control circuit supply voltage | 6.1 |

## 4 Classification

Subclause 5.2 gives all data which could be used as criteria for classification.

## 5 Characteristics of semiconductor motor controllers and starters

### 5.1 Summary of characteristics

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

– type of equipment (5.2);
– rated and limiting values for main circuits (5.3);
– utilization category (5.4);
– control circuits (5.5);
– auxiliary circuits (5.6);
– characteristics of relays and releases (5.7);
– coordination with short-circuit protective devices (5.8).

For information exchange in electronic format, e.g. electronic catalogue, IEC 62683-DB gives the data format of the essential characteristics of motor-starters, contactors and their accessories.

## 5.2 Type of equipment

### 5.2.1 Kind of equipment

The type of semiconductor controllers and starters shall be stated in the following terms:

a) Type of semiconductor motor controller
   - semiconductor motor controller; or
   - semiconductor motor-starter: with suitable overload protection, rated as a unit.

b) Bypassed semiconductor motor controller or starter, if relevant

c) Type of control (not limited to)
   - FULL-ON;
   - controlled acceleration;
   - controlled deceleration;
   - 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

AC only.

### 5.2.4 Interrupting medium (air, vacuum, etc.)

Applicable only to mechanical switching devices used in controllers and starters.

### 5.2.5 Operating conditions of the equipment

#### 5.2.5.1 Method of operation

For example:

– symmetrically controlled controller (such as a semiconductor with fully controlled phases);

– non-symmetrically controlled controller (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):

– motor in delta, thyristors in series with a winding;

– motor in star, thyristors in delta;

– motor in delta, thyristors connected between winding and supply.

## 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.

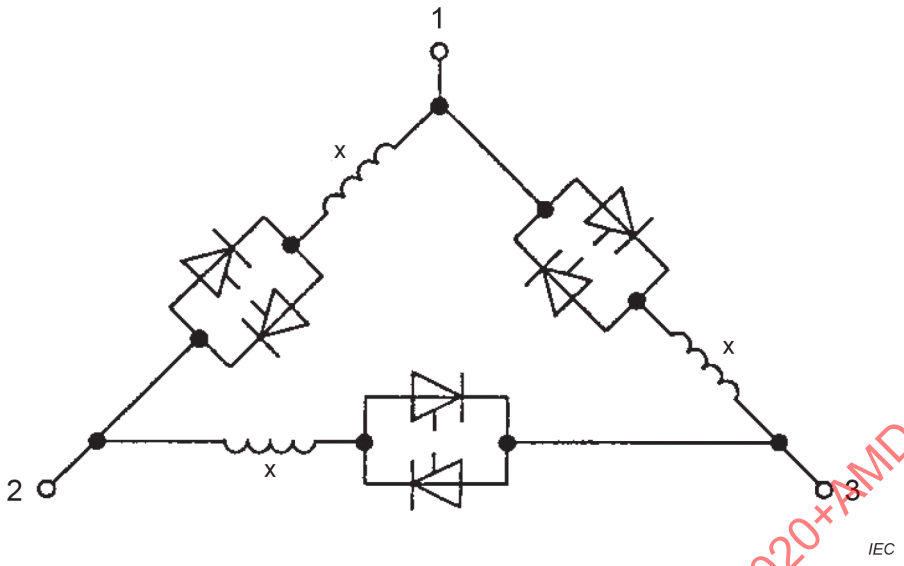



**Figure 2a – Motor in delta – Thyristors in series with a winding**

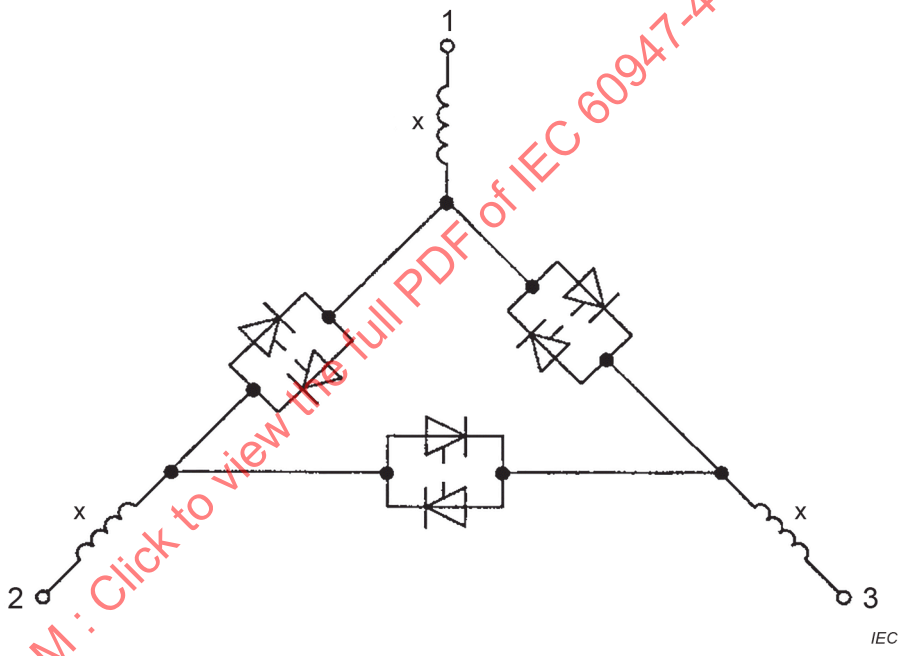



**Figure 2b – Motor in star – Thyristors in delta**

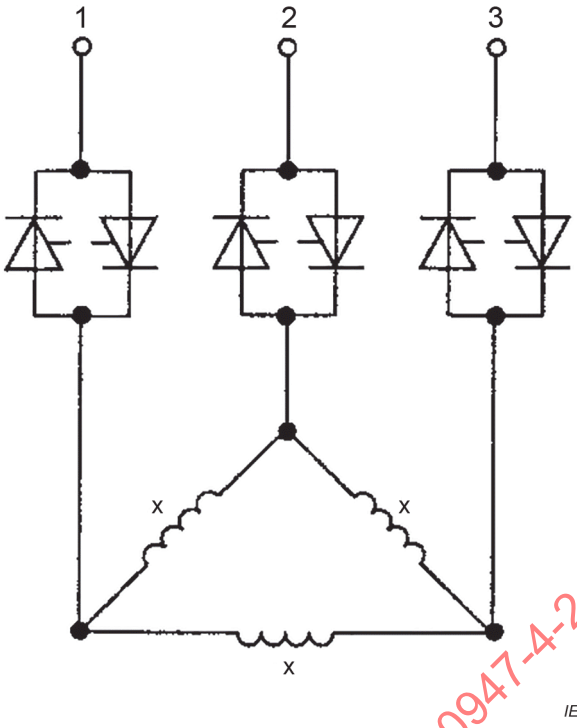



**Figure 2c – Motor in delta – Thyristors connected between winding and supply**

**Figure 2 – Connecting methods**

### 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 controllers and starters 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 duty cycle values and sequences (see 5.3.4), the utilization category (see 5.4), the normal load and overload characteristics (see 5.3.5), and the type of protective enclosure, if any.

The indication of a rated operational current may be replaced or supplemented by an indication of the maximum rated power output, at the rated operational voltage considered, of the motor for which the equipment is intended.

NOTE Annex G gives values concerning the relationship between rated operational currents and rated operational powers.

#### 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 ($I_{Lm}$)

The maximum OFF-state current ($I_{Lm}$) 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~~ 9.3.3.6.4.

### 5.3.3 Rated frequency

Subclause 5.3.3 of IEC 60947-1:2020 applies.

### 5.3.4 Duty cycle values and sequences

#### 5.3.4.1 Duty cycle values and symbols

For the purpose of this document, the duty cycle is expressed by two symbols, $F$ and $S$. These describe the duty, and also set 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 as follows:

$F$ = 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 as follows:

$S$ = 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.

#### 5.3.4.2 Duty cycle sequences

Two duty cycle sequences are defined in relation with the suffix of the designation of a utilisation category as follows:

a) Sequence A: complete duty cycles, where the semiconductor motor controller or starter is carrying the motor current during all the phases of “starting”, “running” and “stopping” of the motor load. It includes the capability to continuously carry the rated current until and after thermal equilibrium;

b) Sequence B: starting and stopping duty cycles, where the semiconductor motor controller or starter is carrying the motor current only during the phases of “starting” and/or “stopping” of the motor load.

### 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 co-ordinates 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 7, and represents the maximum value of operating current due to starting, operating, or manoeuvring under overload conditions. $X = I_T/I_e$ as tested according to Table 10 when no current limit function is provided.

Deliberate overcurrents not exceeding 10 cycles (for example boost, kickstart, etc.), 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 controlled overload currents during starting, operating, and manoeuvring. See Table 7.

For a starter, $T_x$ is the minimum operating time allowed by the tolerances of the overload relay.

#### 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

– the rated operational voltage (see 5.3.1.1);

– the rated operational current (see 5.3.2.3);

– the duty cycle values and sequences (see 5.3.4);

– the overload current profile (see 5.3.5.2);

– the utilization category (see 5.4);

– the availability of a current-limit function;

– the availability of a motor inrush current limiting function.

Requirements are given in 8.2.4.1.

#### 5.3.5.4 Starting, stopping and manoeuvring characteristics

##### 5.3.5.4.1 Starting characteristics of squirrel cage and hermetic refrigeration motors

a) One direction of rotation with the inclusion of phase-control capability to provide any combination of controlled acceleration to normal speed, controlled deceleration to standstill, or an occasional manoeuvre without de-energizing the controller (AC-3a, AC-8a).

b) One direction of rotation with the inclusion of phase-control capability to provide controlled acceleration to normal speed. Controllers and starters are rated for starting and stopping duty cycles only (AC-3b, AC-8b); for example, after starting, the motor may be connected into a circuit that bypasses the semiconductor motor controller or starter.

~~Two directions of rotation may be accomplished by reversing the connections to the controller or motor by means that are beyond the scope of this document, but are covered by the relevant product standard for the selected means.~~

~~Two directions of rotation may also be accomplished by phase reversing within the controller or starter. The requirements for this operation will vary with each application. Therefore, this is subject to agreement between manufacturer and user.~~

Two directions of rotation are not covered by this document.

Due to the control capability of controllers and starters, the current during starting, stopping, and any operation will differ from the conventional values of the prospective locked rotor current listed in Table 9.

#### 5.3.5.4.2 Starting characteristics of rheostatic rotor starters with controllers energizing the stator (AC-2a, AC-2b)

Starters can be used to provide reduced voltage excitation to the stator windings of a slip ring motor, and thereby reduce the number of switching steps required in the rotor circuit. For most applications, one or two starting steps are adequate depending upon load torque and inertia, and the severity of start required.

### 5.3.6 Rated conditional short-circuit current

Subclause 5.3.6.4 of IEC 60947-1:2020 applies.

### 5.3.7 Semiconductor motor controller power losses

#### 5.3.7.1 General

The power consumption of the semiconductor motor controller or starter may be stated by the manufacturer and is determined by calculating the power losses of the power semiconductor components.

A motor controller consists of two or three power semiconductor controlled phases and the semiconductor controlling device. These power semiconductors are bypassed or not bypassed after run up of the motor.

The power semiconductor losses during start-up (and soft stop or braking mode) occur for a very short period of time (seconds) and are therefore not considered.

#### 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

$$P_{\mathrm{vnb}} = n \cdot I_{\mathrm{e}} \cdot 1\mathrm{V}$$

with:

$n$ number of controlled phases,

$I_{\mathrm{e}}$ rated operational current,

$P_{\mathrm{vnb}}$ power losses non-bypassed operation,

1V one volt as typical voltage drop of a power semiconductor.

NOTE 1 The typical factor of 1 V can be changed appropriately by the manufacturer.

b) Formula for bypassed operation

$$P_{\mathrm{vb}} = n \cdot 0{,}1 \cdot I_{\mathrm{e}} \cdot 1\mathrm{V} = 0{,}1 \cdot P_{\mathrm{vnb}}$$

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

$P_{\mathrm{vb}}$ power losses in bypassed operation,

NOTE 2 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 controllers and starters, 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.~~

For semiconductor motor controllers, starters and soft-starters, the utilization categories are given in Table 1.

Each utilization category (see Table 1) is characterized by the values of the currents, voltages, power-factors and other data of Table 2, Table 7, Table 8, Table 9 and Table 10, and by the test conditions specified in this document.

The utilization categories AC-2a, AC-3a and AC-8a (with a-suffix) are defined for the complete duty cycles according to 5.3.4.2a).

The utilization categories AC-2b, AC-3b and AC-8b (with b-suffix) are defined for the starting and stopping duty cycles according to 5.3.4.2b).

### 5.4.2 Assignment of ratings based on the results of tests

A designated controller or starter 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 utilisation category | Harmonised utilization category [a] | Typical motor load | Duty cycle sequence [b] |
|---|---|---|---|
| AC-52a | AC-2a | Slip ring motor | A [c] |
| AC-52b | AC-2b | | B [d] |
| AC-53a | AC-3a | Squirrel-cage motors | A [c] |
| AC-53b | AC-3b | | B [d] |
| AC-58a | AC-8a | Hermetic refrigerant compressor | A [c] |
| AC-58b | AC-8b | | B [d] |

[a] The new utilisation 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.

[b] Includes the whole starter or controller.

[c] Sequence A as complete.

[d] Sequence B as starting and stopping.

**Table 2 – Relative levels of severity**

| Severity level | Utilization category | Overload current profile [a, c] | ON-time/OFF-time requirements [b] |
|---|---|---|---|
| Most severe | AC-2a<br>AC-3a<br>AC-8a | Highest value of<br>$(XI_e)^2 \cdot T_x$ | Highest value of<br>$F \cdot S$ |
| | AC-2b<br>AC-3b<br>AC-8b | Highest value of<br>$(XI_e)^2 \cdot T_x$ | Lowest value of<br>OFF-time |

[a] When the highest value of $(XI_e)^2 \cdot T_x$ occurs at more than one value of $XI_e$, then the highest value of $XI_e$ applies.

[b] When the highest value of $F \cdot S$ occurs at more than one value of $S$, then the highest value of $S$ applies.

[c] When the highest value of $(XI_e)^2 \cdot T_x$ occurs at more than one value of OFF-time, then the lowest value of OFF-time 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.

Electronic auxiliary circuits perform useful functions (for example monitoring, data acquisition, etc.) that are not necessarily functions involved with the intended performance characteristics.

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 controllers and motor-starters, and intended to be compatible with PLCs, shall fulfil the requirements of Annex S of IEC 60947-1:2020.

## 5.7 Characteristics of relays and releases (overload relays)

NOTE In the remainder of this document, the words "overload relay" will be taken to apply equally to an overload relay or an overload release, as appropriate.

### 5.7.1 Summary of characteristics

The characteristics of relays and releases shall be stated in the following terms, whenever applicable:

– types of relay or release (see 5.7.2);
– characteristic values (see 5.7.3);
– designation and current settings of overload relays (see 5.7.4);
– time-current characteristics of overload relays (see 5.7.5);
– influence of ambient air temperature (see 5.7.6).

### 5.7.2 Types of relay or release

a) Under-voltage and under-current opening relay or release.

b) Overload time-delay relay, the time-lag of which is

   1) substantially independent of previous load;

   2) dependent on previous load;

   3) dependent on previous load and also sensitive to phase loss.

c) Instantaneous over-current relay or release (for example jam sensitive).

d) Other relays or releases (for example control relay associated with devices for the thermal protection of the starter).

e) Stall sensitive electronic overload relay or release.

### 5.7.3 Characteristic values

a) Release with shunt coil, under-voltage (under-current), over-voltage (instantaneous over-current), current or voltage asymmetry and phase reversal opening relay or release:

   – rated voltage (current);

   – rated frequency;

   – operating voltage (current);

   – operating time (when applicable);

   – inhibit time (when applicable).

b) Overload relay:

   – designation and current settings (see 5.7.4);

   – rated frequency, when necessary (for example in the case of a current transformer operated overload relay);

   – time-current characteristics (or range of characteristics), when necessary;

   – operating time of ground/earth fault electronic overload relays according to Table T.1 of IEC 60947-1:2020 if applicable;

   – trip class according to classification in Table 4, or the value of the maximum tripping time, in seconds, under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D*, when this time exceeds 40 s;

   – nature of the relay: thermal, electronic or electronic without thermal memory; electronic relay without thermal memory shall be marked ~~Thm~~;

   – type designation for overload relays with extended functions (see Annex T of IEC 60947-1:2020) if applicable;

   – nature of the reset: manual or manual/automatic; in case of manual/automatic, the set position shall be indicated;

   – tripping time of overload relays class 10A where higher than 2 min at 0 °C or below (see 8.2.1.5.1.1.1, item c).

c) Release with residual current sensing relay:

   – rated current;

   – operating current;

   – operating time or time-current characteristic according to Table T.1 of IEC 60947-1:2020;

   – inhibit time (when applicable);

   – type designation (see Annex T of IEC 60947-1:2020).

**Table 3 – Trip classes of overload relays**

| Trip class | Tripping time $T_p$ under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D* [a]<br>s | Tripping time $T_p$ under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D* for tighter tolerances (tolerance band E) [a]<br>s |
|---|---|---|
| 2 | – | $T_p \leq 2$ |
| 3 | – | $2 < T_p \leq 3$ |
| 5 | $0{,}5 < T_p \leq 5$ | $3 < T_p \leq 5$ |
| 10A | $2 < T_p \leq 10$ | – |
| 10 | $4 < T_p \leq 10$ | $5 < T_p \leq 10$ |
| 20 | $6 < T_p \leq 20$ | $10 < T_p \leq 20$ |
| 30 | $9 < T_p \leq 30$ | $20 < T_p \leq 30$ |
| 40 | – | $30 < T_p \leq 40$ |
| NOTE 1 Depending on the nature of the relay, the tripping conditions are given in 8.2.1.5.<br>NOTE 2 The lower limiting values of $T_p$ are selected to allow for differing heater characteristics and manufacturing tolerances. | | |
| [a] The manufacturer shall add the letter E to trip classes to indicate compliance with the band E. | | |

### 5.7.4 Designation and current settings of overload relays

Overload relays are designated by their current setting (or the upper and lower limits of the current setting range, if adjustable) and their trip class.

The current setting (or current setting range) shall be marked on the relays.

However, if the current setting is influenced by the conditions of use or other factors which cannot readily be marked on the relay, then the relay or any interchangeable parts thereof (for example heaters, operating coils or current transformers) shall carry a number or an identifying mark which makes it possible to obtain the relevant information from the manufacturer or his catalogue or, preferably, from data furnished with the starter.

In the case of current transformer operated overload relays, the marking may refer either to the primary current of the current transformer through which they are supplied or to the current setting of the overload relays. In either case, the ratio of the current transformer shall be stated.

### 5.7.5 Time-current characteristics of overload relays

Typical time-current characteristics shall be given in the form of curves supplied by the manufacturer. These curves shall indicate how the tripping time, starting from the cold state (see 5.7.6), varies with the current up to a value of at least maximum ($X \times I_e$) value. The manufacturer shall be prepared to indicate, by suitable means, the general tolerances applicable to these curves and the conductor cross-sections used for establishing these curves (see ~~9.3.3.6.5~~ 9.3.3.3.6, item c)).

It is recommended that the current be plotted as abscissae and the time as ordinates, using logarithmic scales. It is recommended that the current be plotted as multiples of the setting current and the time in seconds on the standard graph sheet detailed in IEC 60269-1.

### 5.7.6 Influence of ambient air temperature

The time-current characteristics (see 5.7.5) refer to a stated value of ambient air temperature and are based on no previous loading of the overload relay (i.e. from an initial cold state). This value of the ambient air temperature shall be clearly given on the time curves; the preferred values are +20 °C or +40 °C.

The overload relays shall be able to operate within the ambient air temperature range of 0 °C to +40 °C, and the manufacturer shall be prepared to state the effect of variation in ambient air temperature on the characteristics of overload relays.

### 5.8 Coordination with short-circuit protective devices (SCPD)

Controllers and starters are characterized by the type, ratings, and characteristics of the SCPD to be used to provide overcurrent discrimination between starter and SCPD, and adequate protection of controllers and starters 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 (5.3.1.1);

e) rated operational currents, corresponding utilization category (5.4), overload current profile (5.3.5.2), and duty cycle value (5.3.4.1) or OFF-time, comprising the rating index;

- The prescribed format for AC-2a, AC-3a, AC-8a is shown by these examples:

  100 A: AC-3a: 6 × $I_e$-6 s: 60 %-1/h

  This indicates 100 A current rating for general applications with squirrel cage motors. The device can accommodate 600 A for 6 s; 60 % on-load factor; one standard operating cycle per hour.

- The prescribed format for AC-2b, AC-3b, AC-8b is shown by the example:

  100 A: AC-3b: 3 × $I_e$-52s: 1 440 s

  This indicates 100 A current rating for starting only. The device can accommodate 300 A for 52 s; the OFF-time shall not be less than 1 440 s before any subsequent start may be initiated.

f) maximum OFF-state current;

g) either the value of the rated frequency 50/60 Hz, or other rated frequencies for example 16 2/3 Hz, 400 Hz;

Safety and installation

h1) rated insulation voltage (5.3.1.2);

h2) galvanic separation between poles if applicable;

i) rated impulse withstand voltage (5.3.1.3);

j) IP code according to Annex C of IEC 60947-1:2020;

k) pollution degree (7.1.3.2);

l1) rated conditional short-circuit current and type of coordination of the controller or starter, and the type, current rating and characteristics of the associated SCPD (see 5.8);

l2) 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 rigid-solid conductors;
– "r" for terminals declared for rigid (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.

Control circuits

m) 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

n) nature and ratings of auxiliary circuits (5.6);

Overload relays and releases

o) characteristics according to 5.7.2, 5.7.5 and 5.7.6;

p) characteristics according to 5.7.3 and 5.7.4;

EMC immunity and emission levels

q1) the immunity levels attained and the specific requirements necessary to maintain compliance (8.3.2);

q2) the equipment class and the specific requirements necessary to maintain compliance (8.3.3);

q3) if an external EMC filter is required to fulfil the emission levels given in Table 17, it shall be specified in the catalogue and in the instruction manual.

Additional information

r) reference of dedicated wiring accessories which can be used for wiring the semiconductor motor controller or starter;

s) type of equipment according to 5.2;

t) maximum permissible altitude of the installation site, if greater than 1 000 m;

u1) pole impedance (Z) of the parallel mechanical switching device of a bypassed semiconductor motor controller or starter according to IEC 60947-4-1;

u2) material declaration according to Annex W of IEC 60947-1:2020;

u3) semiconductor motor controller power losses.

### 6.2 Marking

Subclause 6.2 of IEC 60947-1:2020 applies to controllers and starters, with the following additions.

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

Data under items c), ~~k)~~ j) (if the degree of protection is different than IP00) and q) in 6.1 shall be marked on the equipment; time-current characteristics (or range of characteristics) may be provided in the manufacturer's published literature.

When a radiocommunication device is embedded into the equipment, additional information according to 6.2 and 6.3 of IEC 63404:2024 shall apply.

### 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.

The manufacturer of a semiconductor starter incorporating an automatic reset overload relay capable of being connected to enable automatic restarting shall provide information with the starter to alert the user to the possibility of automatic restarting.

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 semiconductor motor controller or starter (see 8.2.1.6);
– in the event of temperature-rise above 50 K of the metallic radiator surface of the device.

The instructions shall also cover other specific application limitations, when applicable, such as altitude above 1 000 m and two direction starters.

When the embedded radiocommunication device can be upgraded, additional information according to 6.4 of IEC 63404:2024 shall apply.

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 according to 8.1.1, 8.1.15, 8.1.17 and 8.2.2, the manufacturer shall provide safety signs, graphical symbols or safety notes of the hazard for example by using e.g. IEC 60417-5036:2002. Signal words are given by ISO 3864-2.

NOTE ISO/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 starter.

### 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.~~

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

Hazardous substances used by design in the equipment shall be declared in the product documentation.

When declared, the material declarations shall be provided according to IEC TS 63058.

IEC TS 63058 should also be considered carefully for providing measures to prevent emission of or contact with hazardous substances.

NOTE IEC TS 63058 provides methods for assessing the environmental impact of switchgear and controlgear, guidance on environmentally conscious design and on information needed for end-of-life treatments.

## 7 Normal service, mounting and transport conditions

### 7.1 Normal service conditions

#### 7.1.1 Ambient air temperature

Subclause 7.1.1 of IEC 60947-1:2020 applies with the exception that all references to –5 °C are replaced by 0 °C.

#### 7.1.2 Altitude

When rated above 1 000 m, the manufacturer shall specify the maximum altitude in 6.1 t) 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.~~

For the use of the equipment above 1 000 m, specific instruction can be necessary for the additional cooling means of the power semiconductor or the derating of rated values of 5.3.

#### 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~~ in the product documentation, controllers and starters 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 to apply, 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.

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 which are compliant with a relevant IEC product standard do not require separate evaluation if tested under the conditions given in this document. 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~~ shall meet the requirements of their own IEC product standard, and the additional requirements of this document. When a radiocommunication device is embedded into the equipment, C.4.2 of IEC 63404:2024 applies. The interruption of the radiocommunication link shall not affect the current operation of the equipment.

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 measures intended for the user. Clear warning shall be provided in the user manual where adjustments or settings could lead to a hazardous situation.~~

The setting of any automatic resettable overload release needs to be identified in the user manual as a specific safety warning.

~~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.~~

### 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 of 9.2.2.1 in 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 with the following addition.

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 8.1.4 of IEC 60947-1:2020.

Where SELV and PELV circuits are accessible, they shall be separated from other hazardous-live-part according to the requirements of Annex N 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). They shall be marked or provided with other identification in accordance with Clause 5 of IEC 60445:2021.

### 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 19; or

b) a linear or non-linear impedance limits the output in compliance with Table 19. If a positive temperature coefficient (PTC) device (e.g. PTC thermistor) 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 19, 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 20.

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 the case of external power supplies without overcurrent protective devices, they shall not exceed the values given in Table 19. In case of external power supplies with over-current protective devices, they shall not exceed the values given in Table 20.

**Table 19 – Limits for limited energy sources without an over-current protective device**

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

NOTE This table will be moved into a 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 Isc 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 thermistor), and 60 s in other cases.

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

**Table 20 – Limits for limited energy sources with an over-current protective device**

| Output voltage [a] $U_{oc}$ | | Output current [b, d] $I_{sc}$ | Maximum power [c, d] $S$ | Current rating of over-current protective device [e] |
|---|---|---|---|---|
| V AC | V DC | A | VA | A |
| ≤ 20 | ≤ 20 | $\leq \frac{1000}{U_{oc}}$ | 250 | ≤ 5,0 |
| 20 < $U_{oc}$ ≤ 30 | 20 < $U_{oc}$ ≤ 30 [f] | | | $\leq \frac{100}{U_{oc}}$ |
| - | 30 < $U_{oc}$ ≤ 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 a 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 to 200 Hz, 24,8 V DC switching at 10 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:

a) the output voltage is limited in compliance with Table 21, and

b) a linear or non-linear impedance limits the output in compliance with Table 21, 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 21 – Limits for limited energy source with current limiting impedance**

| Output voltage [a] $U_{oc}$ | | Output current [b, d] $I_{sc}$ | Maximum power [c] $S$ |
|---|---|---|---|
| V AC | V DC | A | VA |
| ≤ 30 V RMS. | ≤ 30 V | 0,5 | 15 |

NOTE This table will be moved into a 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 Isc 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 terminal) 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 (including overheating of the power semiconductor) 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 electrical shock and fire hazard will result from failure of the component. Compliance shall be checked by the test of 9.2.5. The analysis shall be included in the test report.

NOTE 1 FMEA (Failure Mode and Effects Analysis) is generally used for this circuit analysis method.

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.

In case of an operating condition with a loss of phase, polyphase products shall not present a hazard. Compliance shall be checked by the test of 9.2.7.2.

NOTE 2 A loss of phase can be the result of an external phase supply interruption from the mains or an internal phase interruption.

### 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~~ review of the product documentation 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 controllers and starters shall be operated in accordance with the manufacturer's instructions and their relevant product standard.

**8.2.1.1.1** Controllers and starters shall be so constructed that they

a) are trip free;

b) can be caused to return to the OPEN or OFF-state by the means provided when controlled running and at any time during the starting sequence or when performing any manoeuvre.

Compliance is verified in accordance with 9.3.3.6.3.

**8.2.1.1.2** Controllers and starters shall not malfunction due to mechanical shock or electromagnetic interference caused by operation of its internal devices.

Compliance is verified in accordance with 9.3.3.6.3.

**8.2.1.1.3** The moving contacts of the series mechanical switching device in semiconductor motor controllers and starters 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 controllers and starters

Controllers or starters 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 according to 9.3.3.6.3. Where a range is declared, 85 % shall apply to the lower value, and 110 % to the higher.

#### 8.2.1.3 Limits of operation of under-voltage relays and releases

An under-voltage relay or release can be associated with a semiconductor motor controller or starter. In addition to the test requirements of ~~9.3.3.6.5~~ 9.3.3.6.6, the limits of operation of the under-voltage relays and releases shall be defined by the manufacturer if applicable.

#### 8.2.1.4 Limits of operation of shunt coil operated releases (shunt trip)

Vacant.

#### 8.2.1.5 Limits of operation of current sensing relays and releases

##### 8.2.1.5.1 Relays and releases in starters

###### 8.2.1.5.1.1 Limits of operation of time-delay overload relays when all poles are energized

####### 8.2.1.5.1.1.1 General tripping requirements of overload relays

~~NOTE 1 The thermal protection of motors in the presence of harmonics in the supply voltage is under consideration.~~

The relays shall comply with the requirements of Table 4 when tested as follows:

a) with the overload relay or starter in its enclosure, if normally fitted, and at $A$ times the current setting, tripping operation shall not occur in less than 2 h starting from the cold state, at the value of reference ambient air temperature stated in Table 4. However, when the overload relay terminals have reached thermal equilibrium at the test current in less than 2 h, the test duration can be the time needed to reach such thermal equilibrium;

b) when the current is subsequently raised to $B$ times the current setting, tripping operation shall occur in less than 2 h;

c) for class 2, 3, 5 and 10 A overload relays energized at $C$ times the current setting, tripping operation shall occur in less than 2 min starting from thermal equilibrium, at the current setting, in accordance with 9.3.3 of IEC 60034-1:2017;

NOTE 2 Subclause 9.3.3 of IEC 60034-1:2017 states: “Polyphase motors having rated outputs not exceeding 315 kW and rated voltages not exceeding 1 kV shall be capable of withstanding a current equal to 1,5 times the rated current for not less than 2 min.

d) for class 10, 20, 30 and 40 overload relays energized at $C$ times the current setting, tripping operation shall occur in less than 4 min, 8 min, 12 min or 16 min respectively, starting from thermal equilibrium, at the current setting;

e) for semiconductor starter without current-limit function at $D$ times the current setting, tripping operation shall occur within the limits given in Table 3 for the appropriate trip class and tolerance band, starting from the cold state. For semiconductor starter with current-limit function, the test shall be done at the maximum $I_{lim}$ and the tripping operation shall occur within the time limits declared by the manufacturer according to 5.7.5.

NOTE ~~3~~2 For semiconductor starters with current-limit function and an overload relay having a current setting range, the test with the maximum $I_{lim}$ is related only to the maximum setting of the overload relay. The test at the minimum setting can be done in the same way as without current-limit function.

In the case of overload relays having a current setting range, the limits of operation shall apply when the relay is carrying the current associated with the maximum setting and also when the relay is carrying the current associated with the minimum setting.

For non-compensated overload relays, the current multiple/ambient temperature characteristic shall not be greater than 1,2 %/K.

NOTE ~~4~~3 1,2 %/K is the derating characteristic of PVC-insulated conductors.

An overload relay is regarded as compensated if it complies with the relevant requirements of Table 4 at +20 °C and is within the limits shown in Table 4 at other temperatures.

**Table 4 – Limits of operation of time-delay overload relays when energized on all poles**

| Type of overload relay | Multiples of current setting | | | | Ambient air temperature values |
|---|---|---|---|---|---|
| | A | B | C | D | |
| Thermal type not compensated for ambient air temperature variations | 1,0 | 1,2 [b] | 1,5 | 7,2 | +40 °C |
| Thermal type compensated for ambient air temperature variations | [c] | [c] | – | – | Less than 0 °C [d] |
| | 1,05 | 1,3 | 1,5 | – | 0 °C |
| | 1,05 | 1,2 [b] | 1,5 | 7,2 | +20 °C |
| | 1,0 | 1,2 [b] | 1,5 | – | +40 °C |
| | [c] | [c] | – | – | More than +40 °C [d] |
| Electronic type [a] | 1,05 | 1,2 [b] | 1,5 | 7,2 | 0 °C, +20 °C and +40 °C |

[a] These tests A, B and D shall only be done at 20 °C.

[b] **If specified by the manufacturer the tripping current could be different from 120 % but shall not exceed 125 %. In this case the test current value shall be equal to this tripping current value. In this case the tripping current value shall be marked on the product.**

[c] Multiples of current setting should be declared by the manufacturers.

[d] See 9.3.3.6.5 for test outside the range 0 °C to +40 °C.

#### 8.2.1.5.1.1.2 Thermal memory test verification

Unless the manufacturer has specified that the device does not contain thermal memory, electronic overload relays shall fulfil the following requirements (see Figure 3):

– apply a current equal to $I_e$ until the device has reached the thermal equilibrium;
– interrupt the current for a duration of 2 × $T_p$ (see Table 3) with a relative tolerance of ±10 % (where $T_p$ is the time measured at the *D* current according to Table 4);
– apply a current equal to 7,2 × $I_e$;
– the relay shall trip within 50 % of the time $T_p$.

For semiconductor starter with current-limit function, the test shall be done at the maximum $I_{lim}$ and the tripping operation shall occur within the time limits declared by the manufacturer.

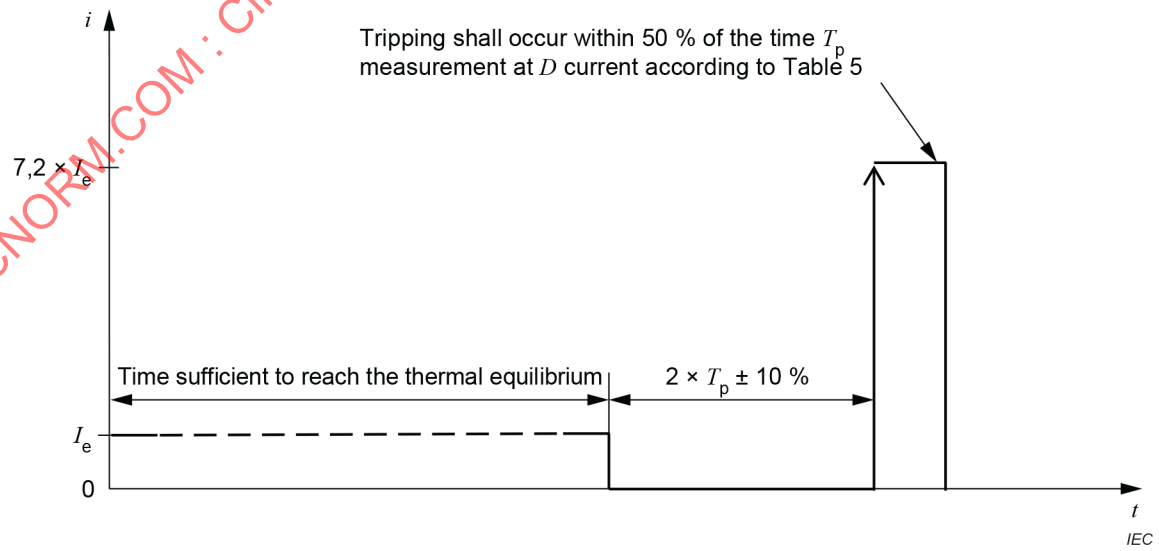



**Figure 3 – Thermal memory test**

#### 8.2.1.5.1.2 Limits of operation of three-pole time-delay overload relays energized on two poles

With reference to Table 5:

The overload relay or starter shall be tested in its enclosure if normally fitted. With the relay energized on three poles, at $A$ times the current setting, tripping operation shall not occur in less than 2 h, starting from the cold state, at the value of the ambient air temperature stated in Table 5.

~~Moreover, when~~ Then, one pole shall be disconnected. When the value of the current flowing in two poles (in phase loss sensitive overload relay or release, those carrying the higher current) is increased to $B$ times the current setting, ~~and the third pole de-energized,~~ tripping operation shall occur in less than 2 h.

The values shall apply to all combinations of poles.

In the case of overload relays having an adjustable current setting, the characteristics shall apply both when the relay is carrying the current associated with the maximum setting and when the relay is carrying the current associated with the minimum setting.

**Table 5 – Limits of operation of three-pole time-delay overload relays when energized on two poles only**

| Type of overload relay | Multiples of current setting | | Reference ambient air temperature |
|---|---|---|---|
| | A | B | |
| Thermal, compensated for ambient air temperature variations or electronic<br>Not phase loss sensitive | 3 poles<br>1,0 | 2 poles<br>1,32<br>1 pole<br>0 | +20 °C |
| Thermal, not compensated for ambient air temperature variations<br>Not phase loss sensitive | 3 poles<br>1,0 | 2 poles<br>1,25<br>1 pole<br>0 | +40 °C |
| Thermal, compensated for ambient air temperature variations or electronic<br>Phase loss sensitive | 2 poles<br>1,0<br>1 pole<br>0,9 | 2 poles<br>1,15<br>1 pole<br>0 | +20 °C |

#### 8.2.1.5.2 Relays and releases associated with controllers

Relays and releases to be associated with a controller to provide protection for the motor shall operate within a time $T_x$ at a current $X \times I_e$, where $X$ and $T_x$ are the values given by the declared rating index. In the case of more than one declared rating index, $X$ and $T_x$ are the values corresponding to the rating index giving the highest product $(XI_e)^2 \times T_x$.

#### 8.2.1.5.3 Limits of operation of under-current relays

An under-current relay or release, when associated with a switching device, shall operate to open the switching device within 90 % to 110 % of the set time when the current during operation is below 0,9 times the under-current setting in all poles.

#### 8.2.1.5.4 Limits of operation of stall sensitive electronic overload relays

A stall sensitive electronic overload relay, when associated with a switching device, shall operate to open the switching device within 80 % to 120 % of the set time (stall inhibit time) or within the accuracy specified by the manufacturer, when

a) for current sensing relays, the current is 20 % higher than the set stall current value;

EXAMPLE Set current of the stall relay: 100 A; set time: 6 s; time setting accuracy: ±10 %. The relay is tripping within 5,4 s and 6,6 s when the current is equal to or greater than 100 A × 1,2 = 120 A.

b) for rotation sensing relays, an input signal indicating no motor rotation exists.

#### 8.2.1.5.5 Limits of operation of jam sensitive electronic overload relays and releases

A jam sensitive electronic overload relay or release, when associated with a switching device, shall operate to open the switching device within 80 % to 120 % of the set time (jam inhibit time) or within the accuracy specified by the manufacturer, when the current is above 1,2 times the set current value of the jam sensitive electronic overload relay, during running after completion of the starting.

#### 8.2.1.6 Mechanical switching devices used in semiconductor motor controllers and starters

The switching devices shall be verified as a part of the semiconductor motor controller or starter. 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.

The effectiveness of the interlocking shall be demonstrated during the thermal stability test or overload capability test in 9.3.3.6.1 or be verified by any other test covering the interlocking function for example by oscillographic means.

### 8.2.2 Temperature-rise

#### 8.2.2.1 General

The requirements of 8.2.2 of IEC 60947-1:2020 apply to controllers and starters 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, guarding and location to prevent danger is the responsibility of the installer. The manufacturer shall provide a suitable warning (for example symbol IEC 60417-5041:2002) in accordance with 6.3.

#### 8.2.2.2 Terminal

Subclause 8.2.2.2 of IEC 60947-1:2020 applies.

#### 8.2.2.3 Accessible parts

Subclause 8.2.2.3 of IEC 60947-1:2020 applies.

#### 8.2.2.4 Ambient air temperature

Subclause 8.2.2.4 of IEC 60947-1:2020 applies.

#### 8.2.2.5 Main circuit

##### 8.2.2.5.1 General

The main circuit of a controller or starter, which carries current in the FULL-ON state, including the over-current releases which may be associated with it, shall be capable of carrying the current $I_e$ 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.

##### 8.2.2.5.2 Mechanical switching devices in controllers and starters

The temperature-rise shall be verified by the procedures given in 9.3.3.3.4 and 9.3.3.6.1 (including Table 10 and Table 14). 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 9.3.3.6.1 (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 6.

**Table 6 – 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) K | |
|---|---|---|
| | 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 series 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

Controllers and starters shall be required to establish an ON-state, to commutate, 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 according to 9.3.3.6.

For controllers that are designated for utilization categories AC-2a, AC-3a, AC-8a, values of $T_x$ corresponding to $X$ values shall not be less than those given in Table 7. For corresponding starters, $T_x$ shall be the maximum tripping time of its overload relay in hot state declared by the manufacturer (see also footnote [b] of Table 8).

Controllers and starters that are designated for utilization categories AC-2b, AC-3b and AC-8b may be designated for those applications where long accelerating times are required. It shall be understood that the maximum thermal capacity of the controller may be depleted fully during the on-load period. Therefore, a suitable off-load period shall be provided for the controller immediately after the starting time has expired. The values of $T_x$ corresponding to $X$ values shall not be less than those given in Table 7. For corresponding starters, $T_x$ shall be the maximum tripping time of its appropriate overload relay (see also footnote [b] of Table 8).

In a locked rotor situation arising while the motor has been running at normal speed, the controller or starter shall be permitted to establish an OFF-state condition in shorter times than those given, provided it is equipped with suitable overload protection.

Ratings shall be verified under the conditions stated in Table 8, Table 9 and Table 10 of this document, and in the relevant parts of 9.3.3.5.2 and 9.3.3.5.3 of IEC 60947-1:2020.

~~Requirements for the higher inrush current for direct-on-line semiconductor controller or direct-on-line semiconductor starter is under consideration.~~

~~NOTE Starting higher locked rotor current to achieve high efficiency class motor according to IEC 60034-30-1 can reach an inrush current larger than the 8 × $I_e$ given in Table 9 which can be managed by e.g. an inrush current limit function or a higher making capacity of the semiconductor controller.~~

~~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).~~

Where $X \times I_e$ is greater than 1 000 A, the overload capability verification may be provided by other methods such as computer modelling simulation. The method and the result shall be described in the test report.

In Table 8 and Table 10, the ON-time and OFF-time should be in accordance with Table 2 for the most severe duty cycle sequence. If a controller is rated and tested for a duty cycle that is more severe than the standard duty cycle sequence based on Table 8, the manufacturer may assign the same rating for a standard duty cycle sequence without further testing.

**Table 7 – Minimum overload current withstand time ($T_x$) in relation to overload current ratio ($X$) and corresponding to overload relay trip class** (see Table 3)

| **Designation** [a] (included as a guide only) | **Minimum overload current withstand time, $T_x$** s | | | | | | |
|---|---|---|---|---|---|---|---|
| | $X$ = 8 | $X$ = 7 | $X$ = 6 | $X$ = 5 | $X$ = 4 | $X$ = 3 | $X$ = 2 |
| 2 | 0,7 | 0,9 | 1,2 | 1,8 | 2,7 | 5 | 11 |
| 3 | 1 | 1,3 | 1,8 | 2,6 | 4 | 7 | 16 |
| 5 | 1,2 | 1,5 | 2 | 3 | 4,6 | 8,3 | 19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10A | 1,6 | 2 | 3 | 4 | 6 | 12 | 26 |
| 10 | 3 | 4 | 6 | 8 | 13 | 23 | 52 |
| 20 | 5 | 6 | 9 | 12 | 19 | 35 | 78 |
| 30 | 7 | 9 | 13 | 19 | 29 | 52 | 112 |
| 40 | 11 | 15 | 20 | 29 | 45 | 80 | 180 |
| [a] Designations are provided for information only without any direct relation to Table 3. | | | | | | | |

**Table 8 – Minimum requirements for thermal stability test conditions**

| Utilization category | Current-limit function | Test current ($I_T$) Operating cycle ON-time s | | | | Operating cycle OFF-times |
|---|---|---|---|---|---|---|
| | | Test level 1 [a] | | Test level 2 [a] | | |
| | | $I_T$ | ON-time [b] | $I_T$ | ON-time [b] | |
| AC-2a, AC-3a, AC-8a | Yes | $I_{lim}$ [d] | t | $I_e$ | (36*F/S)-t | 36*(100-F)/S |
| | No | *0,75* $*I_{LRP}$* | | | | |
| | No (DOL) | $I_{LRP}$ | | | | |
| AC-2b, AC-3b, AC-8b | Yes | $I_{lim}$ [d] | t | Not applicable | Not applicable | (3600/S)-t |
| | No | *0,75** $I_{LRP}$ | | | | |
| | No (DOL) | $I_{LRP}$ | | | | |

Parameters of the test circuit:

$I_{LRP}$ = prospective locked rotor current according to Table 9.

$I_e$ = rated operational current

$I_{lim}$ = current setting of the current-limit function

$I_T$ = test current

$U_T$ = test voltage (may be any value)

Cos φ = test circuit power factor (may be any value)

Number of operating cycles [c]

[a] Changeover time from level 1 to level 2 shall not be greater than three full periods of the power frequency. The current during level 1 shall be carried by the semiconductor only.

[b] For a semiconductor motor controller or starter intended to be used only together with a specified overload relay, t is the maximum operating time allowed by the tolerances of its overload relay in the hot state. For semiconductor motor controller without specified overload relay, t = $T_x$ and is selected from Table 7 according to $X = I_T/I_e$ and the declared overload trip class.

[c] The number of operating cycles will depend upon the length of time required for the controller to reach thermal equilibrium.

[d] $I_{lim}$ is the current-limit value declared by the manufacturer according to the overload current profile according to 5.3.5.2.

**Table 9 – Prospective locked rotor current by utilization categories**

| Utilization category | $I_{LRP}$ |
|---|---|
| AC-2a | 4 × $I_e$ |
| AC-2b | |
| AC-3a | 8 × $I_e$ [a] |
| AC-3b | |
| AC-8a | 6 × $I_e$ |
| AC-8b | |

a For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE to IEC 60034-12:2016, $I_{LRP}$ is equal to 8,5 × $I_e$.

**Table 10 – Minimum requirements for overload capability test conditions**

| Utilization category | Parameters of the test circuit | | | Operating cycle ON-time s | Operating cycle OFF-time s | Number of operating cycles [g] |
|---|---|---|---|---|---|---|
| | $I_T$ [h, f] | $U_r / U_e$ [a] | *Cos φ* [b] | | | |
| AC-2a | $I_{LRP}$ [g,e] | 1,05 | 0,65 | t [c] | ≤ (3600/S)-t | 3 or 4 |
| AC-3a | | | [d] | | | |
| AC-8a | | | [d] | | | |
| AC-2b | $I_{LRP}$ [g,e] | 1,05 | 0,65 | t [c] | ≤ (3600/S)-t [i] | 3 |
| AC-3b | | | [d] | | | |
| AC-8b | | | [d] | | | |

$I_{LRP}$ prospective locked rotor current

$I_e$ rated operational current

$I_T$ test current

$U_e$ rated operational voltage

$U_r$ power frequency recovery voltage

*Temperature conditions*: 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 (see 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 φ 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 For a semiconductor motor controller intended to be used only together with a specified overload relay or starter, t is the maximum operating time allowed by the tolerances of its overload relay in the hot state which is the state of thermal equilibrium reached during the temperature-rise test (see 9.3.3.3).

For a semiconductor motor controller intended to be used without a specified overload relay, t = $T_x$ is selected from Table 7 according to $X = I_T/I_e$ and the declared overload trip class.

d For $I_e$ ≤ 100 A: cos φ = 0,45; for $I_e$ > 100 A: cos φ = 0,35. For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE according to IEC 60034-12:2016, cos φ = 0,35 for $I_e$ ≤ 100 A: cos φ = 0,25; for $I_e$ > 100 A.

e $I_{LRP}$ may be limited by the EUT.

f In case of current-limit function, see 9.3.3.6.3 (3) e).

g See Table 9.

h In the case of three operating cycles, the current shall be carried by the semiconductor only. In the case of

four operating cycles, then the current shall be carried only by the semiconductor in the first two operating cycles. In the last two operating cycles the current shall be carried by the device that is normally carrying the current in the FULL-ON state.

[i] For utilization categories AC-2b, AC-3b, AC-8b, the manufacturer may claim compliance with the capability to perform starting operations with the OFF-time values less than 1 440 s. However, it shall be verified by testing with the OFF-time declared by the manufacturer.

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

##### 8.2.4.2.1 General

The controller or starter, including the over-current releases and the mechanical switching devices associated with it, shall be capable of operating without failure in the presence of locked rotor motor current, starting current and overload current.

The capability of making and breaking currents without failure shall be verified under the conditions stated in both Table 11 and Table 12, for the required utilization categories, and the number of operations indicated.

##### 8.2.4.2.2 Mechanical switching devices of controllers and starters

The making and breaking capacity shall be verified when tested as a combined unit in accordance with the procedures of 9.3.3.5.1 and 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 9.3.3.6.2 and 9.3.3.6.3.

#### 8.2.4.3 Requirements for an induction motor test load

The induction motor test load shall feature a four-pole squirrel cage motor with the following characteristics:

a) the rated voltage of the motor shall be equal to or greater than Ue for the device to be tested;

~~b) when the motor is running, the test current through the motor and the controller may be any value greater than 1 A;~~

~~c) the power factor of the motor may be of any value;~~

~~d) the inner connections of the motor windings may be of any configuration (for example star, delta);~~

~~e~~b) the parameters of the mechanical load connected to the motor shaft shall be adjusted to produce a decelerating time from base speed to zero speed within the range of 2 s to 4 s.

**Table 11 – 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-2a, b | 4,0 | 1,05 | 0,65 | 0,05 | [b] | 50 |
| AC-3a, b | 8,0 [c] | | [a] | | | |
| AC-8a, b | 6,0 | | [a] | | | |

$I_c$ = 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] For $I_e \leq 100$ A: Cos φ = 0,45

For $I_e > 100$ A: Cos φ = 0,35

[b] OFF-time shall not be greater than the values given in the chart.

[c] For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE according to IEC 60034-12:2016, $I_c/I_e$ is equal to 8,5.

| Current $I_c$ A | OFF-time s |
|---|---|
| $I_c \leq 100$ | 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 |
| $1\,600 < I_c$ | 240 |

**Table 12 – 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-2a, b | 2,0 | 1,05 | 0,65 | 0,05 | [b] | 6 000 |
| AC-3a, b | 2,0 | 1,05 | [a] | | | |
| AC-8a, b | 6,0 | 1,05 | 0,35 | 1<br>10 | 9<br>90 | 5 900<br>100 |

$I_c$ = 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] For $I_e \leq 100$ A: Cos φ = 0,45

For $I_e > 100$ A: Cos φ = 0,35

[b] OFF-times shall not be greater than the values given in Table 11.

#### 8.2.4.4 Semiconductor motor controller power losses

Where the power losses of the semiconductor motor controller or starter is given, the power semiconductor losses shall be calculated according to 5.3.7.1 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 current of controllers and starters 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 starter.

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 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 installation and shall be suitable for further use. For mechanical switching device of controllers and starters, 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 a SCPD not in compliance with the manufacturer's recommendations can invalidate the coordination.

#### 8.2.5.2 Coordination at the crossover current between the starter and the SCPD

The manufacturer shall describe the continuity of the short-circuit coordination between the protection functions up to its rated conditional short-circuit current. (SCPD, overload protection, other internal protections, line contactor, bypass contactor etc.).

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

Environments A and B of IEC 60947-1:2020 are implemented in this document in 8.3.3.1 as class A and B equipment according to CISPR 11.

The general electromagnetic environment of the equipment covered by this document is E-III, industrial according to IEC TR 63216.

Other environments defined by IEC TR 63216 may be selected. The environment E-IV is relevant for equipment intended for being installed within high voltage power station and substation. The environment E-II is relevant for accessories such as control device or digital interfaces not directly supplied by the factory mains (see IEC TR 63216).

For EMC test, the minimum system to be considered is the controller interconnected with a motor load and cables.

When a radiocommunication device is embedded into the equipment, 8.4 of IEC 63404:2024 shall apply.

### 8.3.2 Immunity

#### 8.3.2.1 General

Electrical system influences may be destructive or non-destructive, depending on the intensity of the influence. Destructive influences (voltage or current) cause irreversible damage to a controller or starter. Non-destructive influences may cause temporary malfunction or abnormal operation, but the controller or starter returns to normal operation after the influence is minimized or removed; in some cases, this may require manual intervention.

~~The manufacturer should be consulted in those instances where severe external influences may occur, which are greater than the levels for which the controller or starter has been tested, for example installations in remote locations with long power transmission lines; close proximity to ISM equipment as defined in CISPR 11.~~

~~NOTE The careful application of decoupling practices during installation helps to minimize the external transient influences. For example, control circuit wiring are separated from power circuit wiring. Where closely coupled wiring cannot be avoided, twisted pairs or shielded wiring are used for control circuit connections.~~

~~A number of requirements are listed. The test results are specified using the performance criteria of the IEC 61000-4 series. For convenience, the performance criteria are quoted here, and described in more specific detail in Table 13.~~

~~These are:~~

~~1) normal performance within the specification limits;~~

~~2) temporary degradation, or loss of function or performance, which is self-recoverable;~~

~~3) temporary degradation, or loss of function or performance which requires operator intervention or system reset. Normal functions shall be restorable by simple intervention, such as by manual reset or restart. There shall not be any damaged components.~~

The test results are specified using the performance criteria given in Table 13.

**Table 13 – Specific performance criteria when EM disturbances are present**

| Item | Performance criteria (performance during test) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A Overall performance | No noticeable changes of the operating characteristic.<br>Operating as intended. | Noticeable changes (visual or audible) of the operating characteristic.<br>Self-recoverable. | Changes in operating characteristic.<br>Triggering of protective devices.<br>Not self-recoverable. |
| B Operation of power and driving circuits | No maloperation. | Temporary maloperation which cannot cause tripping, or erratic and audible changes in motor torque. | Shut down.<br>Triggering of protective devices.<br>Not self-recoverable. |
| C Operation of displays and control panels | No changes to visible display information.<br>Only slight light intensity fluctuation of LEDs, or slight movement of characters. | Temporary visible changes or loss of information.<br>Undesired LED illumination | Shut down.<br>Permanent loss or display of wrong information.<br>Unpermitted operating mode.<br>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.<br>Loss of data and/or information.<br>Errors in communication.<br>Not self-recoverable. |

#### 8.3.2.2 Electrostatic discharge

The test values and procedures are given in 9.4.2.1.

#### 8.3.2.3 Radio-frequency electromagnetic field

The test values and procedures are given in 9.4.2.2.

#### 8.3.2.4 Fast transients (common mode) (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 General

Subclause 8.3.3 of IEC 60947-1:2020 applies with the following addition.

The limits of CISPR 11 apply for Class B equipment intended to be used in residential areas connected to public low-voltage distribution systems and for Class A equipment intended to be used in all locations other than those allocated in residential areas.

##### 8.3.3.2 Low-frequency emission with reference to main power frequency

###### 8.3.3.2.1 Harmonics

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.

###### 8.3.3.2.2 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.

##### 8.3.3.3 High-frequency emission

###### 8.3.3.3.1 Conducted radio-frequency (RF) emission

The limits given in Table 17 shall be verified in accordance with the procedures of 9.4.3.2.

###### 8.3.3.3.2 Radiated emission

The limits given in Table 18 shall be verified in accordance with the procedures of 9.4.3.3.

## 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 controllers and starters of all types and their dedicated wiring accessories with this document. They comprise the verification of

a) temperature-rise limits (9.3.3.3);
b) dielectric properties (9.3.3.4);
c) operating capability (9.3.3.6);
d) operation and operating limits (9.3.3.6.3);
e) rated making and breaking capacity and conventional operational performance of series mechanical switching devices of equipment (9.3.3.5);
f) performance under short-circuit conditions (9.3.4);
g) mechanical properties of terminals (9.2.5 of IEC 60947-1:2020 applies);

h) degrees of protection of enclosed controllers and starters (Annex C of IEC 60947-1:2020 applies);

i) EMC tests (9.4).

### 9.1.3 Routine tests

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

Routine tests for controllers and starters comprise

– operation and operating limits (9.5.2);

– dielectric tests (9.5.3).

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

### 9.1.4 Sampling tests

Sampling tests for controllers and starters comprise

– operation and operating limits (9.5.2);

– dielectric tests (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 ≤1:

– acceptance number Ac = 0 (no defect accepted);

– rejection number Re = 1 (if 1 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 the above ISO 2859-1 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~~ apply.

### 9.1.5 Special tests

#### 9.1.5.1 General

~~Special test are conducted is at the discretion of the manufacturer.~~

~~Special tests include:~~

~~– environment tests according to 9.1.5.2;~~

~~– verification of coordination between the starter and the SCPD according to 9.1.5.3.~~

Verifications are required when environment withstand data according to 9.1.5.2 or short-circuit coordination data according to 9.1.5.3 are given in the equipment documentation.

#### 9.1.5.2 Environmental 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. The overload relay shall not trip during the test. To check the behaviour 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.

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 AC-3 current, but may be limited to 100 A for practical reasons. During the last hour, the controller shall be operated 5 times. During the test the overload relay is permitted to trip.

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 AC-3 current which may be limited to 100 A for practical reasons. During this last hour the controller shall be operated 5 times. During the test the overload relay shall not trip.

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 AC-3 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. The overload relay may trip only if it is permitted according to its temperature characteristic.

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.~~

#### 9.1.5.3 Coordination between the starter and the SCPD

The verification of the short-circuit coordination between different over-current protections up to the rated conditional short-circuit current shall be demonstrated either by documentation, simulation or test (see Annex C).

### 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 19, Table 20, or Table 21, as applicable. Further adjustment is made, if necessary, to maintain the limit of apparent energy for the time period indicated in Table 19, Table 20, or Table 21, as applicable.

The test complies, if after the test period the available apparent power does not exceed the limits indicated in Table 19, Table 20, or Table 21, 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 20.

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 function 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. This shall include the condition where forced cooling system is made inoperative by physically preventing its operation. In case of multiple cooling channels, only one channel at a time shall be made inoperable.

NOTE 1 The forced cooling system can be made inoperative for example by disconnecting the supply of the fan.

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 a 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 9.3.4.1.2d) of IEC 60947-1:2020, to the supply circuit.

NOTE 2 The definition of enclosed equipment is given in Annex C of IEC 60947-1:2020.

#### 9.2.5.3 Test conditions

In case of a forced cooling system made inoperative, the test shall be terminated when a protective device trips or when the temperature of the semiconductors in the main circuits stabilize. The temperature shall be measured as for the temperature-rise test according to 9.3.3.3.4. Thermal stability is reached when the variation does not exceed 1 K per hour.

### 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.

### 9.2.7 Abnormal operating tests

#### 9.2.7.1 General

Before all abnormal operation tests, the test sample shall be mounted, connected, and operated as described in the temperature-rise test.

Faults that are the direct consequence of an abnormal operating conditions are considered to be part of that abnormal operating condition.

For equipment without a dedicated enclosure, the equipment shall be tested under the conditions of 9.2.5.3.

Surgical cotton shall be placed over all openings, handles, flanges, joints and similar locations on the outside of the enclosure, in a manner which will not significantly affect the cooling when the test lasts long enough to have significant temperature rise.

Where the equipment under test is specified in its installation manual to require external means of protection against faults, these specific means shall be provided for the test.

The individual tests shall be performed until terminated by activation of a protective device or mechanism (internal or external), a component failure occurs that interrupts the fault condition, or the temperature of the semiconductors or the mechanical switching device, as indicated in 9.3.3.3.4, in the main circuits stabilize. The temperature shall be measured as for the temperature-rise test according to 9.3.3.3.4. It is assumed that a steady state is reached when the variation does not exceed 1 K per hour.

#### 9.2.7.2 Loss of phase

This test is not required for a semiconductor motor-starter that meets:

– The test requirements of 9.3.3.6.6 c) for three-pole thermal or electronic overload relays energized on two poles only;

– In addition to the test of 8.2.1.5.1.2, this test shall be repeated with one pole disconnected and with the relay energized on only two poles at B times the current setting. The tripping operation shall occur in less than 2 h, starting from the cold state; and

– The adequacy of the insulation shall be verified by a dielectric test on the controller or starter. The test voltage shall be applied as specified in 9.3.3.4.1 (4).

A multi-phase equipment shall be operated with each phase (including neutral, if used), in turn, disconnected at the input. The test shall be performed by disconnecting one phase with the equipment operating at 1,32 times the rated current $I_e$ (with one phase of the load disconnected) and shall be repeated by initially energizing the equipment with one phase disconnected.

The test shall continue according to the conditions of 9.2.7.1, but shall be terminated after 21 min.

If the disconnection of a single phase can decisively be determined to result in a more severe condition, for example disconnection of the phase with the protective device least likely to respond to the loss of phase, then the test can be conducted by disconnecting only that phase instead of each phase in turn.

NOTE If fuses are used, a voltage can remain at the open phase caused by internal impedances within the equipment connected between the phases.

#### 9.2.7.3 Acceptance criteria

As a result of the abnormal operation tests, the equipment shall comply with the following:

a) there shall be no emission of flame, burning particles or molten metal;

b) the surgical cotton shall not have ignited;

c) the connection to protective earth and the earth continuity of the equipment shall not have opened;

d) doors and covers of enclosed equipment shall remain in place;

e) accessible circuits shall not exhibit hazardous voltages;

f) during and after the test, hazardous live parts at voltages greater than SELV/PELV in accordance with Annex N of IEC 60947-1:2020 or limited energy source levels of 8.1.14 shall not become accessible;

g) components, e.g. busbar supports, used for the mounting of live parts shall not break away from their initial position;

h) no conductor shall get pulled out of its terminal connector; and

i) no parts shall be ejected from the enclosure of the enclosed equipment.

The equipment shall comply with the power frequency or DC withstand voltage t est of 9.3.3.4.1 (4) following the abnormal operation tests.

The equipment is not required to be operational after testing and can become deformed. Overcurrent protection integral to the equipment, or required to be used with the equipment, is allowed to open.

### 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.~~

NOTE 1 More than one test sequence or all test sequences can be conducted on one sample. However, the tests are conducted in the sequence given for each sample.

NOTE 2 Some tests are included in the sequences solely to reduce the number of samples required, the results have no significance for the preceding or following tests in the sequence. Therefore, for convenience of testing, these tests can be conducted on separate new samples and omitted from the relevant sequence. This can only apply to the following tests when called for:

– 9.3.3.4.1, item 7) of IEC 60947-1:2020, Verification of creepage distances;

– 9.2.5 of IEC 60947-1:2020, Mechanical and electrical properties of terminals;

– Annex C of IEC 60947-1:2020, Degrees of protection of enclosed equipment.

The test sequence shall be as follows:

a) Test sequence I
   1) Verification of temperature-rise (9.3.3.3)
   2) Verification of dielectric properties (9.3.3.4)

b) Test sequence II: Operating capability verification (9.3.3.6)
   1) Thermal stability test (9.3.3.6.2)
   2) Overload capability test (9.3.3.6.3)
   3) Blocking and commutating capability test (9.3.3.6.4), including verification of operation and operating limits

c) Test sequence III

   Performance under short-circuit conditions (9.3.4)

d) Test sequence IV
   1) Verification of mechanical properties of terminals

      (see 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 (Annex C of IEC 60947-1:2020)

e) Test sequence V

   EMC tests (9.4)

f) Test sequence VI

Tripping operation test (9.3.3.6.6)

### 9.3.2 General test conditions

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

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 higher 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 applies.

##### 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 8.2.2.4, and with the following additions.~~

Subclause 9.3.3.3.4 of IEC 60947-1:2020 applies with a minimum cross-section of 1 $mm^2$ with additions as below, 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.

For semiconductor switching devices connected in the main circuit (see 8.2.2.4), 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 9.3.3.6.2.

For mechanical switching devices (see 8.2.2.5.2), 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.

Starters shall be fitted with an overload relay, complying with 5.7, and selected as follows:

– non-adjustable relay:

  the current setting shall be equal to the maximum operational current of the starter, and the test shall be at this current;

– adjustable relay:

  the maximum current setting shall be that which is nearest to, but not greater than, the maximum operational current of the starter.

For starters, the test shall be made with that overload relay for which the current setting is nearest to the maximum of its scale.

NOTE The selection method described above is designed to ensure that the temperature-rise of these field wiring terminals of the overload relay, and the power dissipated by the starter, are not less than those that will occur under any combination of relay and controller. In cases where the effect of the overload relay on these values is insignificant (as in solid-state overload relays), the test current is the maximum operational current of the starter.

#### 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 contactors or starters 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 (for example opto-coupler, 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 (3.1.2.31) 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 two last sentences modified as follows:~~

~~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 controller or starters with series mechanical switching device, across the poles of the main circuit, the line terminals being connected together and the load terminals connected together.~~

Subclause 9.3.3.4.1 3) c) of IEC 60947-1:2020 applies with the following addition:

The test voltage shall be applied for semiconductor controller or starters with series mechanical switching device, 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.

(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 Sampling tests for 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.~~

~~Sampling plans and procedure are under consideration.~~

~~(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 motor controllers and starters

The complete unit with bypass installed shall be tested as in normal service. The operational sequence, to simulate starting and stopping, shall be the same as in normal service.

If the mechanical switching devices has already fulfilled the requirements according to Table 11 and Table 12, 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:

– thermal stability test;
– overload capability test;
– 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 $U_s$.

If the controller within a starter has satisfied the requirements of a previous operating capability test, and meets the requirements for assigning ratings based on the results of test as given in 5.4.2, the starter need not be tested.

**Table 14 – Thermal stability test specifications**

| Item | 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.<br>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<br>$\Delta_n = (C_n - C_{n-1} - A_n + A_{n-1})/(C_{n-1})$ | |
| Test conditions | Table 8 | |
| EUT temperature | $C_n$, case temperature | Temperature sensing means attached to the outer surface of one semiconductor switching device (9.3.3.3.4).<br>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 | a) $\Delta_n \leq 0{,}05$ within 8 h<br>b) No visual evidence of damage (such as smoke, discoloration)<br>c) 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.<br>d) 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. | |

**Table 15 – Initial case temperature requirements**

| Operating cycle number | Initial case temperature, $C_i$ °C |
|---|---|
| 1 | Not less than 40 °C |
| 2 | Highest temperature enabling resetting after the first operating cycle of the overload relay of the starter, or the overload relay recommended by the manufacturer to be used together with the controller. |
| 3 and 4 | ≥40 °C plus the maximum case temperature-rise during the temperature-rise test (9.3.3.3) |

If 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, the effectiveness of the interlocking shall be demonstrated in accordance with 8.2.1.6.

#### 9.3.3.6.2 Thermal stability test procedure

Test specifications and acceptance criteria are given in Table 14. The test profiles are illustrated in Figure F.1.

(1) Assign a sequence number, n, to each on-load period in the test series (as $n$ = 0, 1, 2,... N-1, N).

(2) Record initial case temperature $C_0$. Record initial ambient temperature $A_0$.

(3) Set test current, $I_T$, level 1 (see Table 8). Change n to a new value where n = n+1.

(4) The time span of t commences at the instant when the test current reaches the value $I_T$. Therefore, the time for the test current controlled acceleration to reach $I_T$ increases the total test time.

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

NOTE The time span of $T_x$ commences at the instant when the test current reaches the value $X \times I_e$. Therefore, the time for the test current controlled acceleration to reach $X \times I_e$ increases the total test time.

(5) This step needs to be performed with respect to the utilization category.

a) For AC-2a, AC-3a, AC-8a only.

After time interval t (Table 8), change test current, IT, to level 2.

After time interval for level 2, switch EUT to OFF-state.

b) For AC-2b, AC-3b, AC-8b only.

After time interval t (Table 8), 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 (Table 14)

If $\Delta_n$ > 0,05, total test time is less than 8 h, and results to be obtained (a) and b) of Table 14) are not violated, repeat steps 3 to 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 a), b), c) and d) of Table 14 are not violated, end test. This is successful compliance.

#### 9.3.3.6.3 Overload capability test procedure

(1) Test conditions

a) Refer to Table 10. The test profile is represented in Figure F.2.

b) Controllers and starters, utilizing a current controlled cut-out device in addition to an overload relay to provide 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 highest value of $X$ specified for $I_e$.

c) Where the EUT is a starter, its overload relay shall be disabled. The operating cycle ON-time $t$, shall be set in accordance with c) of Table 10.

NOTE The time span of $t$ commences at the instant when the test current reaches the value $I_T$. Therefore, the time for the test current controlled acceleration 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 motor controller or starter 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 10), switch the EUT to the OFF-state.

e) Repeat steps c) and d) for the number of cycles of Table 10. End test.

In the case of the EUT having a current limit function during motor starting (and possibly stopping), but not in the FULL-ON state, the overload capability test procedure for verification of compliance of the EUT with the requirements of 8.2.4.1 is the following.

i) After two operating cycles as described above, the EUT is switched to the ON-state, and loaded with an initial test current $I_{init}$, not higher than $I_e$.

ii) With the EUT in the FULL-ON state, the test circuit specified in Table 10 is connected to the load by means of an external switch. There shall be no current interruption during transition from current $I_{init}$ to $I_T$.

iii) In accordance with Table 7, the test current $I_T$ is maintained for the time *t* before an OFF-state is established by the EUT. The EUT is, however, permitted to establish an OFF-state condition at shorter times than $t$.

iv) This operating cycle is performed twice.

The initial case temperature conditions for these required operating cycles shall be as stated in Table 15.

(4) Verify the criteria (see 9.3.3.6.4)

a) No loss of commutating capability.

b) No loss of blocking capability.

c) No loss of functionality.

d) No visual evidence of damage.

#### 9.3.3.6.4 Blocking and commutating capability test

The test profiles are shown in Figure F.3. The parameters of the induction motor and the mechanical load are given in Table 16.

**Table 16 – Minimum requirements and conditions for performance testing with an induction motor load**

| Utilization category | Test motor parameters | | | | External mechanical load parameters |
|---|---|---|---|---|---|
| | K | $U$ / $U_e$ | Power | Cos φ | |
| AC-2a<br>AC-2b | ≥ 4 | a | a | a | a |
| AC-3a<br>AC-3b | | | | | |
| AC-8a<br>AC-8b | | | | | |
| *K* ratio of locked rotor current to rated full load current of the test motor.<br>During the test, the motor and the ambient air may be at any temperature between +10 °C and +40 °C. | | | | | |
| [a] The characteristics of the induction motor test load are specified in 8.2.4.3. | | | | | |

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 % $U_s$.

With a test cycle in which the ON-time is longer than the time to achieve full voltage and full speed + 1 s and the OFF-time equal 1/3 of the time for coasting to rest.

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 motor 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.
– EUT settings are limited to only those external adjusting means provided by the manufacturer in the normal product offerings.
  a) Controllers fitted with a current-limit function will be set at the lowest value of $X$ that will allow the motor (as defined in Table 16) to start.
  b) Controllers fitted with controlled acceleration will be set at the maximum ramping time or 10 s, whichever is less.
– Initial values of starting current and/or starting voltage will be set at the minimum value that will allow the motor to start immediately.

Results to be obtained

a) a1) or a2) shall be fulfilled
  a1) $I_O$ < 1 mA and $I_F$ < 1 mA
  a2) if $I_O$ > 1 mA or $I_F$ > 1 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.
b) No visual evidence of damage (such as smoke, discoloration).
c) No loss of functionality as specified by the manufacturer.

For semiconductor motor controller or starter 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 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 $U_e$ and $U_s$ 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, $I_0$.

   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 voltages $U_e$ and $U_s$ (as specified above) 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-state and OFF-state as specified above. If the 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 $U_e$ and $U_s$ 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, $I_0$.

8) Determine the values regarding the OFF-state currents through each pole as specified under item a) above.

To obtain successful compliance, the criteria given under item a), b) and c) shall be fulfilled.

#### 9.3.3.6.5 Behaviour of the controller or starter during, and condition after, the operating capability tests

a) Commutating capability

   If semiconductor devices do not commutate 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

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

#### 9.3.3.6.6 Relays and releases

a) Operation of under-voltage relays and releases

Under-voltage relays or releases shall be tested for compliance by a drop-out test from the rated control supply voltage of the relay or release at a rate to reach 0 V in approximately 30 s. The relay or release shall operate according to 8.2.1.3 of IEC 60947-1:2020.

b) Shunt-coil operated releases

Vacant.

c) Thermal and electronic overload relays

Overload relays and starters shall be connected using conductors in accordance with Tables 9, 10 and 11 of IEC 60947-1:2020 for test currents corresponding to:

– 100 % of the current setting of the overload relay for overload relays of trip classes 2, 3, 5 and 10A for all overload relay types (see Table 4) and 10, 20, 30 and 40 for electronic overload relay types;

– 125 % of the current setting of the overload relay for thermal overload relays of trip classes 10, 20, 30 and 40 (see Table 4) and for overload relays for which a maximum tripping time greater than 40 s is specified (see 5.7.3).

It shall be verified that relays and releases operate according to the requirements of 8.2.1.5.1.1.1 with all poles energized.

Moreover, the characteristics defined in 8.2.1.5.1 shall be verified by tests at 0 °C, +20 °C, +40 °C (see Figure 4) and may be verified at minimum and maximum temperatures given by the manufacturer if larger. However, for relays or releases declared compensated for ambient temperature, in case of temperature range declared by the manufacturer larger than those given in Table 4, the characteristics at 0 °C and/or +40 °C need not be verified if, when tested at the declared minimum and maximum temperatures, the corresponding tripping current values are in compliance with the limits specified for 0 °C and/or +40 °C in that Table 4.

For electronic overload relays, the thermal memory test verification of 8.2.1.5.1.1.2 shall be carried out at +20 °C.

Three-pole thermal or electronic overload relays energized on two poles only shall be tested as stated in ~~8.2.1.5.2~~ 8.2.1.5.1.2 on all combinations of poles and at the maximum and minimum current settings for relays with adjustable settings.

**d) Under-current relays**

The limits of operation shall be verified in accordance with 8.2.1.5.3.

e) Stall sensitive electronic overload relays

The limits of operation shall be verified in accordance with 8.2.1.5.4.

For stall sensitive electronic overload relays, the verification shall be made for the minimum and for the maximum set current values and for the minimum and maximum stall inhibit time (four settings).

For stall sensitive electronic overload relays operating in conjunction with a rotation sensing means, the verification shall be made for the minimum and maximum stall inhibit time. The sensor can be simulated by an appropriate signal on the sensor input of the stall sensitive electronic overload relay.

f) Jam sensitive electronic overload relays

The limits of operation shall be verified in accordance with 8.2.1.5.5.

The verification shall be made for the minimum and for the maximum set current values and for the minimum and maximum jam inhibit time (four settings).

For each of the four settings, the test shall be made under the following conditions:

– apply a test current of 95 % of the set current value. The jam sensitive electronic overload relay shall not trip;

– increase the test current to 120 % of the set current value. The jam sensitive electronic overload relay shall trip according to the requirements given in 8.2.1.5.5.

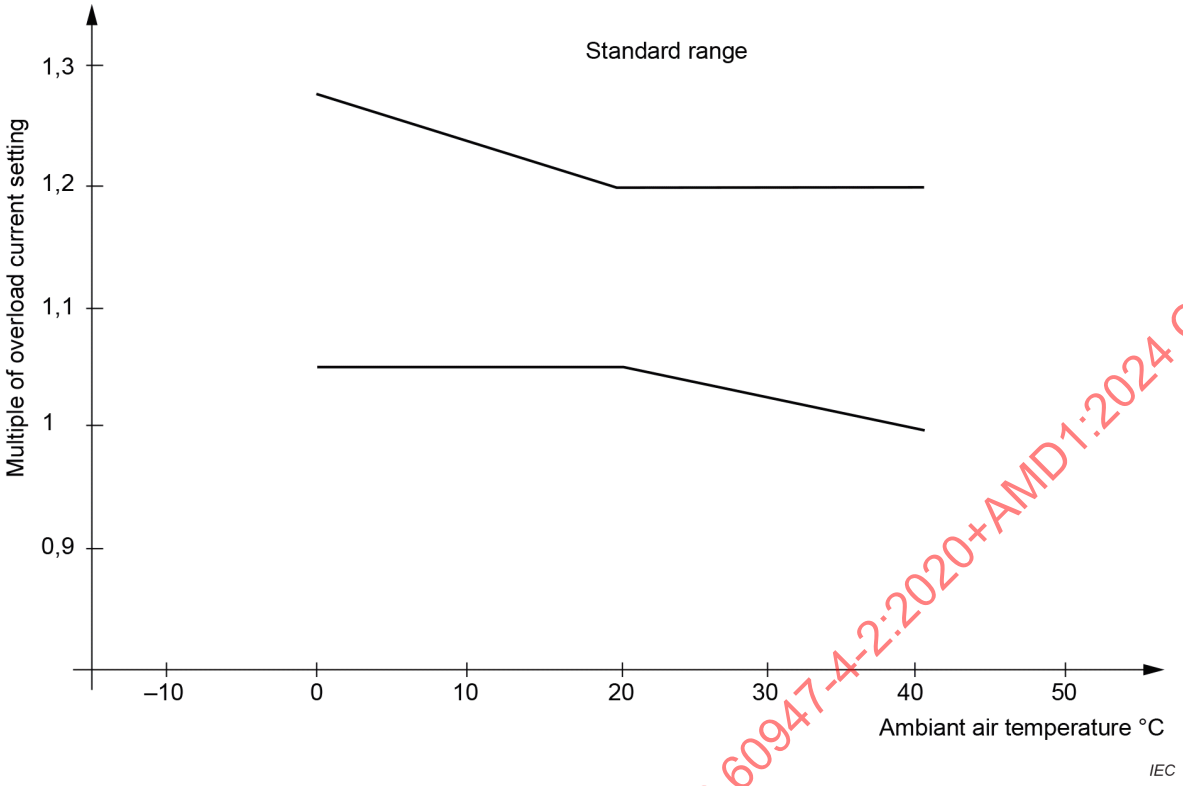



**Figure 4 – Multiple of current setting limits for ambient air temperature compensated time-delay overload relays**

### 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 controller/starter shall be sustained in the ON-state by a dummy motor 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 controller/starter. The short-circuit current is applied to the controller/starter by closing the shorting switch. The SCPD shall interrupt the short-circuit current and the controller/starter shall withstand the let-through current;

– CO operation for direct-on-line semiconductor motor controller or direct-on-line semiconductor starter.

~~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 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 the device has not been evaluated 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 $mm^2$ 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~~ to one of the poles of polyphase equipment. In the case of pole connection, the pole shall be alternated for the successive tests of the test sequence.

NOTE 1 This larger size of wire is not used as a detector but to establish an earth condition allowing the damage to be evaluated.

NOTE 2 Existing device tested according to edition 3 of this document, using a fuse element F, does not need to be re-evaluated according to this subclause.

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 such that the output devices are actuated to a FULL-ON state independent of any loading;

b) a squirrel cage motor with the characteristics that are given in 8.2.4.3 as a dummy load;

c) a resistive or resistive-inductive load connected to the output terminals of the EUT such that enough loading is provided to actuate the output devices. This load shall have the characteristics given in 8.2.4.3.

For b) and c), 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 controller or the starter 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 controller or starter) for each main circuit. The cables length may exceed 2,4 m when they are in the circuit during calibration.

If the SCPD is separate from the controller or starter, it shall be connected to the starter 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) or c) 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 T0).

b) the test voltage is then applied and the dummy motor load shall limit the current to a level that is, at least, sufficient to maintain the controller in the ON-state (time T1).

c) at any arbitrary time after the current through the controller has stabilized, the shorting switch may then be closed at random and thereby establish a short-circuit current path through the EUT (time T2) which shall be cleared by the SCPD (time T3).

#### 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 controllers and starters

#### 9.3.4.3.1 General

The semiconductor motor controller or starter 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 motor controllers or starters shall be submitted to two separate short-circuit tests in accordance with 9.3.4. Test 2 is not required for bypassed semiconductor motor controllers 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 are to 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 is a circuit-breaker with an adjustable current setting, the test shall be carried out with the circuit-breaker adjusted to the maximum setting for type 1 coordination and to the maximum declared setting for type 2 coordination.

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.

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 coordination and to the maximum declared setting for type 2 coordination.

The O operation shall be performed with the sample at $I_q$.

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

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, IEC 60269-1:2006/AMD2:2014) and the maximum let-through $I^2t$ values.

Except for direct on-line controllers or starters, one breaking operation of the SCPD shall be performed with the controller or starter 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 controllers or starters, one breaking operation of the SCPD shall be performed by closing the controller or starter on to the short-circuit.

#### 9.3.4.3.3 Results to be obtained

The controller or starter 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.

Both types of coordination

a) the fault current has been successfully interrupted by the SCPD or the starter. In addition, the fuse or 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 controller and overload relay is acceptable. The starter or the controller may be inoperative after the test.

Type 2 coordination

f) 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 motor controllers and starters 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 10 for the declared utilization category by carrying out 10 operating cycles (instead of 3).

g) the tripping of the overload relay shall be verified at a multiple of the current setting and shall conform to the published tripping operation characteristics, according to 5.7, both before and after the short-circuit test.

h) the adequacy of the insulation shall be verified by a dielectric test on the controller or starter. 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 soft-starters comprise similar control electronics and sensors, within similar frame sizes, it is only necessary to test a single representative sample of the soft-starter.

When a radiocommunication device is embedded into the equipment, Clause 9 of IEC 63404:2024 applies.

A motor is required for the purpose of testing. Except for the purposes of the harmonic emission test, it is not necessary to load the motor. ~~Unless otherwise specified by the manufacturer, the length of the connections to the motor shall be 3 m.~~ The length of the connections to the motor shall be 3 m or the value specified in the instruction manual of the equipment.

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 starter or controller in order to comply with immunity or emission requirements, it shall be included in the report and the instruction manual.

The tests shall be carried out in a reproducible manner.

Semiconductor motor controllers and starters with motor overload protection, 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 ~~chosen by the manufacturer~~ to represent the operation of the controller or starter at the points of sustained maximum emission or susceptibility (see 9.4.2).

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

NOTE 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, relevant result of measurement can only be obtained in steady-state conditions.

### 9.4.2 EMC immunity tests

#### 9.4.2.1 Electrostatic discharges

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

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

The controller or starter shall comply with performance criterion 2 of Table 13.

Tests are not possible if the controller or starter is an open frame or chassis unit, or of degree of protection IP00. In that 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 performance criterion 1 of Table 13.

For radiated radio-frequency electromagnetic field immunity tests, 9.4.2.3 of IEC 60947-1:2020 applies with the performance criterion 1 of Table 13.

#### 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 controller or starter shall comply with the performance criterion 2 of Table 13.

#### 9.4.2.4 Surges (1,2/50 µs-8/20 µs)

Subclause 9.4.2.6 of IEC 60947-1:2020 applies.

The controller or starter shall comply with the performance criterion 2 of Table 13.

#### 9.4.2.5 Harmonics ~~and commutation notches~~ in the supply

~~No requirement, the test levels are under study for the future.~~

For soft-starter with electronic overload relay, in order to avoid unwanted tripping, the true RMS response shall be verified up to the fifth harmonic component at 50 % of the fundamental component:

– by test according to F.4.1 of IEC 60947-2:2016, if applicable; or

NOTE 1 This test method is applicable when current harmonics can be injected on separated current circuits from the supply of the controller.

– by simulation, using models for which the validity has to be demonstrated; or
– by design assessment, i.e. confirmation of the correct application of calculations and design rules, including use of appropriate safety margins.

NOTE 2 Current waveform asymmetry, typically in case of failure of a power semiconductor connected on the network, is creating a significant unbalance and can affect the current detection of an electronic overload protection and therefore a true RMS measurement is relevant.

#### 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 13 except for the 0,5 cycle and 1 cycle for which the performance criterion 2 of Table 13 applies.~~

This test shall be performed in accordance with IEC 61000-4-11 for rated current less than 16 A and in accordance with IEC 61000-4-34 for rated current higher than 16 A and with the performance criterion 3 of Table 13 except for the 0,5 cycle and 1 cycle for which the performance criterion 2 of Table 13 applies.

### 9.4.3 EMC emission tests

#### 9.4.3.1 Condition for the emission tests

The description of the test, the test method and the test set-up are given in Clause 7 of CISPR 11:2015/AMD1:2016 with the exclusion of the first and second paragraphs of its subclause 7.1.

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

If an EMC filter is required to fulfil the emission levels given in Table 17, it shall be specified.

~~NOTE 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, relevant result of measurement can only be obtained in steady-state conditions.~~

#### 9.4.3.2 Conducted radio frequency emission test

~~Descriptions of the test, the test method and the test set-up are given in CISPR 11.~~

It shall be sufficient to test two samples from a range of controllers of different power ratings which represent the highest and lowest power ratings of the range.

The emission shall not exceed the levels given in Table 17.

~~The addition of high-frequency common mode filtering in the main power connections may cause unacceptable reductions in motor starting torque, or render invalid the concept of unearthed or high impedance earthed distribution systems, as employed within process industries, with implications for system safety.~~

~~If, in order to fulfil the emission levels given in Table 17, filters are necessary but are not used for the above reasons, other precautions shall be taken in order not to exceed the emission levels given in this table.~~

**Table 17 – 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 – 0,50 | 79 | 66 | 100 | 90 | 130 | 120 | 66 to 56 [d] | 56 to 46 [d] |
| 0,50 – 5 | 73 | 60 | 86 | 76 | 125 | 115 | 56 | 46 |
| 5 – 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 shall apply.

~~NOTE 2~~ For controller and starter 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 may be applied.

[a] These limits apply to controller and starter 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 controller and starter 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 controller and starter. In particular it shall be indicated that this controller or starter 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 controller and starter 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 controller or starter meets the disturbance voltage limits for high power electronic controller and starter 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 controller or starter 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.~~
- information on installation measures to be applied by the installer shall be provided.

[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 60947-1:2020.

NOTE 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. See Annex G.

#### 9.4.3.3 Radiated radio frequency emission test

~~Descriptions 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~~ mW are exempt from RF emission tests.

It shall be sufficient to test a single representative sample from a range of controllers or starters of different power ratings.

The emission shall not exceed the levels given in Table 18.

**Table 18 – 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 |

[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).

## 9.5 Routine and sampling tests

### 9.5.1 General

Routine tests are tests to which each individual controller or starter 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 overload relay 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

The two following tests shall be carried out.

1) Functionality shall be verified by a blocking and commutating capability test according to 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.

2) It shall be verified that the equipment operates according to the requirements of 8.2.1.5.

   Tests shall be made to verify the calibration of relays. In the case of a time-delay overload relay, this may be a single test with all poles equally energized at a multiple of the current setting, to check that the tripping time conforms (within tolerances) to the curves supplied by the manufacturer. For under-current relays, stall sensitive electronic overload relays and jam sensitive electronic overload relays, tests shall be carried out to verify the proper operation of these relays (see 8.2.1.5.3, 8.2.1.5.4 and 8.2.1.5.5).

### 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 sequences 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.

# 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 starters

### 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 (see Table A.1).

**Table A.1 – Main circuit terminal markings**

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

For particular types of controllers or starters (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 with the following additions.

#### A.2.2.2 Auxiliary circuits and input/output signal terminals

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

## A.3 Marking and identification of terminals of overload relays

L.4 of IEC 60947-1:2020 applies.

# Annex B
(xxx)

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# Annex C
(normative)

# Coordination at the crossover current between the starter and associated SCPD

## C.1 General and definitions

### C.1.1 General

This annex states different methods of verifying the performance of starters and the associated SCPD(s) at currents below and above the intersection $I_{co}$ of their respective time-current characteristics, provided by the starter and SCPD manufacturer(s), and the corresponding types of coordination described in 8.2.5.1.

Coordination at the crossover current between the starter and the SCPD can be verified either by the direct method with the special test of Clause C.2 or, for type "2" coordination, by the indirect method as in Clause C.5.

### C.1.2 Terms and definitions

**C.1.2.1**
**crossover current**
**$I_{co}$**
current corresponding to the crossover point of the mean or published curves representing the time-current characteristics of the overload relay and the SCPD respectively

Note 1 to entry: The mean curves are the curves corresponding to the average values calculated from the tolerances on the time-current characteristics given by the manufacturer.

**C.1.2.2**
**test current**
**$I_{cd}$**
test current greater than $I_{co}$, tolerances included, designated by the manufacturer and verified by the requirements given in Table C.1

**C.1.2.3**
**time-current withstand characteristic capability of controllers/starters**
locus of the currents a controller/starter can withstand as a function of time

## C.2 Condition for the test for the verification of coordination at the crossover current by a direct method

The starter and its associated SCPD shall be mounted and connected as in normal use. All the tests shall be performed starting from the cold state.

## C.3 Test currents and test circuits

The test circuit shall be according to 9.3.3.5.2 of IEC 60947-1:2020 except that the oscillatory transient voltage need not be adjusted. The currents for the tests shall be as follows:

(i) 0,75 $I_{co}$ $^{0}_{-5}$ % and

(ii) 1,25 $I_{co}$ $^{+5}_{0}$ %.

The power factor of the test circuit shall be in accordance with Table 10. In the case of small relays having a high resistance, inductors should be mainly used in order to have a value of power factor as low as possible. The recovery voltage shall be 1,05 times the rated operational voltage.

The SCPD shall be as stated in 8.2.5.1 and of the same rating and characteristics as used in the tests of 9.3.4.3.

The starter shall be connected so that it opens when the overload relay operates. Coils, if any, shall be energized from a separate source at the rated control circuit supply voltage.

## C.4 Test procedure and results to be obtained

### C.4.1 Test procedure

With the starter and the SCPD closed, the test currents stated in Clause C.3 shall be applied by a separate closing device. In each case the device tested shall be at room temperature.

After each test, it is necessary to inspect the SCPD, reset the overload relay and the release of the circuit-breaker, if necessary, or to replace all fuses if at least one of them has melted.

### C.4.2 Results to be obtained

After the test at the lower current (i) in Clause C.3, the SCPD shall not have operated and the overload relay or release shall have operated to open the starter. There shall be no damage to the starter.

After the test at the higher current (ii) in Clause C.3, the SCPD shall have operated before the starter. The starter shall meet the conditions of 9.3.4.3.2 for the type of coordination stated by the manufacturer.

## C.5 Verification of coordination at the crossover current by an indirect method for type "2" coordination

### C.5.1 General

~~NOTE For type "1" coordination, the indirect method can be different from the method described in this annex and is under consideration. For this reason, the indirect method for the verification of coordination at the crossover point is only applicable for type "2" coordination.~~

The indirect method consists in verifying on a diagram (see Figure C.1) that the following conditions for the verification of coordination at the crossover current are met:

– the time-current characteristic of the overload relay/release, starting from cold state, supplied by the manufacturer, shall indicate how the tripping time varies with the current up to a value of at least $I_{co}$; this curve has to lie below the time-current characteristic of the SCPD up to $I_{co}$;
– $I_{cd}$ of the starter, tested as in C.5.2, shall be higher than $I_{co}$;
– the time-current withstand characteristic of the controller, tested as in C.5.3, shall be above the time-current characteristic (starting from cold state) of the overload relay up to $I_{co}$.

### C.5.2 Test for $I_{cd}$

Subclause 9.3.4.1 applies with the following addition.

– Test procedure: the controller or starter shall make and break the test current ($I_{cd}$) for the number of operating cycles given in Table C.1. This is made without the SCPD in the circuit.

**Table C.1 – Test conditions**

| | $U_r/U_e$ | Cos $\phi$ | ON-time (see NOTE 2) s | OFF-time s | Number of operations |
|---|---|---|---|---|---|
| $I_{cd}$ | 1,05 | See NOTE 1 | 0,05 | See NOTE 3 | 3 |
| NOTE 1 Power factor to be selected according to Table 16 of: IEC 60947-1:2020.<br>NOTE 2 Time may be less than 0,05 s provided that contacts, if any, are allowed to become properly seated before re-opening.<br>NOTE 3 See Table 10. | | | | | |

– Behaviour of controllers or starters during and after the $I_{cd}$ test:

a) during the test, there shall be no permanent arcing, no flash-over between poles, no blowing of the fusible element in the earth circuit (see 9.3.4.1.2) and no welding of contacts;

b) after the test,

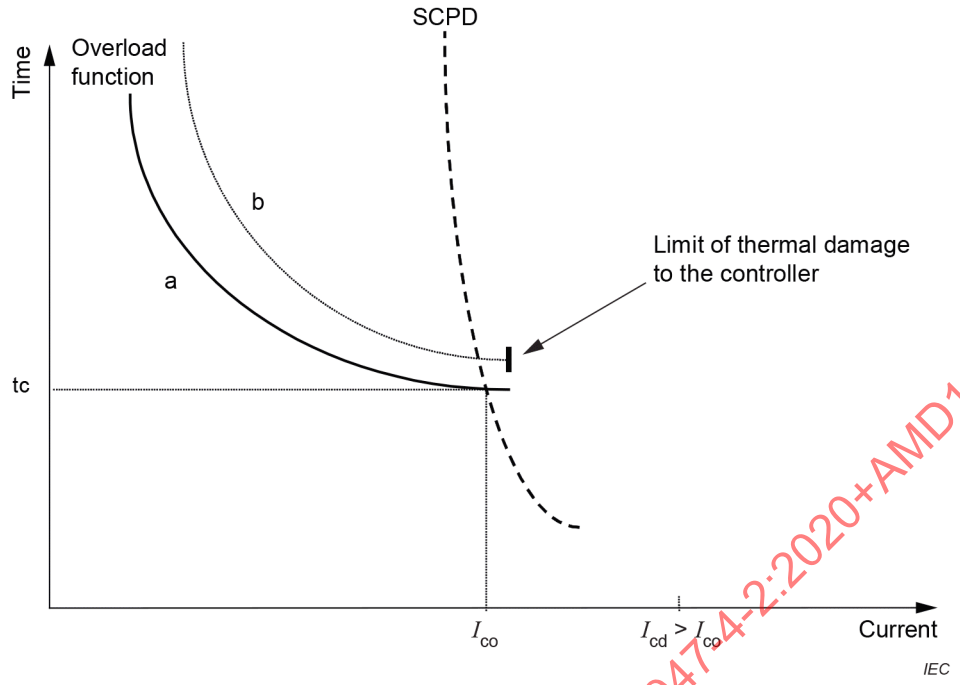
1) the controller or starter shall operate correctly when switched by the applicable method of control;

2) the dielectric properties of the controller and starter shall be verified by a dielectric test on the controller or starter using an essentially sinusoidal test voltage of twice the rated operational voltage $U_e$ used for the $I_{cd}$ test, with a minimum of 1 000 V. The test voltage shall be applied for 5 s, as specified in 9.3.3.4.1, items (2) c) i) and (2) c) ii).

### C.5.3 Time-current characteristic withstand capability of controllers/starters

This characteristic is issued by the manufacturer at least up to $I_{co}$.

This characteristic is valid for overload currents, starting with the controller/starter at room temperature. The minimum cooling duration required by the controller/starter between two such overload tests should be stated by the manufacturer.

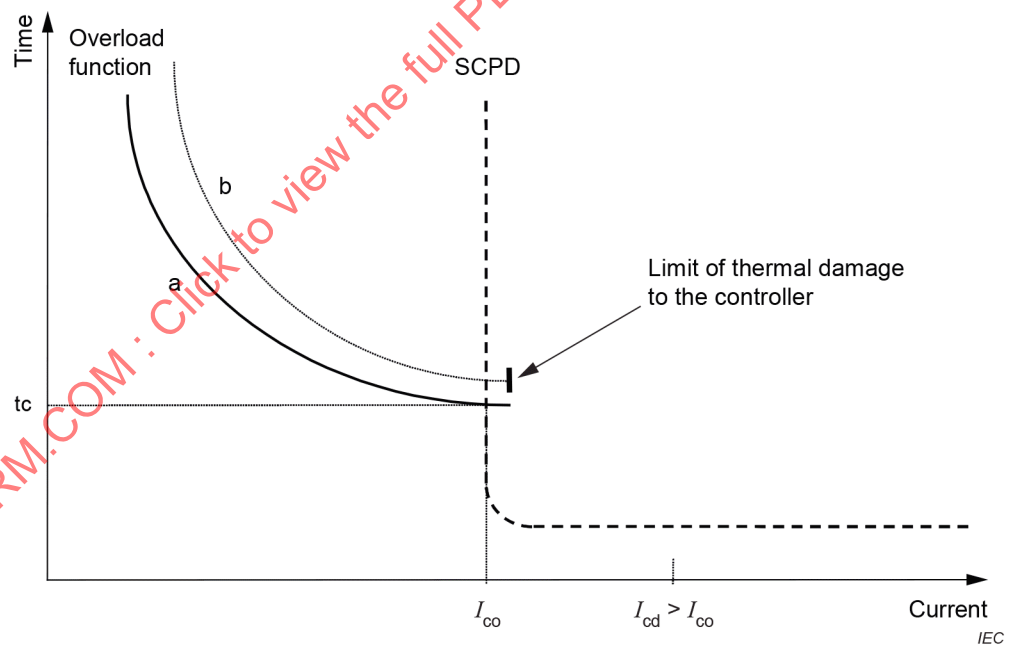



**Key**

a mean overload time-current characteristic from cold state

b time-current characteristic withstand capability of controller

**a) Coordination with fuse**




**Key**

a mean overload relay time-current characteristic from cold state

b time-current characteristic withstand capability of controller

**b) Coordination with circuit-breaker**

**Figure C.1 – Examples of time-current withstand characteristic**

# Annex D
(xxx)

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# Annex E
(xxx)

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# Annex F
(informative)

## Operating capability

The three operating capability test profiles required in 9.3.3.6 are illustrated by Figure F.1 for the thermal stability, Figure F.2 for the overload capability, and Figure F.3 for the blocking and commutating capability.

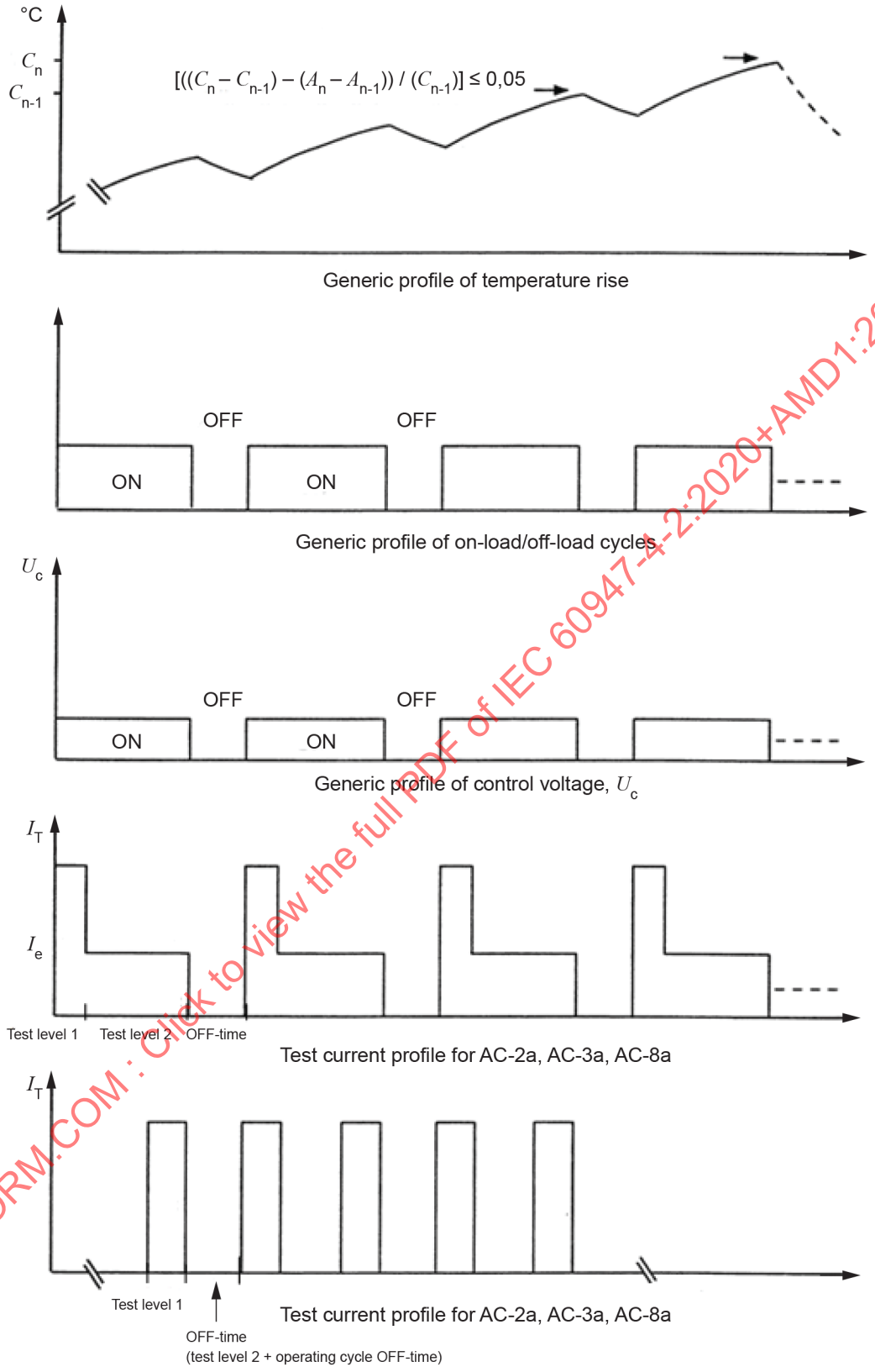


**Figure F.1 – Thermal stability test profile**

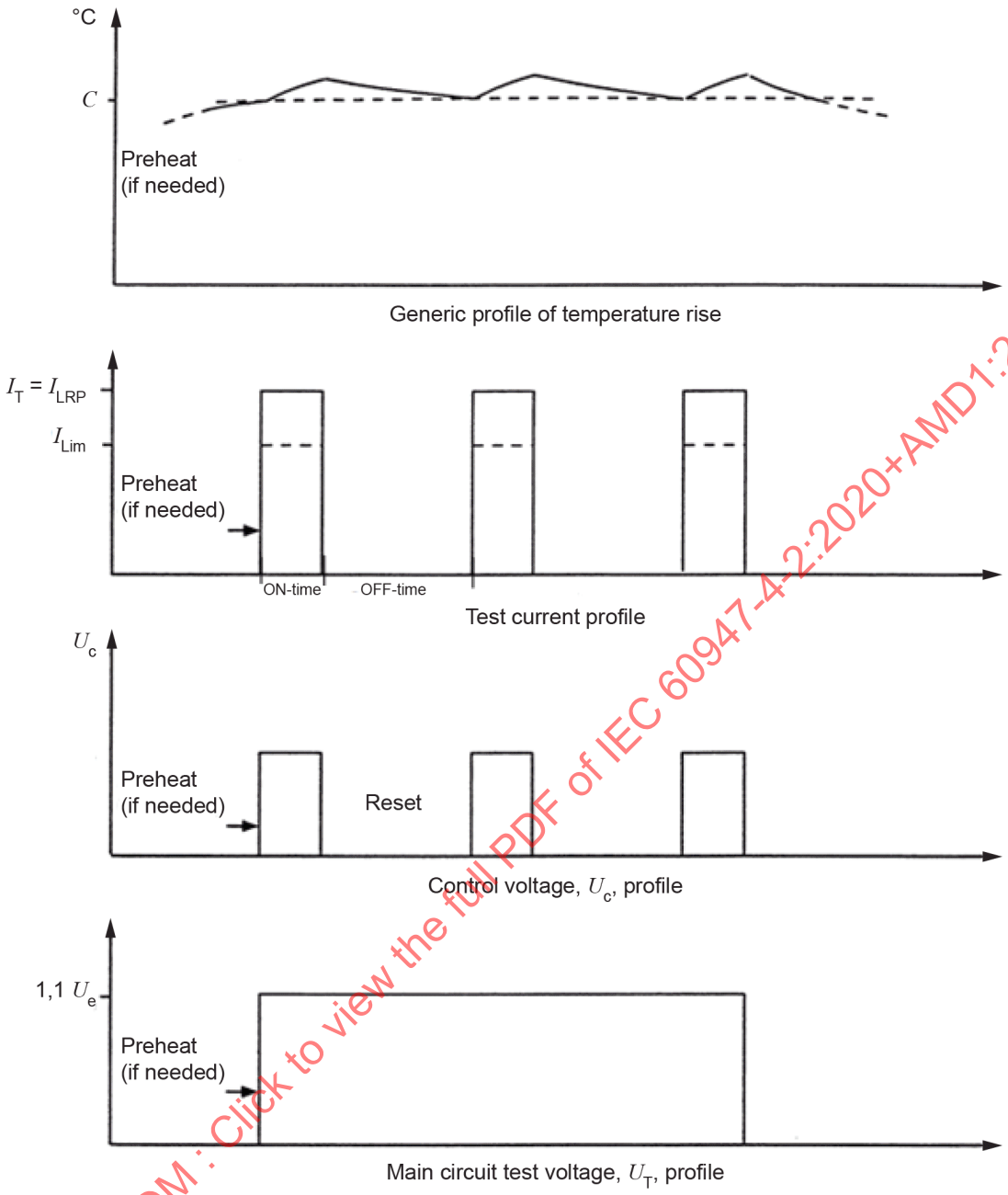


**Figure F.2 – Overload capability test profile**

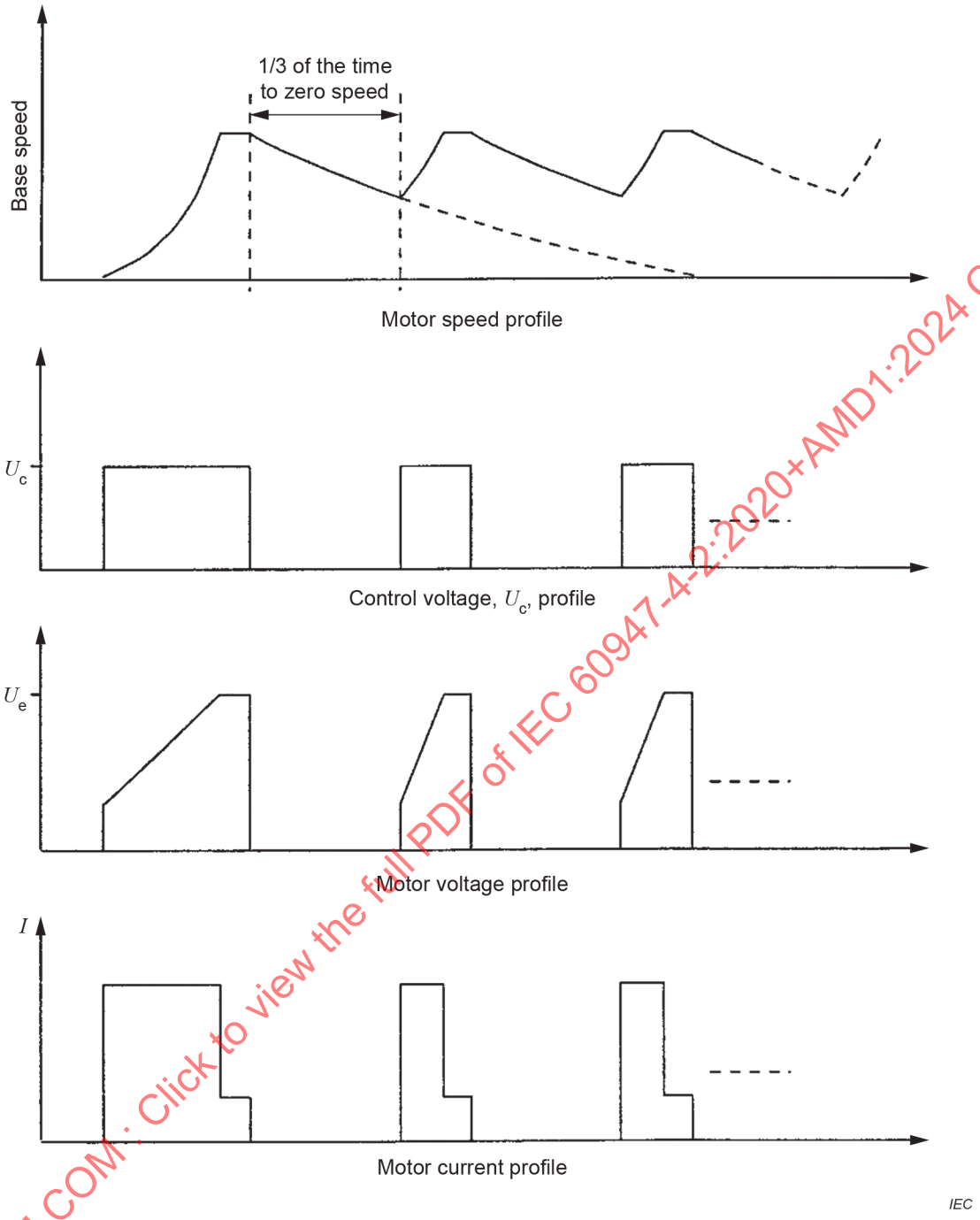


**Figure F.3 – Blocking and commutating capability test profile**

# Annex G
(informative)

# Rated operational currents and rated operational powers of switching devices for electrical motors

## G.1 General

The given values in Table G.1 are guide values for the relationship between rated operational currents and rated operational powers. They should be considered for use when information concerning products has to be given to the customer.

The statements of this annex are applicable to all kind of switching devices for electrical motors.

The figures are harmonized within the IEC and therefore state the basis for all the product information given by the manufacturer.

The values given in the Table G.1 are typical rated operational currents (±5 %) of motors for the corresponding rated operational powers. Design NE and HE motors are within the given variation of ±5 %.

If the devices are in compliance with these values, they are able to switch on and off most of the existing electrical motors.

These values state a harmonized guideline for design of switching devices

## G.2 Rated operational powers and rated operational currents

Rated operational power is linked with individual rated operational currents at different voltages according to Table G.1.

The guide values for rated operational currents are determined on the basis of a four-pole squirrel-cage motor at 400 V, 1 500 $min^{-1}$ and 50 Hz. The rated operational currents for the other voltages are calculated on the basis of values at 400 V.

## Table G.1 – Rated operational powers and rated operational currents of motors

| Rated operational power | | Guide values of rated operational currents at | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW [a] | hp [b] | 110 V to120 V | 200 V | 208 V | 230 V | 220 V to 240 V | 380 V to 415 V | 400 V | 440 V to 480 V | 500 V | 550 V to 600 V | 690 V |
| | | A | A | A | A | A | A | A | A | A | A | A |
| 0,06 | – | – | – | – | 0,35 | – | – | 0,20 | – | 0,16 | – | 0,12 |
| 0,09 | – | – | – | – | 0,52 | – | – | 0,30 | – | 0,24 | – | 0,17 |
| 0,12 | – | – | – | – | 0,70 | – | – | 0,44 | – | 0,32 | – | 0,23 |
| 0,18 | – | – | – | – | 1,0 | – | – | 0,60 | – | 0,48 | – | 0,35 |
| 0,25 | – | – | – | – | 1,5 | – | – | 0,85 | – | 0,68 | – | 0,49 |
| 0,37 | – | – | – | – | 1,9 | – | – | 1,10 | – | 0,88 | – | 0,64 |
| – | 1/2 | 4,4 | 2,5 | 2,4 | – | 2,2 | 1,3 | – | 1,1 | – | 0,9 | – |
| 0,55 | – | – | – | – | 2,6 | – | – | 1,5 | – | 1,2 | – | 0,87 |
| – | 3/4 | 6,4 | 3,7 | 3,5 | – | 3,2 | 1,8 | – | 1,6 | – | 1,3 | – |
| – | 1 | 8,4 | 4,8 | 4,6 | – | 4,2 | 2,3 | – | 2,1 | – | 1,7 | – |
| 0,75 | – | – | – | – | 3,3 | – | – | 1,9 | – | 1,5 | – | 1,1 |
| 1,1 | – | – | – | – | 4,7 | – | – | 2,7 | – | 2,2 | – | 1,6 |
| – | 1-1/2 | 12,0 | 6,9 | 6,6 | – | 6,0 | 3,3 | – | 3,0 | – | 2,4 | – |
| – | 2 | 13,6 | 7,8 | 7,5 | – | 6,8 | 4,3 | – | 3,4 | – | 2,7 | – |
| 1,5 | – | – | – | – | 6,3 | – | – | 3,6 | – | 2,9 | – | 2,1 |
| 2,2 | – | – | – | – | 8,5 | – | – | 4,9 | – | 3,9 | – | 2,8 |
| – | 3 | 19,2 | 11,0 | 10,6 | – | 9,6 | 6,1 | – | 4,8 | – | 3,9 | – |
| 3,0 | – | – | – | – | 11,3 | – | – | 6,5 | – | 5,2 | – | 3,8 |
| 4 | – | – | – | – | 15 | – | – | 8,5 | – | 6,8 | – | 4,9 |
| – | 5 | 30,4 | 17,5 | 16,7 | – | 15,2 | 9,7 | – | 7,6 | – | 6,1 | – |
| 5,5 | – | – | – | – | 20 | – | – | 11,5 | – | 9,2 | – | 6,7 |
| – | 7-1/2 | 44,0 | 25,3 | 24,2 | – | 22,0 | 14,0 | – | 11,0 | – | 9,0 | – |
| – | 10 | 56,0 | 32,2 | 30,8 | – | 28,0 | 18,0 | – | 14,0 | – | 11,0 | – |
| 7,5 | – | – | – | – | 27 | – | – | 15,5 | – | 12,4 | – | 8,9 |
| 11 | – | – | – | – | 38,0 | – | – | 22,0 | – | 17,6 | – | 12,8 |
| – | 15 | 84 | 48,3 | 46,2 | – | 42,0 | 27,0 | – | 21,0 | – | 17,0 | – |
| – | 20 | 108 | 62,1 | 59,4 | – | 54,0 | 34,0 | – | 27,0 | – | 22,0 | – |
| 15 | – | – | – | – | 51 | – | – | 29 | – | 23 | – | 17 |
| 18,5 | – | – | – | – | 61 | – | – | 35 | – | 28 | – | 21 |
| – | 25 | 136 | 78,2 | 74,8 | – | 68 | 44 | – | 34 | – | 27 | |

| Rated operational power | | Guide values of rated operational currents at | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW [a] | hp [b] | 110 V to120 V<br>A | 200 V<br>A | 208 V<br>A | 230 V<br>A | 220 V to 240 V<br>A | 380 V to 415 V<br>A | 400 V<br>A | 440 V to 480 V<br>A | 500 V<br>A | 550 V to 600 V<br>A | 690 V<br>A |
| 22 | – | – | – | – | 72 | – | – | 41 | – | 33 | – | 24 |
| – | 30 | 160 | 92 | 88 | – | 80 | 51 | – | 40 | – | 32 | – |
| – | 40 | 208 | 120 | 114 | – | 104 | 66 | – | 52 | – | 41 | – |
| 30 | – | – | – | – | 96 | – | – | 55 | – | 44 | – | 32 |
| 37 | – | – | – | – | 115 | – | – | 66 | – | 53 | – | 39 |
| – | 50 | 260 | 150 | 143 | – | 130 | 83 | – | 65 | – | 52 | – |
| – | 60 | – | 177 | 169 | – | 154 | 103 | – | 77 | – | 62 | – |
| 45 | – | – | – | – | 140 | – | – | 80 | – | 64 | – | 47 |
| 55 | – | – | – | – | 169 | – | – | 97 | – | 78 | – | 57 |
| – | 75 | – | 221 | 211 | – | 192 | 128 | – | 96 | – | 77 | – |
| – | 100 | – | 285 | 273 | – | 248 | 165 | – | 124 | – | 99 | – |
| 75 | – | – | – | – | 230 | – | – | 132 | – | 106 | – | 77 |
| 90 | – | – | – | – | 278 | – | – | 160 | – | 128 | – | 93 |
| – | 125 | – | 359 | 343 | – | 312 | 208 | – | 156 | – | 125 | – |
| 110 | – | – | – | – | 340 | – | – | 195 | – | 156 | – | 113 |
| – | 150 | – | 414 | 396 | – | 360 | 240 | – | 180 | – | 144 | – |
| 132 | – | – | – | – | 400 | – | – | 230 | – | 184 | – | 134 |
| – | 200 | – | 552 | 528 | – | 480 | 320 | – | 240 | – | 192 | – |
| 150 | – | – | – | – | – | – | – | – | – | – | – | – |
| 160 | – | – | – | – | 487 | – | – | 280 | – | 224 | – | 162 |
| 185 | – | – | – | – | – | – | – | – | – | – | – | – |
| – | 250 | – | – | – | – | 604 | 403 | – | 302 | – | 242 | – |
| 200 | – | – | – | – | 609 | – | – | 350 | – | 280 | – | 203 |
| 220 | – | – | – | – | – | – | – | – | – | – | – | – |
| – | 300 | – | – | – | – | 722 | 482 | – | 361 | – | 289 | – |
| 250 | – | – | – | – | 748 | – | – | 430 | – | 344 | – | 250 |
| 280 | – | – | – | – | – | – | – | – | – | – | – | – |
| – | 350 | – | – | – | – | 828 | 560 | – | 414 | – | 336 | – |
| – | 400 | – | – | – | – | 954 | 636 | – | 477 | – | 382 | – |
| 300 | – | – | – | – | – | – | – | – | – | – | – | – |

| Rated operational power | | Guide values of rated operational currents at | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW [a] | hp [b] | 110 V to120 V | 200 V | 208 V | 230 V | 220 V to 240 V | 380 V to 415 V | 400 V | 440 V to 480 V | 500 V | 550 V to 600 V | 690 V |
| | | A | A | A | A | A | A | A | A | A | A | A |
| 315 | – | – | – | – | 940 | – | – | 540 | – | 432 | – | 313 |
| – | 450 | – | – | – | – | 1 030 | – | – | 515 | – | 412 | – |
| 335 | – | – | – | – | – | – | – | – | – | – | – | – |
| 355 | – | – | – | – | 1 061 | – | – | 610 | – | 488 | – | 354 |
| – | 500 | – | – | – | – | 1 180 | 786 | – | 590 | – | 472 | – |
| 375 | – | – | – | – | – | – | – | – | – | – | – | – |
| 400 | – | – | – | – | 1 200 | – | – | 690 | – | 552 | – | 400 |
| 425 | – | – | – | – | – | – | – | – | – | – | – | – |
| 450 | – | – | – | – | – | – | – | – | – | – | – | – |
| 475 | – | – | – | – | – | – | – | – | – | – | – | – |
| 500 | – | – | – | – | 1 478 | – | – | 850 | – | 680 | – | 493 |
| 530 | – | – | – | – | – | – | – | – | – | – | – | – |
| 560 | – | – | – | – | 1 652 | – | – | 950 | – | 760 | – | 551 |
| 600 | – | – | – | – | – | – | – | – | – | – | – | – |
| 630 | – | – | – | – | 1 844 | – | – | 1 060 | – | 848 | – | 615 |
| 670 | – | – | – | – | – | – | – | – | – | – | – | – |
| 710 | – | – | – | – | 2 070 | – | – | 1 190 | – | 952 | – | 690 |
| 750 | – | – | – | – | – | – | – | – | – | – | – | – |
| 800 | – | – | – | – | 2 340 | – | – | 1 346 | – | 1 076 | – | 780 |
| 850 | – | – | – | – | – | – | – | – | – | – | – | – |
| 900 | – | – | – | – | 2 640 | – | – | 1 518 | – | 1 214 | – | 880 |
| 950 | – | – | – | – | – | – | – | – | – | – | – | – |
| 1 000 | – | – | – | – | 2 910 | – | – | 1 673 | – | 1 339 | – | 970 |

[a] Preferred rated values according to IEC 60072-1:1991 (primary series).

[b] Horsepower and currents values according to NFPA 70, National Electrical Code and CSA C22.1 Canadian Electrical Code.

# Annex H
(xxx)

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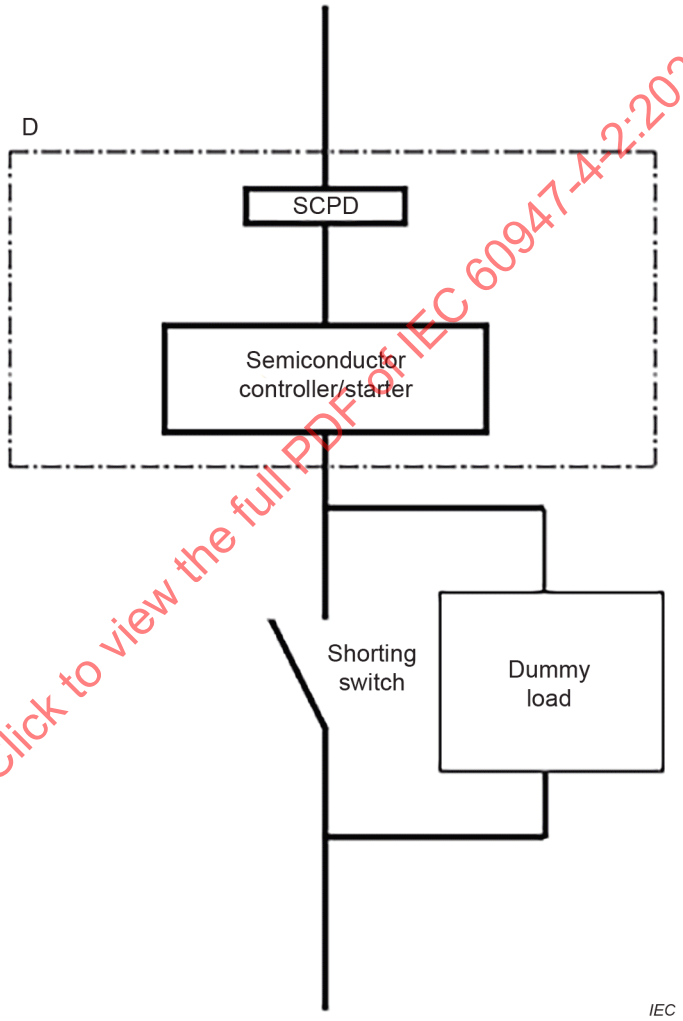
# Annex I
(normative)

## Modified test circuit for short-circuit testing of semiconductor motor controllers and starters

The standard circuits for short-circuit tests are illustrated in Figures 9 to 12 of IEC 60947-1:2020.

The diagram in Figure I.1 illustrates the modifications to only one phase of the standard test circuit for conducting short-circuit tests of semiconductor controllers. The modifications to each phase of the test circuit are identical for testing polyphase devices. The only modifications to be made are those shown in Figure I.1.

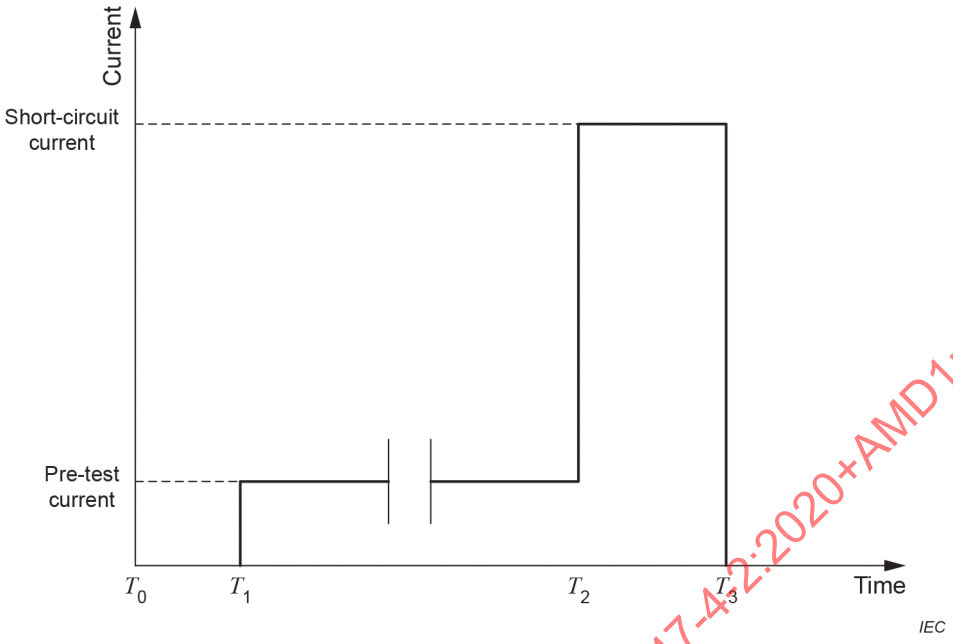



**Key**

D equipment under test (including connecting cables)

NOTE Outline includes metallic screen or enclosure.

**Figure I.1 – Modified circuit for short-circuit testing of semiconductor devices**




**Key**

$T_0$ shorting switch opens (9.3.4.1.6 a))

$T_1$ test circuit is energized (9.3.4.1.6 b))

$T_2$ shorting switch is closed (9.3.4.1.6 c))

$T_3$ SCPD clears the fault

**Figure I.2 – Time line for the short-circuit test of 9.3.4.1.6**

# Annex J
(xxx)

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# Annex K
(xxx)

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# Annex L
(normative)

# Examples of overvoltage category reduction

## L.1 General

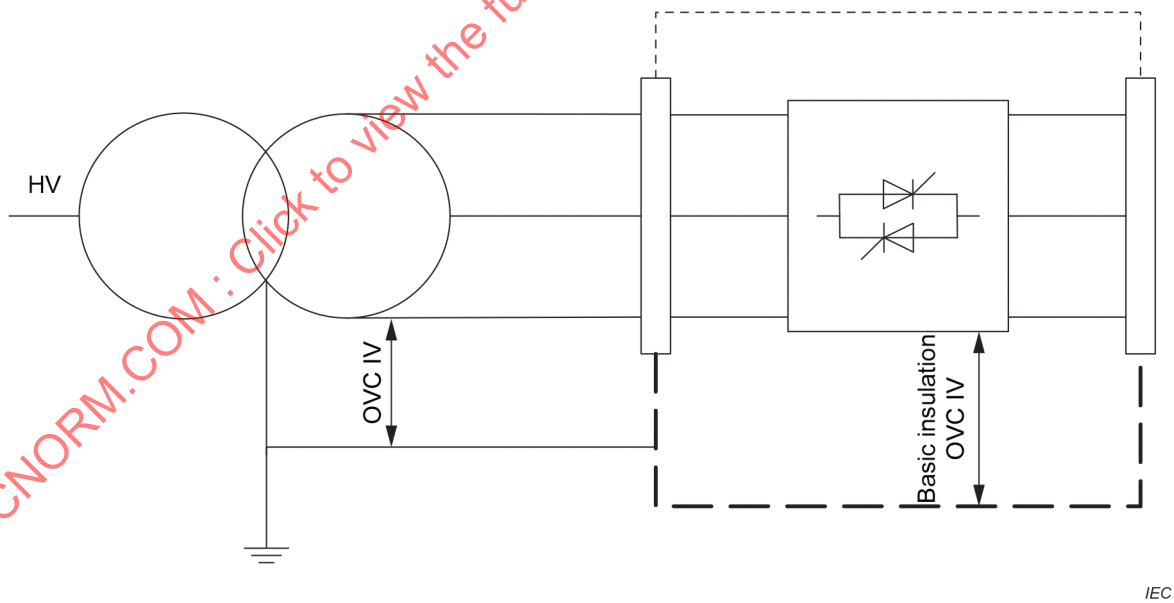
Figure L.1 to Figure L.9 are intended as illustrations of the requirements in 8.1.4, 8.2.3, and 8.1.14 of this document and Annex N of IEC 60947-1:2020. They are not intended as indications of good design practice. Table L.1 gives the drawing keys used in the figures.

**Table L.1 – Drawing keys**

| | |
|---|---|
| --------- | Basic protection |
| – – – – – | Conductive accessible parts |
| - · – · – · – · | Protective separation |
| SPD | Surge protection device (example of measure to reduce transient overvoltages) |
| OVC | Overvoltage category. See Annex H of IEC 60947-1:2020 for correlation of overvoltage category to impulse voltage. |

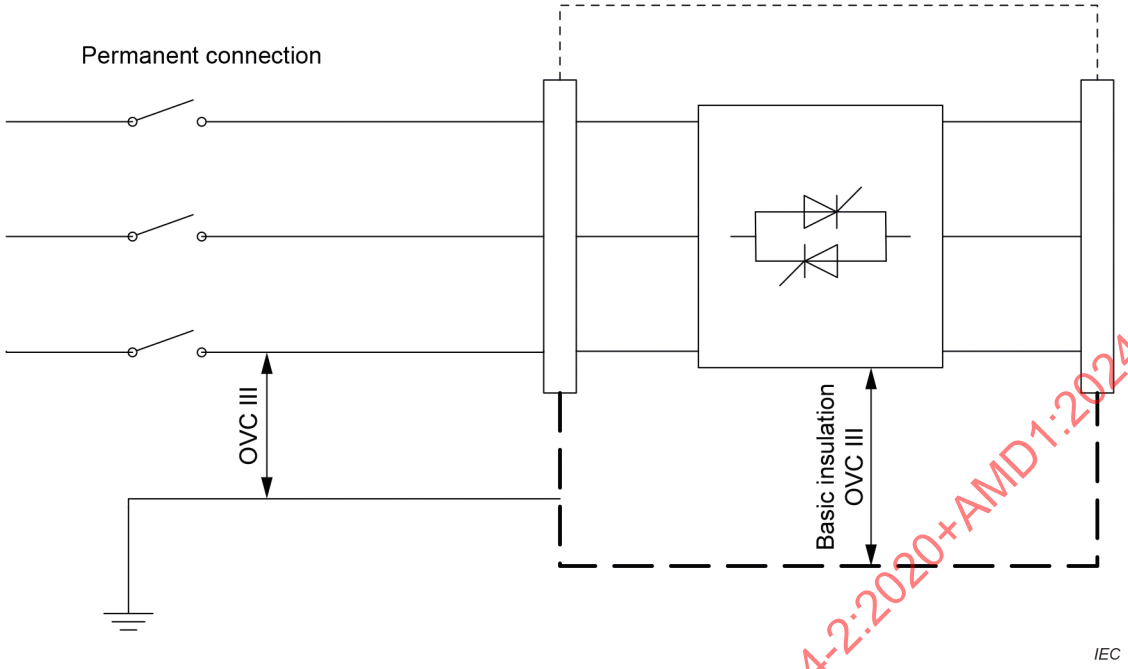
## L.2 Insulation to the surroundings

### L.2.1 Circuits connected directly to the supply mains



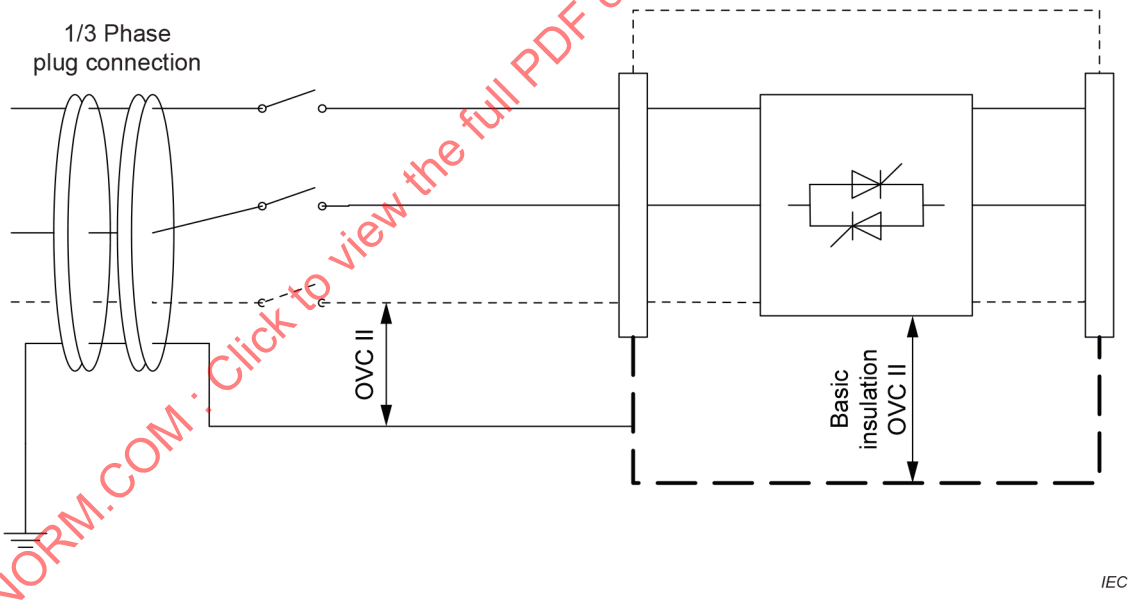

NOTE See Table L.1 for keys.

**Figure L.1 – Basic insulation evaluation for circuits connected directly to the origin of the installation mains supply**




NOTE See Table L.1 for keys.

**Figure L.2 – Basic insulation evaluation for circuits connected directly to the mains supply**

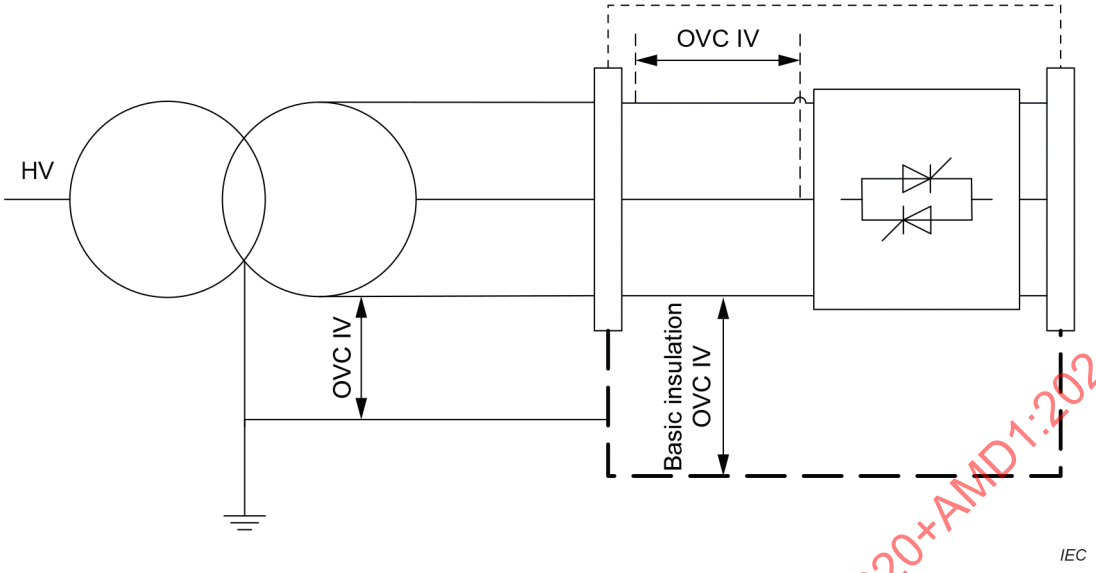



NOTE See Table L.1 for keys.

**Figure L.3 – Basic insulation evaluation for equipment not permanently connected to the mains supply**

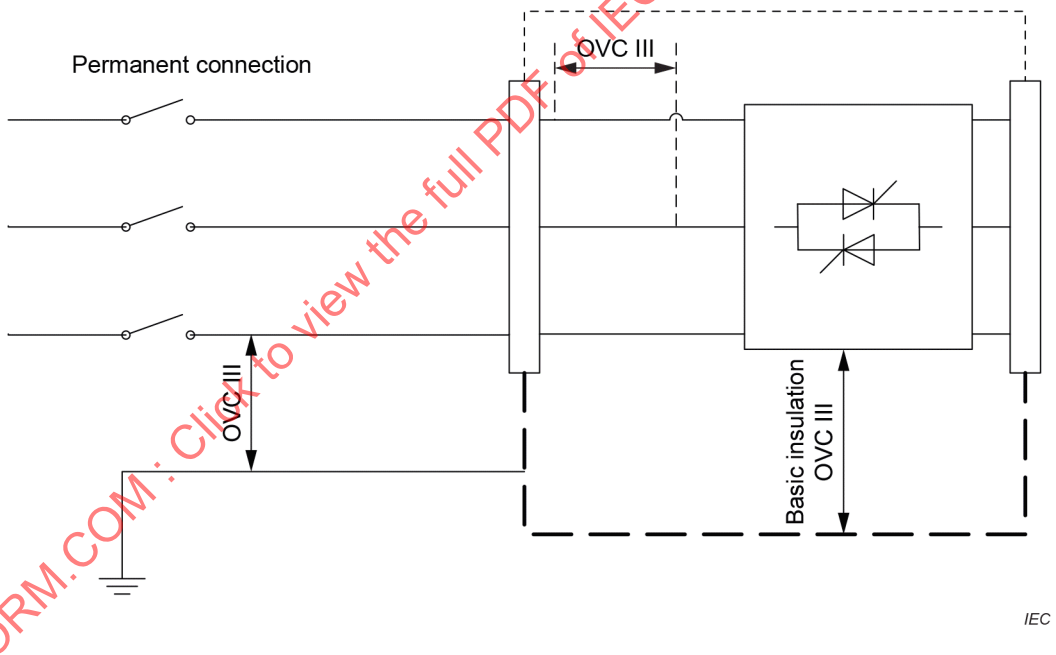
### L.2.2 Insulation between circuits

Insulation between two circuits that are declared galvanically separated shall be designed according to the circuit having the more severe requirement.



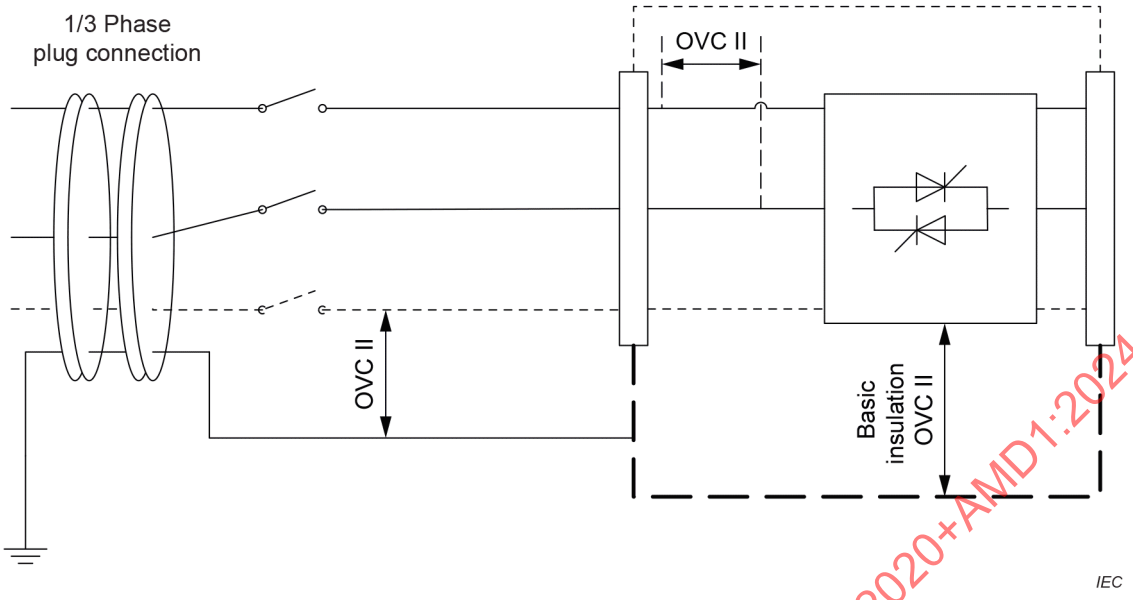

NOTE See Table L.1 for keys.

**Figure L.4 – Basic insulation evaluation for insulation between circuits connected directly to the origin of the installation mains supply and that are declared galvanically separated**



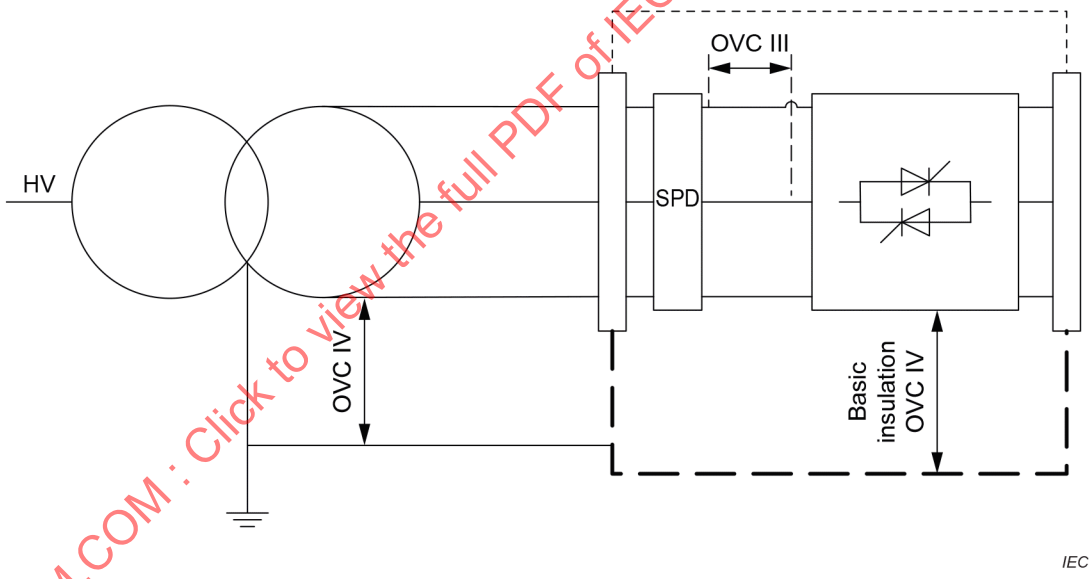

NOTE See Table L.1 for keys.

**Figure L.5 – Basic insulation evaluation for insulation between circuits connected directly to the mains supply and that are declared galvanically separated**




NOTE See Table L.1 for keys.

**Figure L.6 – Basic insulation evaluation for insulation between circuits not permanently connected directly to the mains supply and that are declared galvanically separated**

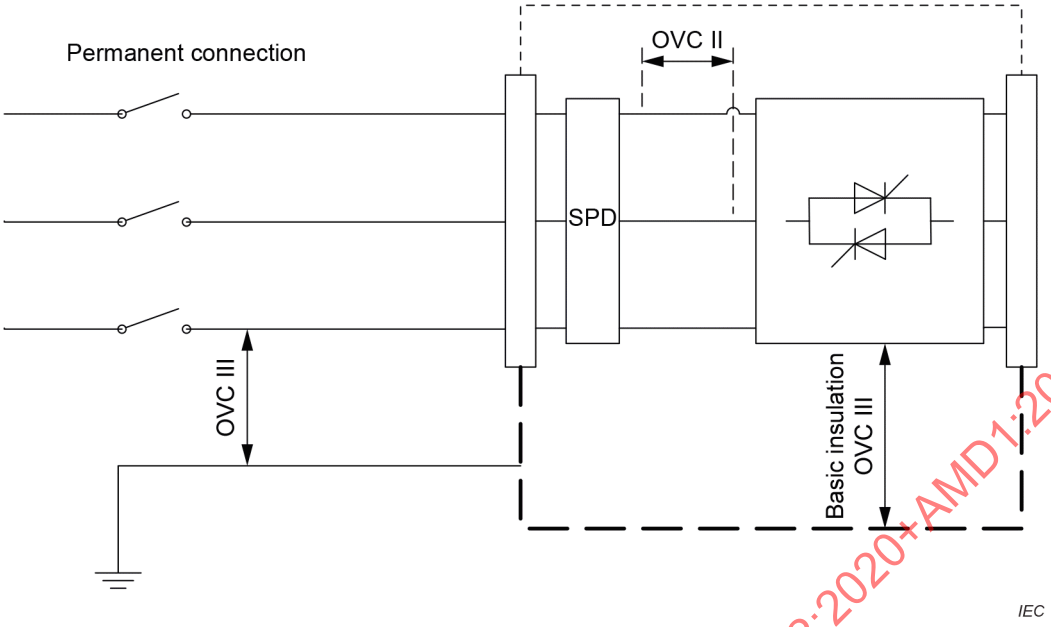



NOTE 1 See Table L.1 for keys.

NOTE 2 Refer to 8.1.14.

The SPD shall be monitored. A designated SCPD could also be used for monitoring for a SPD.

**Figure L.7 – Basic insulation evaluation for insulation between circuits connected directly to the origin of the installation mains supply and that are declared galvanically separated where internal SPDs are used**

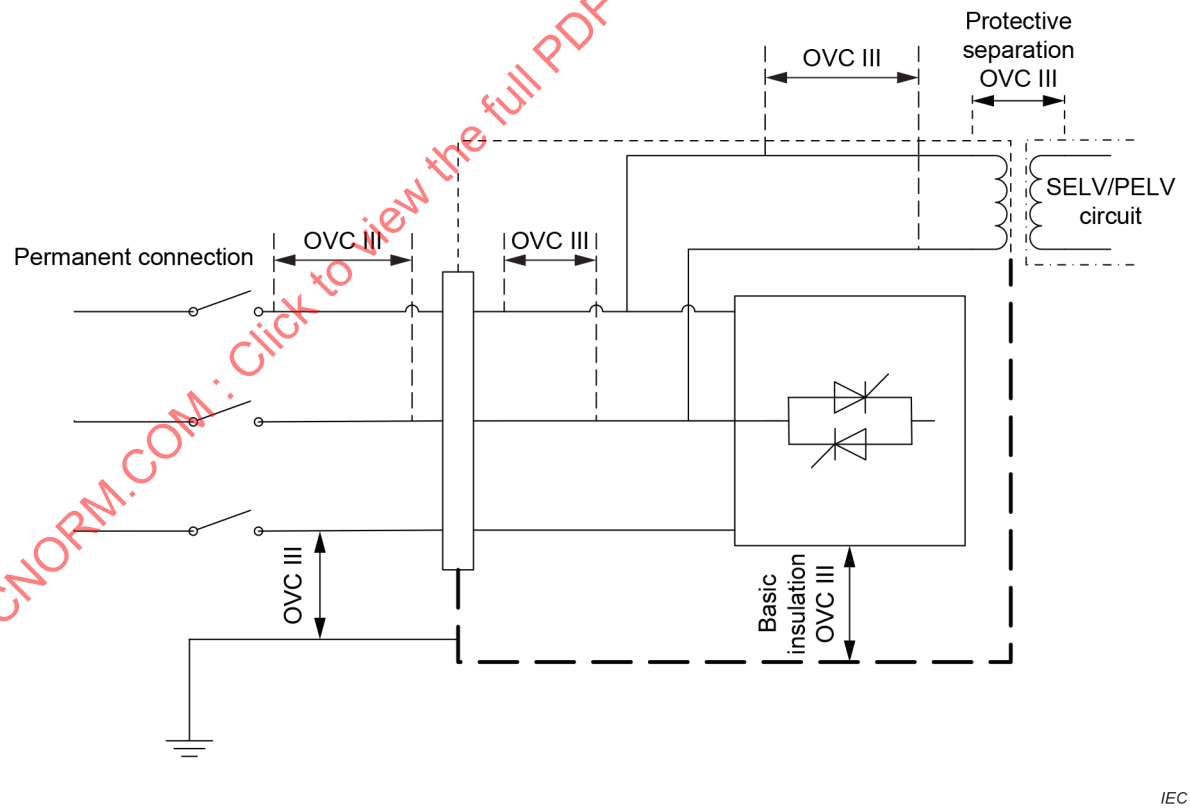



NOTE 1 See Table L.1 for keys.

NOTE 2 Refer to 8.1.14.

The SPD shall be monitored. A designated SCPD could also be used for monitoring for a SPD.

**Figure L.8 – Basic insulation evaluation for insulation between circuits connected directly to the mains supply and that are declared galvanically separated where internal SPDs are used**




NOTE 1 See Table L.1 for keys.

NOTE 2 Refer to 8.1.14.

**Figure L.9 – Basic insulation evaluation for insulation between circuits connected directly to the mains supply and that are declared galvanically separated**

# Annex M
(xxx)

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# Annex N
(normative)

# Additional requirements and tests for equipment with protective separation

## N.1 General

The purpose of this annex is to provide additional requirements to Annex N of IEC 60947-1:2020.

## N.2 Definitions

For the purposes of this document, the terms and definitions of Clause N.2 of IEC 60947-1:2020, as well as the following terms and definitions applies.

**N.2.1**
**touch current**
electric current passing through a human body or through an animal body when it touches one or more accessible parts of an electrical installation or electrical equipment

[SOURCE: IEC 60050-826:2004-08, 826-11-12]

## N.3 Requirements

### N.3.1 Test method for implementing protective impedance

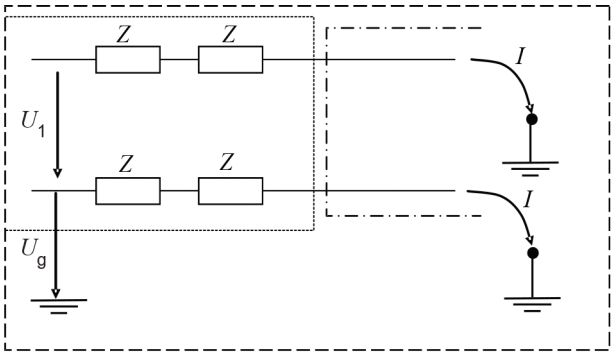
Protective impedance shall be arranged so that under both normal and single fault conditions, according respectively to 4.2 and 4.3 of IEC 61140:2016, the touch current and the discharge energy available shall be limited.

The protective impedances shall be designed and tested to withstand the impulse voltages and temporary overvoltages for the circuits to which they are connected.

Compliance with the requirement for the limitation of touch current is checked by test of N.3.2.

Compliance with a limited value of 0,5 mJ for the discharge energy shall be checked by performing calculations and/or measurements to determine the voltage and capacitance.

Figure N.1 show examples of the method used to implement protective impedance.




**Key**

| | |
|---|---|
| $Z$ | impedance |
| $U_1$ | hazardous voltage, earthed or unearthed |
| $U_g$ | hazardous voltage in a fault condition to earth |
| $I$ | touch current |

NOTE 1 To provide protection in single-fault conditions, use the following equation $I = \frac{U_g}{Z}$.

NOTE 2 This figure is derived from Figure A.2 of IEC 62477-1:2012.

**Figure N.1 – Protection by means of protective impedance**

### N.3.2 Touch current measurement

The equipment under test shall be set up in an insulated state without any connection to the earth and shall be operated at rated voltage. Under these conditions, the touch current shall be measured between the touchable parts and the earth according to the test circuit of Figure N.2.

For an equipment to be connected to an earthed neutral system, the neutral of the mains of the test site shall be directly connected to earth.

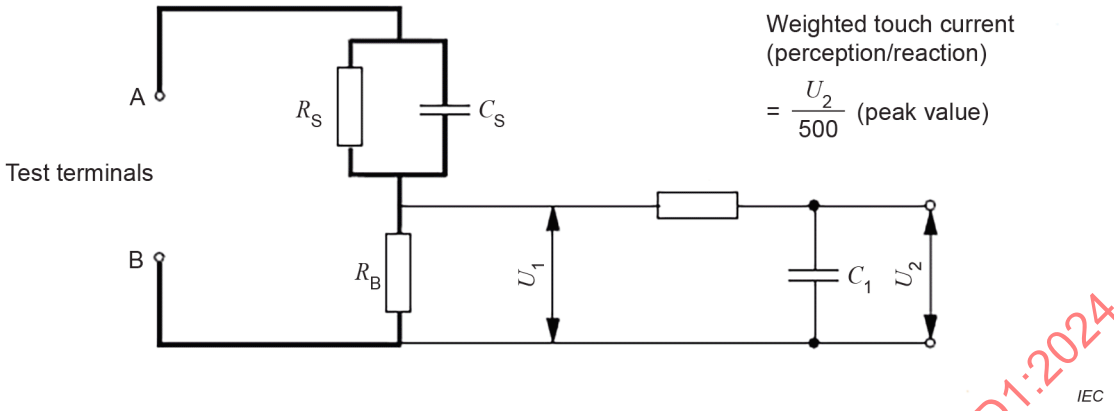
For an equipment to be connected to an earthed neutral system or impedance system, the neutral of the mains of the test circuit shall be directly connected to each.

The following maximum values of touch current (AC values for frequencies up to 100 Hz) are permitted:

a) a steady-state current flowing between simultaneously accessible conductive parts not exceeding 0.5 mA AC or direct current under normal operating conditions;

b) values not exceeding 3.5 mA AC or 10 mA DC under single fault conditions.

As shown in Figure N.2, the voltage $U_2$ is measured and the current is calculated by dividing the measured voltage $U_2$ by 500 Ω.




Voltmeter or oscilloscope (RMS or peak reading)
input resistance: >1 MΩ
input capacitance: < 200pF
frequency range: 15 Hz up to 1 MHz (appropriate for the highest frequency of interest)

**Key**

$R_S$ 1 500 Ω
$R_B$ 500 Ω
$R_1$ 10 kΩ
$C_S$ 0,22 µF
$C_1$ 0,022 µF

NOTE The measuring test circuit of this figure is reproduced from Figure 4 of IEC 60990:2016.

**Figure N.2 – Measuring instrument**

Electrical measuring instruments shall have adequate bandwidth to provide accurate readings, taking into account all components (direct current, alternating current mains supply frequency, high frequency and harmonic content) of the parameter being measured. If the RMS. value is measured, care shall be taken that measuring instruments give true RMS readings of non-sinusoidal waveforms as well as sinusoidal waveforms.

# Bibliography

IEC 60034-30-1, *Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motors (IE code)*

IEC 60050-151:2001, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*
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IEC 60050-195:1998, *International Electrotechnical Vocabulary (IEV) – Part 195: Earthing and protection against electric shock*
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IEC 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*
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IEC 60050-442:1998, *International Electrotechnical Vocabulary (IEV) – Part 442: Electrical accessories*
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IEC 60079 (all parts), *Explosive atmospheres*

IEC 60085:2007, *Electrical insulation – Thermal evaluation and designation*

IEC 60269-1:2006, *Low-voltage fuses – Part 1: General requirements*

IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60417, *Graphical symbols for use on equipment* (available at http://www.graphical-symbols.info/equipment)

IEC 60664 (all parts), *Insulation coordination for equipment within low-voltage systems*

IEC 60947-2, *Low-voltage switchgear and controlgear – Part 2: Circuit-breakers*

IEC 60947-3, *Low-voltage switchgear and controlgear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

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

IEC 60947-4-3, *Low-voltage switchgear and controlgear – Part 4-3: Contactors and motor-starters – AC semiconductor controllers and contactors for non-motor loads*

IEC 60990:2016, *Methods of measurement of touch current and protective conductor current*

IEC 61000-4 (all parts), *Electromagnetic compatibility (EMC) – Testing and measurement techniques*

IEC 61032, *Protection of persons and equipment by enclosures – Probes for verification*

IEC 61800 (all parts), *Adjustable speed electrical power drive systems*

IEC 62443 (all parts), *Security for industrial automation and control systems*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*
IEC 62477-1:2012/AMD1:2016

IEC 62683-1, *Low-voltage switchgear and controlgear – Product data and properties for information exchange – Part 1: Catalogue data*

IEC TR 63054, *Low-voltage switchgear and controlgear – Fire risk analysis and risk reduction measures*

IEC TS 63058[2], *Environmental aspects for low-voltage switchgear and controlgear and their assemblies*

IEC TR 63201, *Low-voltage switchgear and controlgear – Guidance for the development of embedded software*

IEC TS 63208, *Low-voltage switchgear and controlgear – Security aspects*

IEC TR 63216, *Low-voltage switchgear and controlgear – Electromagnetic compatibility assessment for switchgear and controlgear and their assemblies*

IEC Guide 104:2019, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC 82079-1, *Preparation of instructions for use – Structuring, content and presentation – Part 1: General principles and detailed requirements*

ISO/IEC Guide 51:2014, *Safety aspects – Guidelines for their inclusion in standards*

ISO 3864-2, *Graphical symbols – Safety colours and safety signs – Part 2: Design principles for product safety labels*

NFPA 70, *National Electrical Code*

CSA C22.1, *Canadian Electrical Code (CE Code)*



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2 Under preparation. Stage at the time of publication: IEC/APUB 63058:2020.

UL 508:2013, *Industrial Control Equipment*

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 4-2: Contactors and motor-starters – Semiconductor motor controllers, starters and soft-starters

## AMENDMENT 1

## FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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**This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.**

**IEC 60947-4-2 edition 4.1 contains the fourth edition (2020-06) [documents 121A/353/FDIS and 121A/360/RVD] and its amendment 1 (2024-11) [documents 121A/615/FDIS and 121A/626/RVD].**

**This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.**

International Standard IEC 60947-4-2 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 fourth edition cancels and replaces the third edition published in 2011. This edition constitutes a technical revision.

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

- scope exclusions;
- editorial correction of notes and hanging paragraphs;
- reference to IEC 62683-1;
- safety aspects related to:
  - general aspects;
  - limited energy circuits;
  - electronic circuits;
- mention of dedicated wiring accessories;
- power consumption measurement;
- alignment to IEC 60947-1:2020.

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.

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

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

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

- reconfirmed,
- withdrawn, or
- revised.

# INTRODUCTION

This document covers low-voltage semiconductor motor controllers, starters and soft-starters that have many capabilities and features beyond the simple starting and stopping of an induction motor, such as controlled starting and stopping, manoeuvring and controlled running.

The generic term “controller” is used in this document wherever reference is made to elements of power semiconductor switching devices.

The generic term “starter” is used in this document wherever reference is made to the elements of power semiconductor switching devices together with suitable overload protective devices.

# LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

# Part 4-2: Contactors and motor-starters – Semiconductor motor controllers, starters and soft-starters

## 1 Scope

This part of IEC 60947 applies to semiconductor motor controllers, starters and soft-starters which can include a series mechanical switching device, intended to be connected to circuits the rated voltage of which does not exceed 1 000 V AC.

This document characterizes semiconductor motor controllers and starters with and without bypass means.

This document does not apply to:

– semiconductor motor controllers and starters used for continuous operation of AC motors at motor speeds other than the normal speed;
– electromechanical contactors and external overload relays (see IEC 60947-4-1);
– short-circuit protective device associated with semiconductor motor controllers and starters (see IEC 60947-4-1 (MPSD), IEC 60947-2 and IEC 60947-3);
– semiconductor equipment, including semiconductor contactors (3.4.13 of IEC 60947-1:2020) controlling non-motor loads (see IEC 60947-4-3);
– semiconductor motor controllers and starters used for rotor circuits;
– adjustable speed electrical power drive systems (see IEC 61800 series);
– use of the product within explosive atmospheres (see IEC 60079 series);
– software and firmware requirements;

NOTE 1 Guidance on embedded software is given in IEC TR 63201.

– cyber security aspects (see IEC TS 63208).

Contactors, overload relays and control circuit devices used in semiconductor motor controllers and starters 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 motor controllers, starters and soft-starters and associated equipment;
– the conditions with which semiconductor motor controllers, starters and soft-starters 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.

NOTE 2 For the purpose of this document, the term "controller" is used instead of "semiconductor motor controller".

## 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 60034-1:2017, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60445:2021, *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 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 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*

IEC 63404:2024, *Switchgear and controlgear and their assemblies for low voltage – Integration of radiocommunication device above 380 MHz into an equipment*

IEC TS 63058, *Environmental aspects for low-voltage switchgear and controlgear and their assemblies*

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*

# 3 Terms, definitions, symbols and abbreviated terms

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60947-1:2020, as well as the following terms, definitions, symbol and abbreviations apply.

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

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

### 3.1.1 Terms and definitions concerning the types of semiconductor motor controllers and starters

**3.1.1.1**
**semiconductor switching device**
switching device designed to make and/or break the current in an electric circuit by means of the controlled conductivity of a semiconductor

Note 1 to entry: This definition differs from IEC 60050-441:1984, 441-14-03 since a semiconductor switching device is also designed for breaking the current.

[SOURCE: IEC 60947-1:2020, 3.4.3, modified – Note 1 to entry added.]

**3.1.1.2**
**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 (3.1.2.12) exist in a semiconductor controller, the load terminals should be 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.

Note 4 to entry: This device can include internal electromechanical switching device(s) bypassing or in series with the semiconductor at the manufacturer's discretion.

**3.1.1.3**
**semiconductor motor controller**
semiconductor controller that provides the starting function for an AC motor and an OFF-state

Note 1 to entry: This device can include any starting method specified by the manufacturer, control functions which can have any combination of manoeuvring, controlled acceleration, running or controlled deceleration of an AC motor. A FULL-ON state can also be provided.

Note 2 to entry: See Figure 1.

**3.1.1.4**
**direct-on-line semiconductor motor controller**
**DOL semiconductor motor controller**
semiconductor motor controller, in which the starting function is limited to a full-voltage, unramped starting method only, and where the additional control function is limited to providing FULL-ON

Note 1 to entry: This device can include a very short controlled ramp time of a few cycles which contribute to limit the inrush current of the motor to the level of Table 9.

Note 2 to entry: See Figure 1.

**3.1.1.5**
**semiconductor motor-starter**
**soft-starter**
semiconductor motor controller with suitable overload protection, rated as a unit

Note 1 to entry: The term “soft-starter” is often used on the market to designate a semiconductor motor controller with or without overload protection but, in this document, it is a type of starter which by definition includes an overload protection.

**3.1.1.6**
**direct-on-line semiconductor motor-starter**
**DOL semiconductor motor-starter**
direct-on-line semiconductor motor controller with suitable overload protection, rated as a unit

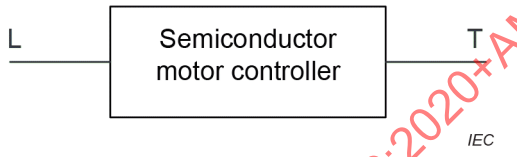
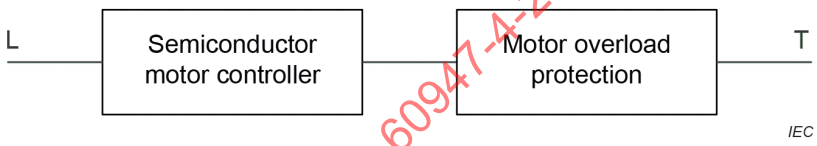
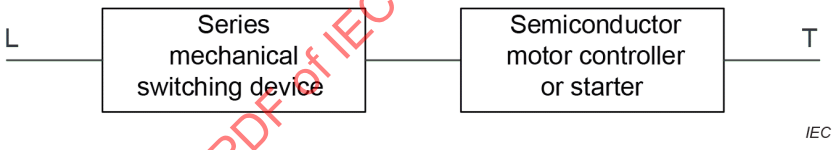
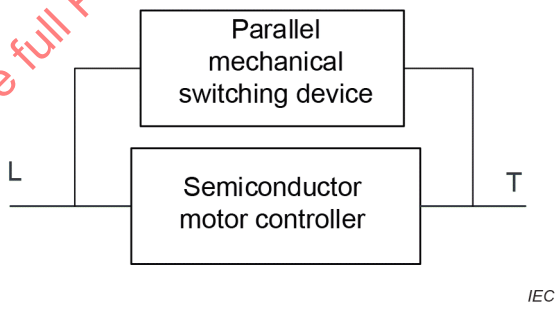
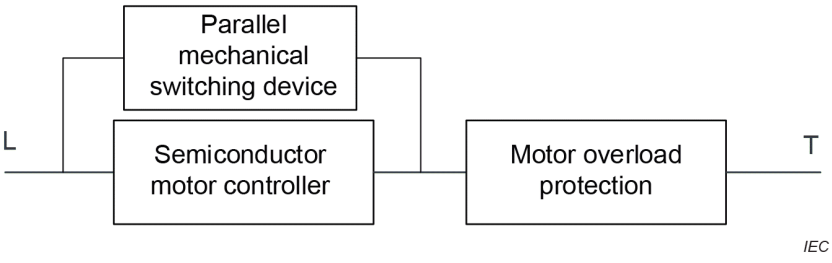
| Device | Functional unit diagram |
|---|---|
| Semiconductor motor controller |   |
| Semiconductor motor-starter |   |
| Semiconductor motor controller or starter in series with a mechanical switching device |   |
| Bypassed semiconductor motor controller |   |
| Bypassed semiconductor motor-starter |   |

**Figure 1 – Semiconductor motor control devices**

### 3.1.2 Terms and definitions concerning semiconductor motor controllers and starters

**3.1.2.1**
**current-limit function**
ability of the controller to limit the motor current to a specified value

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

**3.1.2.2**
**manoeuvre**
any deliberate operation that causes current changes which shall be characterized and controlled (for example jogging, braking)

Note 1 to entry: Starting is a mandatory manoeuvre that is recognized separately.

Note 2 to entry: Braking operations performed by the semiconductor motor controller or starter are considered to be a manoeuvre within the scope of this document.

**3.1.2.3**
**controlled acceleration**
control of motor performance while increasing motor speed by acting on the motor supply

**3.1.2.4**
**controlled deceleration**
control of motor performance while decreasing motor speed by acting on the motor supply

**3.1.2.5**
**controlled running**
control of motor performance by acting on the motor supply while the motor is running at normal speed (for example, energy saving)

**3.1.2.6**
**prospective current**
<circuit with respect to a switching device or a fuse> current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is to be specified in the relevant product standard.

[SOURCE: IEC 60947-1:2020, 3.7.5]

**3.1.2.7**
**prospective locked rotor current**
**$I_{LRP}$**
prospective current that would flow when the rated voltage is applied to the motor with a locked rotor

Note 1 to entry: The test current of $I_{LRP}$ for overload capability is given by Table 9.

**3.1.2.8**
**ON-state**
the condition of a controller when the conduction current can flow through its main circuit

**3.1.2.9**
**FULL-ON**
<state of controllers> condition of a controller when the controlling functions are set to provide normal full voltage excitation to the load

**3.1.2.10**
**minimum load current**
minimum operational current in the main circuit which is necessary for correct action of a controller in the ON-state

Note 1 to entry: The minimum load current is given as the RMS value.

**3.1.2.11**
**OFF-state**
the condition of a controller when no control signal is applied, and no current exceeding the OFF-state current flows through the main circuit

**3.1.2.12**
**OFF-state current**
the current which flows through the main circuit of a controller in the OFF-state

**3.1.2.13**
**operation**
<controller> transition from the ON-state to the OFF-state, or the reverse

**3.1.2.14**
**operating cycle**
<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.

**3.1.2.15**
**operating capability**
under prescribed conditions, the ability to perform a series of operating cycles without failure

**3.1.2.16**
**overload current profile**
current-time co-ordinate specifying the requirement to accommodate overload currents for a period of time

Note 1 to entry: See 5.3.5.2.

**3.1.2.17**
**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

Note 1 to entry: See 6.1 e).

**3.1.2.18**
**tripping operation**
<of a motor controller or starter> operation to establish and maintain an OFF-state (or open position in the case of series mechanical switching device) initiated by a control signal

**3.1.2.19**
**phase loss sensitive overload relay or release**
multipole overload relay or release which operates in case of overload and also in case of loss of phase in accordance with specified requirements

**3.1.2.20**
**under-current relay or release**
measuring relay or release which operates automatically when the current through it is reduced below a predetermined value

**3.1.2.21**
**under-voltage relay or release**
measuring relay or release which operates automatically when the voltage applied to it is reduced below a predetermined value

**3.1.2.22**
**stall sensitive electronic overload relay**
electronic overload relay which operates when the current has not decreased below a predetermined value for a specific period of time during start-up or when the relay receives the input indicating there is no rotation of the motor after a predetermined time in accordance with specified requirements

Note 1 to entry: Explanation of stall: rotor locked during start.

**3.1.2.23**
**jam sensitive electronic overload relay**
electronic overload relay which operates in the case of overload and also when the current has increased above a predetermined value for a specific period of time during run in accordance with specified requirements

Note 1 to entry: Explanation of jam: high overload occurring after the completion of starting which causes the current to reach the locked rotor current value of the motor being controlled.

**3.1.2.24**
**inhibit time**
time-delay period during which the tripping function of the relay is inhibited (may be adjustable)

**3.1.2.25**
**ON-time**
period of time during which the controller is on-load

Note 1 to entry: See the example in Figure F.1.

**3.1.2.26**
**OFF-time**
period of time during which the controller is off-load

Note 1 to entry: See the example in Figure F.1.

**3.1.2.27**
**bypassed semiconductor motor controller**
**bypassed semiconductor motor-starter**
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, tested and rated as a unit

Note 1 to entry: See rows 4 and 5 of Figure 1.

**3.1.2.28**
**CO operation**
breaking of the circuit by the SCPD resulting from closing the circuit by the equipment under test

**3.1.2.29**
**O operation**
breaking of the circuit by the SCPD resulting from closing the circuit on the equipment under test which is in the closed position

**3.1.2.30**
**semiconductor motor controller power losses**
power consumed by the semiconductor motor controller or starter at FULL-ON at the maximum power rating

**3.1.2.31**
**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 a opto-coupler.

[SOURCE: IEC 60050-151:2001-07, 151-12-26]

### 3.1.3 Terms and definitions concerning safety aspects

**3.1.3.1**
**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.

**3.1.3.2**
**accessible part**
part which can be touched by means of the standard test finger

[SOURCE: IEC 60050-442:1998-11, 442-01-15, modified – removal of “a” at the beginning]

**3.1.3.3**
**hazardous-live-part**
live part which, under certain conditions, can give a harmful electric shock

[SOURCE: IEC 60050-195:1998-08, 195-06-05]

**3.1.3.4**
**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

**3.1.3.5**
**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]

**3.1.3.6**
**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 – Deletion of Notes to entry]

**3.1.3.7**
**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.

Note 2 to entry: Reinforced protection is defined in IEC 60050-903:2013, 903-02-08.

[SOURCE: IEC Guide 104:2019-07, 3.8]

### 3.1.4 Alphabetical index of terms

O



P



R



S



T



U

### 3.2 Symbols and abbreviated terms

| Symbol and abbreviated term | Description | Definition or occurrence |
|---|---|---|
| $A_f$ | Final ambient temperature | 9.3.3.3.4 |
| $C_f$ | Final case temperature | 9.3.3.3.4 |
| $I_c$ | Current made and broken | Table 11 |
| $I_e$ | Rated operational current | 5.3.2.3 |
| $I_F$ | OFF-state current after the blocking and commutating capability test | 9.3.3.6.4 |
| $I_{init}$ | Initial test current | 9.3.3.6.3 |
| $I_{LRP}$ | Prospective locked rotor current | 3.1.2.7 |
| $I_O$ | OFF-state current before the blocking and commutating capability test | 9.3.3.6.4 |
| $I_{Lm}$ | Maximum OFF-state current | 5.3.2.5 |
| $I_q$ | Maximum conditional short-circuit test current | 9.3.4.3.2 |
| $I_{lim}$ | Current setting of the current-limit function | 8.2.4.1 |
| $I_{th}$ | Conventional free air thermal current | 5.3.2 |
| $I_{the}$ | Conventional enclosed thermal current | 5.3.2.2 |
| $I_u$ | Rated uninterrupted current | 5.3.2.4 |
| SCPD | Short-circuit protective device | 5.8 |
| $U_c$ | Rated control circuit voltage | 6.1 |
| $U_e$ | 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 10 |
| $U_s$ | Rated control circuit supply voltage | 6.1 |

## 4 Classification

Subclause 5.2 gives all data which could be used as criteria for classification.

## 5 Characteristics of semiconductor motor controllers and starters

### 5.1 Summary of characteristics

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

– type of equipment (5.2);
– rated and limiting values for main circuits (5.3);
– utilization category (5.4);
– control circuits (5.5);
– auxiliary circuits (5.6);
– characteristics of relays and releases (5.7);
– coordination with short-circuit protective devices (5.8).

For information exchange in electronic format, e.g. electronic catalogue, IEC 62683-DB gives the data format of the essential characteristics of motor-starters, contactors and their accessories.

## 5.2 Type of equipment

### 5.2.1 Kind of equipment

The type of semiconductor controllers and starters shall be stated in the following terms:

a) Type of semiconductor motor controller
   - semiconductor motor controller; or
   - semiconductor motor-starter: with suitable overload protection, rated as a unit.

b) Bypassed semiconductor motor controller or starter, if relevant

c) Type of control (not limited to)
   - FULL-ON;
   - controlled acceleration;
   - controlled deceleration;
   - 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

AC only.

### 5.2.4 Interrupting medium (air, vacuum, etc.)

Applicable only to mechanical switching devices used in controllers and starters.

### 5.2.5 Operating conditions of the equipment

#### 5.2.5.1 Method of operation

For example:

– symmetrically controlled controller (such as a semiconductor with fully controlled phases);

– non-symmetrically controlled controller (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):

– motor in delta, thyristors in series with a winding;

– motor in star, thyristors in delta;

– motor in delta, thyristors connected between winding and supply.

## 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.

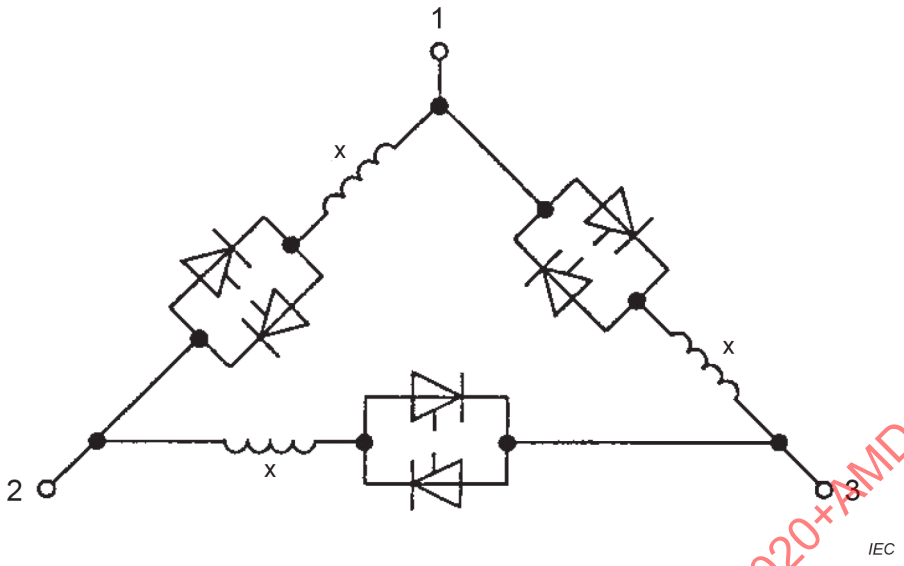



**Figure 2a – Motor in delta – Thyristors in series with a winding**

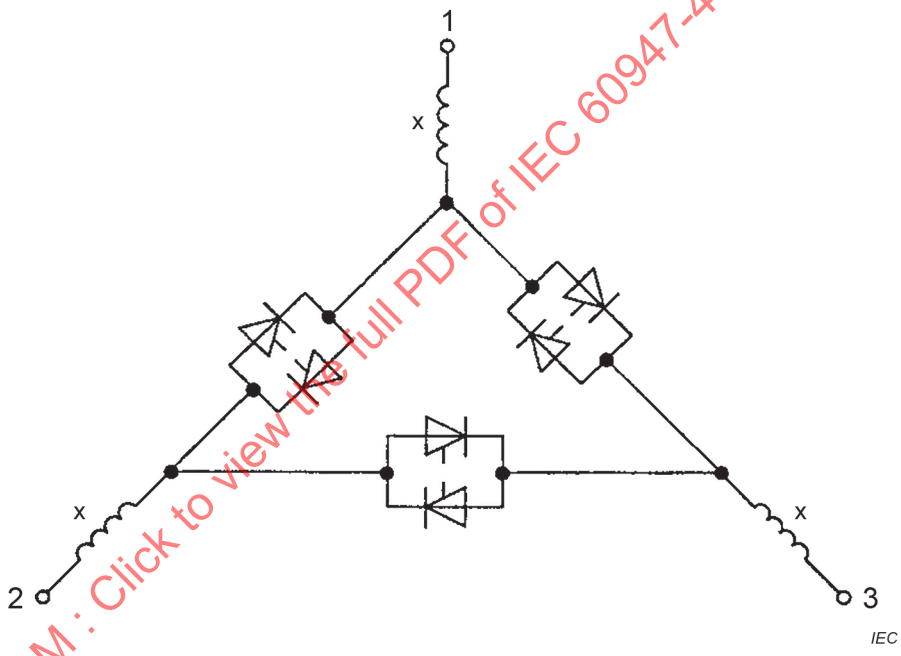



**Figure 2b – Motor in star – Thyristors in delta**

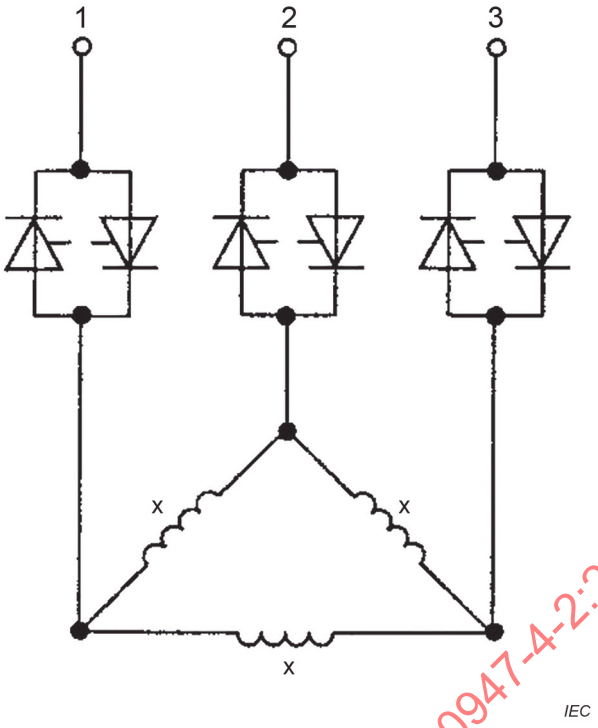



**Figure 2c – Motor in delta – Thyristors connected between winding and supply**

**Figure 2 – Connecting methods**

### 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 controllers and starters 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 duty cycle values and sequences (see 5.3.4), the utilization category (see 5.4), the normal load and overload characteristics (see 5.3.5), and the type of protective enclosure, if any.

The indication of a rated operational current may be replaced or supplemented by an indication of the maximum rated power output, at the rated operational voltage considered, of the motor for which the equipment is intended.

NOTE Annex G gives values concerning the relationship between rated operational currents and rated operational powers.

#### 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 ($I_{Lm}$)

The maximum OFF-state current ($I_{Lm}$) is the maximum current flowing through the main circuit of the controller when it is in the OFF state, in the test condition of 9.3.3.6.4.

### 5.3.3 Rated frequency

Subclause 5.3.3 of IEC 60947-1:2020 applies.

### 5.3.4 Duty cycle values and sequences

#### 5.3.4.1 Duty cycle values and symbols

For the purpose of this document, the duty cycle is expressed by two symbols, $F$ and $S$. These describe the duty, and also set 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 as follows:

$F$ = 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 as follows:

$S$ = 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.

#### 5.3.4.2 Duty cycle sequences

Two duty cycle sequences are defined in relation with the suffix of the designation of a utilisation category as follows:

a) Sequence A: complete duty cycles, where the semiconductor motor controller or starter is carrying the motor current during all the phases of “starting”, “running” and “stopping” of the motor load. It includes the capability to continuously carry the rated current until and after thermal equilibrium;

b) Sequence B: starting and stopping duty cycles, where the semiconductor motor controller or starter is carrying the motor current only during the phases of “starting” and/or “stopping” of the motor load.

### 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 co-ordinates 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 7, and represents the maximum value of operating current due to starting, operating, or manoeuvring under overload conditions. $X = I_T/I_e$ as tested according to Table 10 when no current limit function is provided.

Deliberate overcurrents not exceeding 10 cycles (for example boost, kickstart, etc.), 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 controlled overload currents during starting, operating, and manoeuvring. See Table 7.

For a starter, $T_x$ is the minimum operating time allowed by the tolerances of the overload relay.

#### 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

– the rated operational voltage (see 5.3.1.1);

– the rated operational current (see 5.3.2.3);

– the duty cycle values and sequences (see 5.3.4);

– the overload current profile (see 5.3.5.2);

– the utilization category (see 5.4);

– the availability of a current-limit function;

– the availability of a motor inrush current limiting function.

Requirements are given in 8.2.4.1.

#### 5.3.5.4 Starting, stopping and manoeuvring characteristics

##### 5.3.5.4.1 Starting characteristics of squirrel cage and hermetic refrigeration motors

a) One direction of rotation with the inclusion of phase-control capability to provide any combination of controlled acceleration to normal speed, controlled deceleration to standstill, or an occasional manoeuvre without de-energizing the controller (AC-3a, AC-8a).

b) One direction of rotation with the inclusion of phase-control capability to provide controlled acceleration to normal speed. Controllers and starters are rated for starting and stopping duty cycles only (AC-3b, AC-8b); for example, after starting, the motor may be connected into a circuit that bypasses the semiconductor motor controller or starter.

Two directions of rotation are not covered by this document.

Due to the control capability of controllers and starters, the current during starting, stopping, and any operation will differ from the conventional values of the prospective locked rotor current listed in Table 9.

##### 5.3.5.4.2 Starting characteristics of rheostatic rotor starters with controllers energizing the stator (AC-2a, AC-2b)

Starters can be used to provide reduced voltage excitation to the stator windings of a slip ring motor, and thereby reduce the number of switching steps required in the rotor circuit. For most applications, one or two starting steps are adequate depending upon load torque and inertia, and the severity of start required.

#### 5.3.6 Rated conditional short-circuit current

Subclause 5.3.6.4 of IEC 60947-1:2020 applies.

### 5.3.7 Semiconductor motor controller power losses

#### 5.3.7.1 General

The power consumption of the semiconductor motor controller or starter may be stated by the manufacturer and is determined by calculating the power losses of the power semiconductor components.

A motor controller consists of two or three power semiconductor controlled phases and the semiconductor controlling device. These power semiconductors are bypassed or not bypassed after run up of the motor.

The power semiconductor losses during start-up (and soft stop or braking mode) occur for a very short period of time (seconds) and are therefore not considered.

#### 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

$$P_{vnb} = n \cdot I_e \cdot 1V$$

with:

$n$ number of controlled phases,

$I_e$ rated operational current,

$P_{vnb}$ power losses non-bypassed operation,

1V one volt as typical voltage drop of a power semiconductor.

NOTE 1 The typical factor of 1 V can be changed appropriately by the manufacturer.

b) Formula for bypassed operation

$$P_{vb} = n \cdot 0{,}1 \cdot I_e \cdot 1V = 0{,}1 \cdot P_{vnb}$$

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

$P_{vb}$ power losses in bypassed operation,

NOTE 2 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 motor controllers, starters and soft-starters, the utilization categories are given in Table 1.

Each utilization category (see Table 1) is characterized by the values of the currents, voltages, power-factors and other data of Table 2, Table 7, Table 8, Table 9 and Table 10, and by the test conditions specified in this document.

The utilization categories AC-2a, AC-3a and AC-8a (with a-suffix) are defined for the complete duty cycles according to 5.3.4.2a).

The utilization categories AC-2b, AC-3b and AC-8b (with b-suffix) are defined for the starting and stopping duty cycles according to 5.3.4.2b).

### 5.4.2 Assignment of ratings based on the results of tests

A designated controller or starter 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 utilisation category | Harmonised utilization category [a] | Typical motor load | Duty cycle sequence [b] |
|---|---|---|---|
| AC-52a | AC-2a | Slip ring motor | A [c] |
| AC-52b | AC-2b | | B [d] |
| AC-53a | AC-3a | Squirrel-cage motors | A [c] |
| AC-53b | AC-3b | | B [d] |
| AC-58a | AC-8a | Hermetic refrigerant compressor | A [c] |
| AC-58b | AC-8b | | B [d] |

[a] The new utilisation 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.

[b] Includes the whole starter or controller.

[c] Sequence A as complete.

[d] Sequence B as starting and stopping.

**Table 2 – Relative levels of severity**

| Severity level | Utilization category | Overload current profile [a, c] | ON-time/OFF-time requirements [b] |
|---|---|---|---|
| Most severe | AC-2a<br>AC-3a<br>AC-8a | Highest value of<br>$(XI_e)^2 \cdot T_x$ | Highest value of<br>$F \cdot S$ |
| | AC-2b<br>AC-3b<br>AC-8b | Highest value of<br>$(XI_e)^2 \cdot T_x$ | Lowest value of<br>OFF-time |

[a] When the highest value of $(XI_e)^2 \cdot T_x$ occurs at more than one value of $XI_e$, then the highest value of $XI_e$ applies.

[b] When the highest value of $F \cdot S$ occurs at more than one value of $S$, then the highest value of $S$ applies.

[c] When the highest value of $(XI_e)^2 \cdot T_x$ occurs at more than one value of OFF-time, then the lowest value of OFF-time 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.

Electronic auxiliary circuits perform useful functions (for example monitoring, data acquisition, etc.) that are not necessarily functions involved with the intended performance characteristics.

Under normal conditions, auxiliary circuits are characterized in the same way as control circuits, and are subject to the same kinds of requirements.

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

### 5.7 Characteristics of relays and releases (overload relays)

NOTE In the remainder of this document, the words "overload relay" will be taken to apply equally to an overload relay or an overload release, as appropriate.

#### 5.7.1 Summary of characteristics

The characteristics of relays and releases shall be stated in the following terms, whenever applicable:

– types of relay or release (see 5.7.2);
– characteristic values (see 5.7.3);
– designation and current settings of overload relays (see 5.7.4);
– time-current characteristics of overload relays (see 5.7.5);
– influence of ambient air temperature (see 5.7.6).

#### 5.7.2 Types of relay or release

a) Under-voltage and under-current opening relay or release.
b) Overload time-delay relay, the time-lag of which is
   1) substantially independent of previous load;
   2) dependent on previous load;
   3) dependent on previous load and also sensitive to phase loss.
c) Instantaneous over-current relay or release (for example jam sensitive).
d) Other relays or releases (for example control relay associated with devices for the thermal protection of the starter).
e) Stall sensitive electronic overload relay or release.

#### 5.7.3 Characteristic values

a) Release with shunt coil, under-voltage (under-current), over-voltage (instantaneous over-current), current or voltage asymmetry and phase reversal opening relay or release:
   – rated voltage (current);

- rated frequency;
- operating voltage (current);
- operating time (when applicable);
- inhibit time (when applicable).

b) Overload relay:

- designation and current settings (see 5.7.4);
- rated frequency, when necessary (for example in the case of a current transformer operated overload relay);
- time-current characteristics (or range of characteristics), when necessary;
- operating time of ground/earth fault electronic overload relays according to Table T.1 of IEC 60947-1:2020 if applicable;
- trip class according to classification in Table 4, or the value of the maximum tripping time, in seconds, under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D*, when this time exceeds 40 s;
- nature of the relay: thermal, electronic or electronic without thermal memory; electronic relay without thermal memory shall be marked ~~Th~~;
- type designation for overload relays with extended functions (see Annex T of IEC 60947-1:2020) if applicable;
- nature of the reset: manual or manual/automatic; in case of manual/automatic, the set position shall be indicated;
- tripping time of overload relays class 10A where higher than 2 min at 0 °C or below (see 8.2.1.5.1.1.1, item c).

c) Release with residual current sensing relay:

- rated current;
- operating current;
- operating time or time-current characteristic according to Table T.1 of IEC 60947-1:2020;
- inhibit time (when applicable);
- type designation (see Annex T of IEC 60947-1:2020).

**Table 3 – Trip classes of overload relays**

| Trip class | Tripping time $T_p$ under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D* [a] | Tripping time $T_p$ under the conditions specified in 8.2.1.5.1.1.1 and Table 4, column *D* for tighter tolerances (tolerance band E) [a] |
|---|---|---|
| | s | s |
| 2 | – | $T_p \leq 2$ |
| 3 | – | $2 < T_p \leq 3$ |
| 5 | $0{,}5 < T_p \leq 5$ | $3 < T_p \leq 5$ |
| 10A | $2 < T_p \leq 10$ | – |
| 10 | $4 < T_p \leq 10$ | $5 < T_p \leq 10$ |
| 20 | $6 < T_p \leq 20$ | $10 < T_p \leq 20$ |
| 30 | $9 < T_p \leq 30$ | $20 < T_p \leq 30$ |
| 40 | – | $30 < T_p \leq 40$ |

| |
|---|
| NOTE 1 Depending on the nature of the relay, the tripping conditions are given in 8.2.1.5.<br><br>NOTE 2 The lower limiting values of $T_p$ are selected to allow for differing heater characteristics and manufacturing tolerances. |
| [a] The manufacturer shall add the letter E to trip classes to indicate compliance with the band E. |

### 5.7.4 Designation and current settings of overload relays

Overload relays are designated by their current setting (or the upper and lower limits of the current setting range, if adjustable) and their trip class.

The current setting (or current setting range) shall be marked on the relays.

However, if the current setting is influenced by the conditions of use or other factors which cannot readily be marked on the relay, then the relay or any interchangeable parts thereof (for example heaters, operating coils or current transformers) shall carry a number or an identifying mark which makes it possible to obtain the relevant information from the manufacturer or his catalogue or, preferably, from data furnished with the starter.

In the case of current transformer operated overload relays, the marking may refer either to the primary current of the current transformer through which they are supplied or to the current setting of the overload relays. In either case, the ratio of the current transformer shall be stated.

### 5.7.5 Time-current characteristics of overload relays

Typical time-current characteristics shall be given in the form of curves supplied by the manufacturer. These curves shall indicate how the tripping time, starting from the cold state (see 5.7.6), varies with the current up to a value of at least maximum ($X \times I_e$) value. The manufacturer shall be prepared to indicate, by suitable means, the general tolerances applicable to these curves and the conductor cross-sections used for establishing these curves (see 9.3.3.3.6, item c)).

It is recommended that the current be plotted as abscissae and the time as ordinates, using logarithmic scales. It is recommended that the current be plotted as multiples of the setting current and the time in seconds on the standard graph sheet detailed in IEC 60269-1.

### 5.7.6 Influence of ambient air temperature

The time-current characteristics (see 5.7.5) refer to a stated value of ambient air temperature and are based on no previous loading of the overload relay (i.e. from an initial cold state). This value of the ambient air temperature shall be clearly given on the time curves; the preferred values are +20 °C or +40 °C.

The overload relays shall be able to operate within the ambient air temperature range of 0 °C to +40 °C, and the manufacturer shall be prepared to state the effect of variation in ambient air temperature on the characteristics of overload relays.

## 5.8 Coordination with short-circuit protective devices (SCPD)

Controllers and starters are characterized by the type, ratings, and characteristics of the SCPD to be used to provide overcurrent discrimination between starter and SCPD, and adequate protection of controllers and starters 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 (5.3.1.1);

e) rated operational currents, corresponding utilization category (5.4), overload current profile (5.3.5.2), and duty cycle value (5.3.4.1) or OFF-time, comprising the rating index;

- The prescribed format for AC-2a, AC-3a, AC-8a is shown by these examples:

  100 A: AC-3a: 6 × $I_e$-6 s: 60 %-1/h

  This indicates 100 A current rating for general applications with squirrel cage motors. The device can accommodate 600 A for 6 s; 60 % on-load factor; one standard operating cycle per hour.

- The prescribed format for AC-2b, AC-3b, AC-8b is shown by the example:

  100 A: AC-3b: 3 × $I_e$-52s: 1 440 s

  This indicates 100 A current rating for starting only. The device can accommodate 300 A for 52 s; the OFF-time shall not be less than 1 440 s before any subsequent start may be initiated.

f) maximum OFF-state current;

g) either the value of the rated frequency 50/60 Hz, or other rated frequencies for example 16 2/3 Hz, 400 Hz;

Safety and installation

h1) rated insulation voltage (5.3.1.2);

h2) galvanic separation between poles if applicable;

i) rated impulse withstand voltage (5.3.1.3);

j) IP code according to Annex C of IEC 60947-1:2020;

k) pollution degree (7.1.3.2);

l1) rated conditional short-circuit current and type of coordination of the controller or starter, and the type, current rating and characteristics of the associated SCPD (see 5.8);

l2) 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 rigid-solid conductors;
– "r" for terminals declared for rigid (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.

Control circuits

m) 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

n) nature and ratings of auxiliary circuits (5.6);

Overload relays and releases

o) characteristics according to 5.7.2, 5.7.5 and 5.7.6;

p) characteristics according to 5.7.3 and 5.7.4;

EMC immunity and emission levels

q1) the immunity levels attained and the specific requirements necessary to maintain compliance (8.3.2);

q2) the equipment class and the specific requirements necessary to maintain compliance (8.3.3);

q3) if an external EMC filter is required to fulfil the emission levels given in Table 17, it shall be specified in the catalogue and in the instruction manual.

Additional information

r) reference of dedicated wiring accessories which can be used for wiring the semiconductor motor controller or starter;

s) type of equipment according to 5.2;

t) maximum permissible altitude of the installation site, if greater than 1 000 m;

u1) pole impedance (Z) of the parallel mechanical switching device of a bypassed semiconductor motor controller or starter according to IEC 60947-4-1;

u2) material declaration according to Annex W of IEC 60947-1:2020;

u3) semiconductor motor controller power losses.

### 6.2 Marking

Subclause 6.2 of IEC 60947-1:2020 applies to controllers and starters, with the following additions.

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

Data under items c), j) (if the degree of protection is different than IP00) and q) in 6.1 shall be marked on the equipment; time-current characteristics (or range of characteristics) may be provided in the manufacturer's published literature.

When a radiocommunication device is embedded into the equipment, additional information according to 6.2 and 6.3 of IEC 63404:2024 shall apply.

### 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.

The manufacturer of a semiconductor starter incorporating an automatic reset overload relay capable of being connected to enable automatic restarting shall provide information with the starter to alert the user to the possibility of automatic restarting.

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 semiconductor motor controller or starter (see 8.2.1.6);
– in the event of temperature-rise above 50 K of the metallic radiator surface of the device.

The instructions shall also cover other specific application limitations, when applicable, such as altitude above 1 000 m and two direction starters.

When the embedded radiocommunication device can be upgraded, additional information according to 6.4 of IEC 63404:2024 shall apply.

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 potential hazard according to 8.1.1, 8.1.15, 8.1.17 and 8.2.2, the manufacturer shall provide safety signs, graphical symbols or safety notes of the hazard for example by using e.g. IEC 60417-5036:2002. Signal words are given by ISO 3864-2.

NOTE ISO/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 starter.

### 6.4 Environmental information

Hazardous substances used by design in the equipment shall be declared in the product documentation.

When declared, the material declarations shall be provided according to IEC TS 63058.

IEC TS 63058 should also be considered carefully for providing measures to prevent emission of or contact with hazardous substances.

NOTE IEC TS 63058 provides methods for assessing the environmental impact of switchgear and controlgear, guidance on environmentally conscious design and on information needed for end-of-life treatments.

## 7 Normal service, mounting and transport conditions

### 7.1 Normal service conditions

#### 7.1.1 Ambient air temperature

Subclause 7.1.1 of IEC 60947-1:2020 applies with the exception that all references to –5 °C are replaced by 0 °C.

#### 7.1.2 Altitude

When rated above 1 000 m, the manufacturer shall specify the maximum altitude in 6.1 t) 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 the use of the equipment above 1 000 m, specific instruction can be necessary for the additional cooling means of the power semiconductor or the derating of rated values of 5.3.

#### 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 in the product documentation, controllers and starters 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 to apply, 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.

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 which are compliant with a relevant IEC product standard do not require separate evaluation if tested under the conditions given in this document. 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 shall meet the requirements of their own IEC product standard, and the additional requirements of this document. When a radiocommunication device is embedded into the equipment, C.4.2 of IEC 63404:2024 applies. The interruption of the radiocommunication link shall not affect the current operation of the equipment.

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 setting of any automatic resettable overload release needs to be identified in the user manual as a specific safety warning.

### 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 of 9.2.2.1 in 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 with the following addition.

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 8.1.4 of IEC 60947-1:2020.

Where SELV and PELV circuits are accessible, they shall be separated from other hazardous-live-part according to the requirements of Annex N 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). They shall be marked or provided with other identification in accordance with Clause 5 of IEC 60445:2021.

### 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 19; or

b) a linear or non-linear impedance limits the output in compliance with Table 19. If a positive temperature coefficient (PTC) device (e.g. PTC thermistor) 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 19, 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 20.

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 the case of external power supplies without overcurrent protective devices, they shall not exceed the values given in Table 19. In case of external power supplies with over-current protective devices, they shall not exceed the values given in Table 20.

**Table 19 – Limits for limited energy sources without an over-current protective device**

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

NOTE This table will be moved into a 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 Isc 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 thermistor), and 60 s in other cases.

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

**Table 20 – Limits for limited energy sources with an over-current protective device**

| Output voltage [a] $U_{oc}$ | | Output current [b, d] $I_{sc}$ | Maximum power [c, d] $S$ | Current rating of over-current protective device [e] |
|---|---|---|---|---|
| V AC | V DC | A | VA | A |
| ≤ 20 | ≤ 20 | $\leq \frac{1000}{U_{oc}}$ | 250 | ≤ 5,0 |
| 20 < $U_{oc}$ ≤ 30 | 20 < $U_{oc}$ ≤ 30 | | | $\leq \frac{100}{U_{oc}}$ |
| - | 30 < $U_{oc}$ ≤ 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 a 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 to 200 Hz, 24,8 V DC switching at 10 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:

a) the output voltage is limited in compliance with Table 21, and

b) a linear or non-linear impedance limits the output in compliance with Table 21, 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 21 – Limits for limited energy source with current limiting impedance**

| Output voltage [a] $U_{oc}$ | | Output current [b, d] $I_{sc}$ | Maximum power [c] $S$ |
|---|---|---|---|
| V AC | V DC | A | VA |
| ≤ 30 V RMS. | ≤ 30 V | 0,5 | 15 |
| NOTE This table will be moved into a 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 Isc 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 terminal) 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 (including overheating of the power semiconductor) 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 electrical shock and fire hazard will result from failure of the component. Compliance shall be checked by the test of 9.2.5. The analysis shall be included in the test report.

NOTE 1 FMEA (Failure Mode and Effects Analysis) is generally used for this circuit analysis method.

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.

In case of an operating condition with a loss of phase, polyphase products shall not present a hazard. Compliance shall be checked by the test of 9.2.7.2.

NOTE 2 A loss of phase can be the result of an external phase supply interruption from the mains or an internal phase interruption.

#### 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 review of the product documentation 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 controllers and starters shall be operated in accordance with the manufacturer's instructions and their relevant product standard.

**8.2.1.1.1** Controllers and starters shall be so constructed that they

a) are trip free;

b) can be caused to return to the OPEN or OFF-state by the means provided when controlled running and at any time during the starting sequence or when performing any manoeuvre.

Compliance is verified in accordance with 9.3.3.6.3.

**8.2.1.1.2** Controllers and starters shall not malfunction due to mechanical shock or electromagnetic interference caused by operation of its internal devices.

Compliance is verified in accordance with 9.3.3.6.3.

**8.2.1.1.3** The moving contacts of the series mechanical switching device in semiconductor motor controllers and starters 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 controllers and starters

Controllers or starters 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 according to 9.3.3.6.3. Where a range is declared, 85 % shall apply to the lower value, and 110 % to the higher.

#### 8.2.1.3 Limits of operation of under-voltage relays and releases

An under-voltage relay or release can be associated with a semiconductor motor controller or starter. In addition to the test requirements of 9.3.3.6.6, the limits of operation of the under-voltage relays and releases shall be defined by the manufacturer if applicable.

#### 8.2.1.4 Limits of operation of shunt coil operated releases (shunt trip)

Vacant.

#### 8.2.1.5 Limits of operation of current sensing relays and releases

##### 8.2.1.5.1 Relays and releases in starters

##### 8.2.1.5.1.1 Limits of operation of time-delay overload relays when all poles are energized

##### 8.2.1.5.1.1.1 General tripping requirements of overload relays

The relays shall comply with the requirements of Table 4 when tested as follows:

a) with the overload relay or starter in its enclosure, if normally fitted, and at $A$ times the current setting, tripping operation shall not occur in less than 2 h starting from the cold state, at the value of reference ambient air temperature stated in Table 4. However, when the overload relay terminals have reached thermal equilibrium at the test current in less than 2 h, the test duration can be the time needed to reach such thermal equilibrium;

b) when the current is subsequently raised to $B$ times the current setting, tripping operation shall occur in less than 2 h;

c) for class 2, 3, 5 and 10 A overload relays energized at $C$ times the current setting, tripping operation shall occur in less than 2 min starting from thermal equilibrium, at the current setting, in accordance with 9.3.3 of IEC 60034-1:2017;

NOTE 2 Subclause 9.3.3 of IEC 60034-1:2017 states: “Polyphase motors having rated outputs not exceeding 315 kW and rated voltages not exceeding 1 kV shall be capable of withstanding a current equal to 1,5 times the rated current for not less than 2 min.

d) for class 10, 20, 30 and 40 overload relays energized at $C$ times the current setting, tripping operation shall occur in less than 4 min, 8 min, 12 min or 16 min respectively, starting from thermal equilibrium, at the current setting;

e) for semiconductor starter without current-limit function at $D$ times the current setting, tripping operation shall occur within the limits given in Table 3 for the appropriate trip class and tolerance band, starting from the cold state. For semiconductor starter with current-limit function, the test shall be done at the maximum $I_{lim}$ and the tripping operation shall occur within the time limits declared by the manufacturer according to 5.7.5.

NOTE 2 For semiconductor starters with current-limit function and an overload relay having a current setting range, the test with the maximum $I_{lim}$ is related only to the maximum setting of the overload relay. The test at the minimum setting can be done in the same way as without current-limit function.

In the case of overload relays having a current setting range, the limits of operation shall apply when the relay is carrying the current associated with the maximum setting and also when the relay is carrying the current associated with the minimum setting.

For non-compensated overload relays, the current multiple/ambient temperature characteristic shall not be greater than 1,2 %/K.

NOTE 3 1,2 %/K is the derating characteristic of PVC-insulated conductors.

An overload relay is regarded as compensated if it complies with the relevant requirements of Table 4 at +20 °C and is within the limits shown in Table 4 at other temperatures.

**Table 4 – Limits of operation of time-delay overload relays when energized on all poles**

| Type of overload relay | Multiples of current setting | | | | Ambient air temperature values |
|---|---|---|---|---|---|
| | A | B | C | D | |
| Thermal type not compensated for ambient air temperature variations | 1,0 | 1,2 [b] | 1,5 | 7,2 | +40 °C |
| Thermal type compensated for ambient air temperature variations | [c] | [c] | – | – | Less than 0 °C [d] |
| | 1,05 | 1,3 | 1,5 | – | 0 °C |
| | 1,05 | 1,2 [b] | 1,5 | 7,2 | +20 °C |
| | 1,0 | 1,2 [b] | 1,5 | – | +40 °C |
| | [c] | [c] | – | – | More than +40 °C [d] |
| Electronic type [a] | 1,05 | 1,2 [b] | 1,5 | 7,2 | 0 °C, +20 °C and +40 °C |

[a] These tests A, B and D shall only be done at 20 °C.

[b] **If specified by the manufacturer the tripping current could be different from 120 % but shall not exceed 125 %. In this case the test current value shall be equal to this tripping current value. In this case the tripping current value shall be marked on the product.**

[c] Multiples of current setting should be declared by the manufacturers.

[d] See 9.3.3.6.5 for test outside the range 0 °C to +40 °C.

#### 8.2.1.5.1.1.2 Thermal memory test verification

Unless the manufacturer has specified that the device does not contain thermal memory, electronic overload relays shall fulfil the following requirements (see Figure 3):

– apply a current equal to $I_e$ until the device has reached the thermal equilibrium;
– interrupt the current for a duration of 2 × $T_p$ (see Table 3) with a relative tolerance of ±10 % (where $T_p$ is the time measured at the *D* current according to Table 4);
– apply a current equal to 7,2 × $I_e$;
– the relay shall trip within 50 % of the time $T_p$.

For semiconductor starter with current-limit function, the test shall be done at the maximum $I_{lim}$ and the tripping operation shall occur within the time limits declared by the manufacturer.

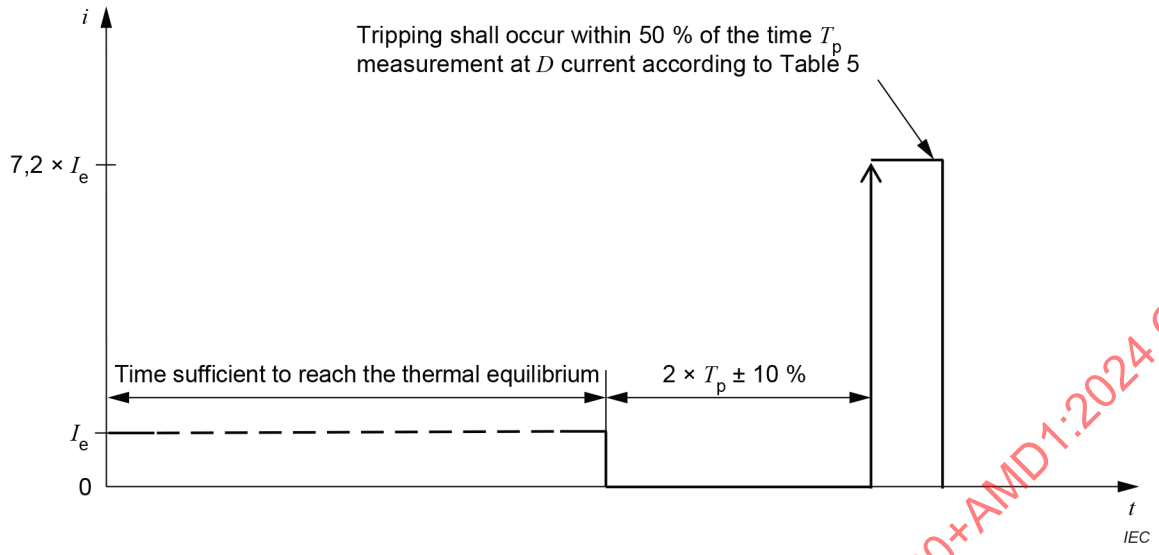



**Figure 3 – Thermal memory test**

#### 8.2.1.5.1.2 Limits of operation of three-pole time-delay overload relays energized on two poles

With reference to Table 5:

The overload relay or starter shall be tested in its enclosure if normally fitted. With the relay energized on three poles, at $A$ times the current setting, tripping operation shall not occur in less than 2 h, starting from the cold state, at the value of the ambient air temperature stated in Table 5.

Then, one pole shall be disconnected. When the value of the current flowing in two poles (in phase loss sensitive overload relay or release, those carrying the higher current) is increased to $B$ times the current setting, tripping operation shall occur in less than 2 h.

The values shall apply to all combinations of poles.

In the case of overload relays having an adjustable current setting, the characteristics shall apply both when the relay is carrying the current associated with the maximum setting and when the relay is carrying the current associated with the minimum setting.

**Table 5 – Limits of operation of three-pole time-delay overload relays when energized on two poles only**

| Type of overload relay | Multiples of current setting | | Reference ambient air temperature |
|---|---|---|---|
| | A | B | |
| Thermal, compensated for ambient air temperature variations or electronic<br><br>Not phase loss sensitive | 3 poles<br>1,0 | 2 poles<br>1,32<br><br>1 pole<br>0 | +20 °C |
| Thermal, not compensated for ambient air temperature variations<br><br>Not phase loss sensitive | 3 poles<br>1,0 | 2 poles<br>1,25<br><br>1 pole<br>0 | +40 °C |
| Thermal, compensated for ambient air temperature variations or electronic<br><br>Phase loss sensitive | 2 poles<br>1,0<br><br>1 pole<br>0,9 | 2 poles<br>1,15<br><br>1 pole<br>0 | +20 °C |

#### 8.2.1.5.2 Relays and releases associated with controllers

Relays and releases to be associated with a controller to provide protection for the motor shall operate within a time $T_x$ at a current $X \times I_e$, where $X$ and $T_x$ are the values given by the declared rating index. In the case of more than one declared rating index, $X$ and $T_x$ are the values corresponding to the rating index giving the highest product $(XI_e)^2 \times T_x$.

#### 8.2.1.5.3 Limits of operation of under-current relays

An under-current relay or release, when associated with a switching device, shall operate to open the switching device within 90 % to 110 % of the set time when the current during operation is below 0,9 times the under-current setting in all poles.

#### 8.2.1.5.4 Limits of operation of stall sensitive electronic overload relays

A stall sensitive electronic overload relay, when associated with a switching device, shall operate to open the switching device within 80 % to 120 % of the set time (stall inhibit time) or within the accuracy specified by the manufacturer, when

a) for current sensing relays, the current is 20 % higher than the set stall current value;

EXAMPLE Set current of the stall relay: 100 A; set time: 6 s; time setting accuracy: ±10 %. The relay is tripping within 5,4 s and 6,6 s when the current is equal to or greater than 100 A × 1,2 = 120 A.

b) for rotation sensing relays, an input signal indicating no motor rotation exists.

#### 8.2.1.5.5 Limits of operation of jam sensitive electronic overload relays and releases

A jam sensitive electronic overload relay or release, when associated with a switching device, shall operate to open the switching device within 80 % to 120 % of the set time (jam inhibit time) or within the accuracy specified by the manufacturer, when the current is above 1,2 times the set current value of the jam sensitive electronic overload relay, during running after completion of the starting.

#### 8.2.1.6 Mechanical switching devices used in semiconductor motor controllers and starters

The switching devices shall be verified as a part of the semiconductor motor controller or starter. 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.

The effectiveness of the interlocking shall be demonstrated during the thermal stability test or overload capability test in 9.3.3.6.1 or be verified by any other test covering the interlocking function for example by oscillographic means.

### 8.2.2 Temperature-rise

#### 8.2.2.1 General

The requirements of 8.2.2 of IEC 60947-1:2020 apply to controllers and starters 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, guarding and location to prevent danger is the responsibility of the installer. The manufacturer shall provide a suitable warning (for example symbol IEC 60417-5041:2002) in accordance with 6.3.

#### 8.2.2.2 Terminal

Subclause 8.2.2.2 of IEC 60947-1:2020 applies.

#### 8.2.2.3 Accessible parts

Subclause 8.2.2.3 of IEC 60947-1:2020 applies.

#### 8.2.2.4 Ambient air temperature

Subclause 8.2.2.4 of IEC 60947-1:2020 applies.

#### 8.2.2.5 Main circuit

##### 8.2.2.5.1 General

The main circuit of a controller or starter, which carries current in the FULL-ON state, including the over-current releases which may be associated with it, shall be capable of carrying the current $I_e$ 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.

##### 8.2.2.5.2 Mechanical switching devices in controllers and starters

The temperature-rise shall be verified by the procedures given in 9.3.3.3.4 and 9.3.3.6.1 (including Table 10 and Table 14). 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 9.3.3.6.1 (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 6.

**Table 6 – 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) K | |
|---|---|---|
| | 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 series 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

Controllers and starters shall be required to establish an ON-state, to commutate, 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 according to 9.3.3.6.

For controllers that are designated for utilization categories AC-2a, AC-3a, AC-8a, values of $T_x$ corresponding to $X$ values shall not be less than those given in Table 7. For corresponding starters, $T_x$ shall be the maximum tripping time of its overload relay in hot state declared by the manufacturer (see also footnote [b] of Table 8).

Controllers and starters that are designated for utilization categories AC-2b, AC-3b and AC-8b may be designated for those applications where long accelerating times are required. It shall be understood that the maximum thermal capacity of the controller may be depleted fully during the on-load period. Therefore, a suitable off-load period shall be provided for the controller immediately after the starting time has expired. The values of $T_x$ corresponding to $X$ values shall not be less than those given in Table 7. For corresponding starters, $T_x$ shall be the maximum tripping time of its appropriate overload relay (see also footnote [b] of Table 8).

In a locked rotor situation arising while the motor has been running at normal speed, the controller or starter shall be permitted to establish an OFF-state condition in shorter times than those given, provided it is equipped with suitable overload protection.

Ratings shall be verified under the conditions stated in Table 8, Table 9 and Table 10 of this document, and in the relevant parts of 9.3.3.5.2 and 9.3.3.5.3 of IEC 60947-1:2020.

Where X × $I_e$ is greater than 1 000 A, the overload capability verification may be provided by other methods such as computer modelling simulation. The method and the result shall be described in the test report.

In Table 8 and Table 10, the ON-time and OFF-time should be in accordance with Table 2 for the most severe duty cycle sequence. If a controller is rated and tested for a duty cycle that is more severe than the standard duty cycle sequence based on Table 8, the manufacturer may assign the same rating for a standard duty cycle sequence without further testing.

**Table 7 – Minimum overload current withstand time ($T_x$) in relation to overload current ratio ($X$) and corresponding to overload relay trip class** (see Table 3)

| **Designation** [a] (included as a guide only) | **Minimum overload current withstand time, $T_x$** s | | | | | | |
|---|---|---|---|---|---|---|---|
| | $X$ = 8 | $X$ = 7 | $X$ = 6 | $X$ = 5 | $X$ = 4 | $X$ = 3 | $X$ = 2 |
| 2 | 0,7 | 0,9 | 1,2 | 1,8 | 2,7 | 5 | 11 |
| 3 | 1 | 1,3 | 1,8 | 2,6 | 4 | 7 | 16 |
| 5 | 1,2 | 1,5 | 2 | 3 | 4,6 | 8,3 | 19 |
| 10A | 1,6 | 2 | 3 | 4 | 6 | 12 | 26 |
| 10 | 3 | 4 | 6 | 8 | 13 | 23 | 52 |
| 20 | 5 | 6 | 9 | 12 | 19 | 35 | 78 |
| 30 | 7 | 9 | 13 | 19 | 29 | 52 | 112 |
| 40 | 11 | 15 | 20 | 29 | 45 | 80 | 180 |
| [a] Designations are provided for information only without any direct relation to Table 3. | | | | | | | |

**Table 8 – Minimum requirements for thermal stability test conditions**

| **Utilization category** | **Current-limit function** | **Test current ($I_T$) Operating cycle ON-time** s | | | | **Operating cycle OFF-times** |
|---|---|---|---|---|---|---|
| | | **Test level 1** [a] | | **Test level 2** [a] | | |
| | | **$I_T$** | **ON-time** [b] | **$I_T$** | **ON-time** [b] | |
| AC-2a, AC-3a, AC-8a | Yes | $I_{lim}$ [d] | t | $I_e$ | (36*F/S)-t | 36*(100-F)/S |
| | No | *0,75 *$I_{LRP}$* | | | | |
| | No (DOL) | $I_{LRP}$ | | | | |
| AC-2b, AC-3b, AC-8b | Yes | $I_{lim}$ [d] | t | Not applicable | Not applicable | (3600/S)-t |
| | No | *0,75* $I_{LRP}$* | | | | |
| | No (DOL) | $I_{LRP}$ | | | | |

Parameters of the test circuit:

$I_{LRP}$ = prospective locked rotor current according to Table 9.
$I_e$ = rated operational current
$I_{lim}$ = current setting of the current-limit function
$I_T$ = test current
$U_T$ = test voltage (may be any value)
Cos φ = test circuit power factor (may be any value)
Number of operating cycles [c]

[a] Changeover time from level 1 to level 2 shall not be greater than three full periods of the power frequency. The current during level 1 shall be carried by the semiconductor only.

[b] For a semiconductor motor controller or starter intended to be used only together with a specified overload relay, t is the maximum operating time allowed by the tolerances of its overload relay in the hot state. For semiconductor motor controller without specified overload relay, t = $T_x$ and is selected from Table 7 according to $X = I_T/I_e$ and the declared overload trip class.

[c] The number of operating cycles will depend upon the length of time required for the controller to reach thermal equilibrium.

[d] $I_{lim}$ is the current-limit value declared by the manufacturer according to the overload current profile according to 5.3.5.2.

**Table 9 – Prospective locked rotor current by utilization categories**

| Utilization category | $I_{LRP}$ |
|---|---|
| AC-2a | 4 × $I_e$ |
| AC-2b | |
| AC-3a | 8 × $I_e$ [a] |
| AC-3b | |
| AC-8a | 6 × $I_e$ |
| AC-8b | |
| a For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE to IEC 60034-12:2016, $I_{LRP}$ is equal to 8,5 × $I_e$. | |

**Table 10 – Minimum requirements for overload capability test conditions**

| Utilization category | Parameters of the test circuit | | | Operating cycle ON-time s | Operating cycle OFF-time s | Number of operating cycles [g] |
|---|---|---|---|---|---|---|
| | $I_T$ [h, f] | $U_r / U_e$ [a] | Cos φ [b] | | | |
| AC-2a | $I_{LRP}$ [g,e] | 1,05 | 0,65 | t [c] | ≤ (3600/S)-t | 3 or 4 |
| AC-3a | | | [d] | | | |
| AC-8a | | | [d] | | | |
| AC-2b | $I_{LRP}$ [g,e] | 1,05 | 0,65 | t [c] | ≤ (3600/S)-t [i] | 3 |
| AC-3b | | | [d] | | | |
| AC-8b | | | [d] | | | |

$I_{LRP}$ prospective locked rotor current

$I_e$ rated operational current

$I_T$ test current

$U_e$ rated operational voltage

$U_r$ power frequency recovery voltage

*Temperature conditions:* 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 (see 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 φ 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] For a semiconductor motor controller intended to be used only together with a specified overload relay or

starter, t is the maximum operating time allowed by the tolerances of its overload relay in the hot state which is the state of thermal equilibrium reached during the temperature-rise test (see 9.3.3.3).

For a semiconductor motor controller intended to be used without a specified overload relay, t = $T_x$ is selected from Table 7 according to $X = I_T/I_e$ and the declared overload trip class.

[d] For $I_e$ ≤ 100 A: cos φ = 0,45; for $I_e$ > 100 A: cos φ = 0,35. For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE according to IEC 60034-12:2016, cos φ = 0,35 for $I_e$ ≤ 100 A: cos φ = 0,25; for $I_e$ > 100 A.

[e] $I_{LRP}$ may be limited by the EUT.

[f] In case of current-limit function, see 9.3.3.6.3 (3) e).

[g] See Table 9.

[h] In the case of three operating cycles, the current shall be carried by the semiconductor only. In the case of four operating cycles, then the current shall be carried only by the semiconductor in the first two operating cycles. In the last two operating cycles the current shall be carried by the device that is normally carrying the current in the FULL-ON state.

[i] For utilization categories AC-2b, AC-3b, AC-8b, the manufacturer may claim compliance with the capability to perform starting operations with the OFF-time values less than 1 440 s. However, it shall be verified by testing with the OFF-time declared by the manufacturer.

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

##### 8.2.4.2.1 General

The controller or starter, including the over-current releases and the mechanical switching devices associated with it, shall be capable of operating without failure in the presence of locked rotor motor current, starting current and overload current.

The capability of making and breaking currents without failure shall be verified under the conditions stated in both Table 11 and Table 12, for the required utilization categories, and the number of operations indicated.

##### 8.2.4.2.2 Mechanical switching devices of controllers and starters

The making and breaking capacity shall be verified when tested as a combined unit in accordance with the procedures of 9.3.3.5.1 and 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 9.3.3.6.2 and 9.3.3.6.3.

#### 8.2.4.3 Requirements for an induction motor test load

The induction motor test load shall feature a four-pole squirrel cage motor with the following characteristics:

a) the rated voltage of the motor shall be equal to or greater than Ue for the device to be tested;

b) the parameters of the mechanical load connected to the motor shaft shall be adjusted to produce a decelerating time from base speed to zero speed within the range of 2 s to 4 s.

**Table 11 – 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-2a, b | 4,0 | 1,05 | 0,65 | 0,05 | [b] | 50 |
| AC-3a, b | 8,0 [c] | | [a] | | | |
| AC-8a, b | 6,0 | | [a] | | | |

| | | |
|---|---|---|
| $I_c$ = current made and broken, expressed in AC RMS symmetrical values<br>$I_e$ = rated operational current<br>$U_e$ = rated operational voltage<br>$U_r$ = power frequency recovery voltage<br>[a] For $I_e \leq 100$ A: Cos φ = 0,45<br>For $I_e > 100$ A: Cos φ = 0,35<br>[b] OFF-time shall not be greater than the values given in the chart.<br>[c] For devices with no controlled acceleration (DOL) and intended for use with an asynchronous motor of design NE or HE according to IEC 60034-12:2016, $I_c/I_e$ is equal to 8,5. | **Current $I_c$** A | **OFF-time** s |
| | $I_c \leq 100$ | 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 |
| | $1\,600 < I_c$ | 240 |

**Table 12 – 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-2a, b | 2,0 | 1,05 | 0,65 | 0,05 | [b] | 6 000 |
| AC-3a, b | 2,0 | 1,05 | [a] | | | |
| AC-8a, b | 6,0 | 1,05 | 0,35 | 1<br>10 | 9<br>90 | 5 900<br>100 |

| |
|---|
| $I_c$ = current made and broken, expressed in AC RMS symmetrical values<br>$I_e$ = rated operational current<br>$U_e$ = rated operational voltage<br>$U_r$ = power frequency recovery voltage |
| [a] For $I_e \leq 100$ A: Cos φ = 0,45<br>For $I_e > 100$ A: Cos φ = 0,35<br>[b] OFF-times shall not be greater than the values given in Table 11. |

#### 8.2.4.4 Semiconductor motor controller power losses

Where the power losses of the semiconductor motor controller or starter is given, the power semiconductor losses shall be calculated according to 5.3.7.1 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 current of controllers and starters backed up by short-circuit device(s) (SCPDs) shall be verified by short-circuit tests as specified in 9.3.4.

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 starter.

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 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 installation and shall be suitable for further use. For mechanical switching device of controllers and starters, 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 a SCPD not in compliance with the manufacturer's recommendations can invalidate the coordination.

#### 8.2.5.2 Coordination at the crossover current between the starter and the SCPD

The manufacturer shall describe the continuity of the short-circuit coordination between the protection functions up to its rated conditional short-circuit current. (SCPD, overload protection, other internal protections, line contactor, bypass contactor etc.).

## 8.3 EMC requirements

### 8.3.1 General

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

Environments A and B of IEC 60947-1:2020 are implemented in this document in 8.3.3.1 as class A and B equipment according to CISPR 11.

The general electromagnetic environment of the equipment covered by this document is E-III, industrial according to IEC TR 63216.

Other environments defined by IEC TR 63216 may be selected. The environment E-IV is relevant for equipment intended for being installed within high voltage power station and substation. The environment E-II is relevant for accessories such as control device or digital interfaces not directly supplied by the factory mains (see IEC TR 63216).

For EMC test, the minimum system to be considered is the controller interconnected with a motor load and cables.

When a radiocommunication device is embedded into the equipment, 8.4 of IEC 63404:2024 shall apply.

### 8.3.2 Immunity

#### 8.3.2.1 General

Electrical system influences may be destructive or non-destructive, depending on the intensity of the influence. Destructive influences (voltage or current) cause irreversible damage to a controller or starter. Non-destructive influences may cause temporary malfunction or abnormal operation, but the controller or starter returns to normal operation after the influence is minimized or removed; in some cases, this may require manual intervention.

The test results are specified using the performance criteria given in Table 13.

**Table 13 – Specific performance criteria when EM disturbances are present**

| Item | Performance criteria (performance during test) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| A Overall performance | No noticeable changes of the operating characteristic.<br>Operating as intended. | Noticeable changes (visual or audible) of the operating characteristic.<br>Self-recoverable. | Changes in operating characteristic.<br>Triggering of protective devices.<br>Not self-recoverable. |
| B Operation of power and driving circuits | No maloperation. | Temporary maloperation which cannot cause tripping, or erratic and audible changes in motor torque. | Shut down.<br>Triggering of protective devices.<br>Not self-recoverable. |
| C Operation of displays and control panels | No changes to visible display information.<br>Only slight light intensity fluctuation of LEDs, or slight movement of characters. | Temporary visible changes or loss of information.<br>Undesired LED illumination | Shut down.<br>Permanent loss or display of wrong information.<br>Unpermitted operating mode.<br>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.<br>Loss of data and/or information.<br>Errors in communication.<br>Not self-recoverable. |

#### 8.3.2.2 Electrostatic discharge

The test values and procedures are given in 9.4.2.1.

#### 8.3.2.3 Radio-frequency electromagnetic field

The test values and procedures are given in 9.4.2.2.

#### 8.3.2.4 Fast transients (common mode) (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 General

Subclause 8.3.3 of IEC 60947-1:2020 applies with the following addition.

The limits of CISPR 11 apply for Class B equipment intended to be used in residential areas connected to public low-voltage distribution systems and for Class A equipment intended to be used in all locations other than those allocated in residential areas.

#### 8.3.3.2 Low-frequency emission with reference to main power frequency

##### 8.3.3.2.1 Harmonics

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.

##### 8.3.3.2.2 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.

#### 8.3.3.3 High-frequency emission

##### 8.3.3.3.1 Conducted radio-frequency (RF) emission

The limits given in Table 17 shall be verified in accordance with the procedures of 9.4.3.2.

##### 8.3.3.3.2 Radiated emission

The limits given in Table 18 shall be verified in accordance with the procedures of 9.4.3.3.

## 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 controllers and starters of all types and their dedicated wiring accessories with this document. They comprise the verification of

a) temperature-rise limits (9.3.3.3);
b) dielectric properties (9.3.3.4);
c) operating capability (9.3.3.6);
d) operation and operating limits (9.3.3.6.3);
e) rated making and breaking capacity and conventional operational performance of series mechanical switching devices of equipment (9.3.3.5);
f) performance under short-circuit conditions (9.3.4);
g) mechanical properties of terminals (9.2.5 of IEC 60947-1:2020 applies);
h) degrees of protection of enclosed controllers and starters (Annex C of IEC 60947-1:2020 applies);
i) EMC tests (9.4).

### 9.1.3 Routine tests

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

Routine tests for controllers and starters comprise

– operation and operating limits (9.5.2);
– dielectric tests (9.5.3).

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

### 9.1.4 Sampling tests

Sampling tests for controllers and starters comprise

– operation and operating limits (9.5.2);
– dielectric tests (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 ≤1:

– acceptance number Ac = 0 (no defect accepted);
– rejection number Re = 1 (if 1 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 the above ISO 2859-1 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 apply.

### 9.1.5 Special tests

#### 9.1.5.1 General

Verifications are required when environment withstand data according to 9.1.5.2 or short-circuit coordination data according to 9.1.5.3 are given in the equipment documentation.

#### 9.1.5.2 Environmental 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. The overload relay shall not trip during the test. To check the behaviour 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.

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 AC-3 current, but may be limited to 100 A for practical reasons. During the last hour, the controller shall be operated 5 times. During the test the overload relay is permitted to trip.

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 AC-3 current which may be limited to 100 A for practical reasons. During this last hour the controller shall be operated 5 times. During the test the overload relay shall not trip.

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 AC-3 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. The overload relay may trip only if it is permitted according to its temperature characteristic.

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

#### 9.1.5.3 Coordination between the starter and the SCPD

The verification of the short-circuit coordination between different over-current protections up to the rated conditional short-circuit current shall be demonstrated either by documentation, simulation or test (see Annex C).

### 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 19, Table 20, or Table 21, as applicable. Further adjustment is made, if necessary, to maintain the limit of apparent energy for the time period indicated in Table 19, Table 20, or Table 21, as applicable.

The test complies, if after the test period the available apparent power does not exceed the limits indicated in Table 19, Table 20, or Table 21, 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 20.

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 function 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. This shall include the condition where forced cooling system is made inoperative by physically preventing its operation. In case of multiple cooling channels, only one channel at a time shall be made inoperable.

NOTE 1 The forced cooling system can be made inoperative for example by disconnecting the supply of the fan.

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 a 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 9.3.4.1.2d) of IEC 60947-1:2020, to the supply circuit.

NOTE 2 The definition of enclosed equipment is given in Annex C of IEC 60947-1:2020.

#### 9.2.5.3 Test conditions

In case of a forced cooling system made inoperative, the test shall be terminated when a protective device trips or when the temperature of the semiconductors in the main circuits stabilize. The temperature shall be measured as for the temperature-rise test according to 9.3.3.3.4. Thermal stability is reached when the variation does not exceed 1 K per hour.

### 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.

### 9.2.7 Abnormal operating tests

#### 9.2.7.1 General

Before all abnormal operation tests, the test sample shall be mounted, connected, and operated as described in the temperature-rise test.

Faults that are the direct consequence of an abnormal operating conditions are considered to be part of that abnormal operating condition.

For equipment without a dedicated enclosure, the equipment shall be tested under the conditions of 9.2.5.3.

Surgical cotton shall be placed over all openings, handles, flanges, joints and similar locations on the outside of the enclosure, in a manner which will not significantly affect the cooling when the test lasts long enough to have significant temperature rise.

Where the equipment under test is specified in its installation manual to require external means of protection against faults, these specific means shall be provided for the test.

The individual tests shall be performed until terminated by activation of a protective device or mechanism (internal or external), a component failure occurs that interrupts the fault condition, or the temperature of the semiconductors or the mechanical switching device, as indicated in 9.3.3.3.4, in the main circuits stabilize. The temperature shall be measured as for the temperature-rise test according to 9.3.3.3.4. It is assumed that a steady state is reached when the variation does not exceed 1 K per hour.

#### 9.2.7.2 Loss of phase

This test is not required for a semiconductor motor-starter that meets:

– The test requirements of 9.3.3.6.6 c) for three-pole thermal or electronic overload relays energized on two poles only;

– In addition to the test of 8.2.1.5.1.2, this test shall be repeated with one pole disconnected and with the relay energized on only two poles at B times the current setting. The tripping operation shall occur in less than 2 h, starting from the cold state; and

– The adequacy of the insulation shall be verified by a dielectric test on the controller or starter. The test voltage shall be applied as specified in 9.3.3.4.1 (4).

A multi-phase equipment shall be operated with each phase (including neutral, if used), in turn, disconnected at the input. The test shall be performed by disconnecting one phase with the equipment operating at 1,32 times the rated current $I_e$ (with one phase of the load disconnected) and shall be repeated by initially energizing the equipment with one phase disconnected.

The test shall continue according to the conditions of 9.2.7.1, but shall be terminated after 21 min.

If the disconnection of a single phase can decisively be determined to result in a more severe condition, for example disconnection of the phase with the protective device least likely to respond to the loss of phase, then the test can be conducted by disconnecting only that phase instead of each phase in turn.

NOTE If fuses are used, a voltage can remain at the open phase caused by internal impedances within the equipment connected between the phases.

#### 9.2.7.3 Acceptance criteria

As a result of the abnormal operation tests, the equipment shall comply with the following:

a) there shall be no emission of flame, burning particles or molten metal;

b) the surgical cotton shall not have ignited;

c) the connection to protective earth and the earth continuity of the equipment shall not have opened;

d) doors and covers of enclosed equipment shall remain in place;

e) accessible circuits shall not exhibit hazardous voltages;

f) during and after the test, hazardous live parts at voltages greater than SELV/PELV in accordance with Annex N of IEC 60947-1:2020 or limited energy source levels of 8.1.14 shall not become accessible;

g) components, e.g. busbar supports, used for the mounting of live parts shall not break away from their initial position;

h) no conductor shall get pulled out of its terminal connector; and

i) no parts shall be ejected from the enclosure of the enclosed equipment.

The equipment shall comply with the power frequency or DC withstand voltage t est of 9.3.3.4.1 (4) following the abnormal operation tests.

The equipment is not required to be operational after testing and can become deformed. Overcurrent protection integral to the equipment, or required to be used with the equipment, is allowed to open.

### 9.3 Compliance with performance requirements

#### 9.3.1 Test sequences

Each test sequence is made on a new sample.

NOTE 1 More than one test sequence or all test sequences can be conducted on one sample. However, the tests are conducted in the sequence given for each sample.

NOTE 2 Some tests are included in the sequences solely to reduce the number of samples required, the results have no significance for the preceding or following tests in the sequence. Therefore, for convenience of testing, these tests can be conducted on separate new samples and omitted from the relevant sequence. This can only apply to the following tests when called for:

– 9.3.3.4.1, item 7) of IEC 60947-1:2020, Verification of creepage distances;

– 9.2.5 of IEC 60947-1:2020, Mechanical and electrical properties of terminals;

– Annex C of IEC 60947-1:2020, Degrees of protection of enclosed equipment.

The test sequence shall be as follows:

a) Test sequence I
   1) Verification of temperature-rise (9.3.3.3)
   2) Verification of dielectric properties (9.3.3.4)

b) Test sequence II: Operating capability verification (9.3.3.6)
   1) Thermal stability test (9.3.3.6.2)
   2) Overload capability test (9.3.3.6.3)
   3) Blocking and commutating capability test (9.3.3.6.4), including verification of operation and operating limits

c) Test sequence III

   Performance under short-circuit conditions (9.3.4)

d) Test sequence IV
   1) Verification of mechanical properties of terminals

      (see 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 (Annex C of IEC 60947-1:2020)

e) Test sequence V

   EMC tests (9.4)

f) Test sequence VI

Tripping operation test (9.3.3.6.6)

### 9.3.2 General test conditions

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

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 higher 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 applies.

##### 9.3.3.3.4 Temperature-rise of the main circuit

Subclause 9.3.3.3.4 of IEC 60947-1:2020 applies with a minimum cross-section of 1 $mm^2$ with additions as below, 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.

For semiconductor switching devices connected in the main circuit (see 8.2.2.4), 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 9.3.3.6.2.

For mechanical switching devices (see 8.2.2.5.2), 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.

Starters shall be fitted with an overload relay, complying with 5.7, and selected as follows:

– non-adjustable relay:

  the current setting shall be equal to the maximum operational current of the starter, and the test shall be at this current;

– adjustable relay:

  the maximum current setting shall be that which is nearest to, but not greater than, the maximum operational current of the starter.

For starters, the test shall be made with that overload relay for which the current setting is nearest to the maximum of its scale.

NOTE The selection method described above is designed to ensure that the temperature-rise of these field wiring terminals of the overload relay, and the power dissipated by the starter, are not less than those that will occur under any combination of relay and controller. In cases where the effect of the overload relay on these values is insignificant (as in solid-state overload relays), the test current is the maximum operational current of the starter.

#### 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 contactors or starters 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 (for example opto-coupler, 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 (3.1.2.31) 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 addition:

The test voltage shall be applied for semiconductor controller or starters with series mechanical switching device, 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.

(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

### 9.3.3.5 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 motor controllers and starters

The complete unit with bypass installed shall be tested as in normal service. The operational sequence, to simulate starting and stopping, shall be the same as in normal service.

If the mechanical switching devices has already fulfilled the requirements according to Table 11 and Table 12, 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:

– thermal stability test;
– overload capability test;
– 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 $U_s$.

If the controller within a starter has satisfied the requirements of a previous operating capability test, and meets the requirements for assigning ratings based on the results of test as given in 5.4.2, the starter need not be tested.

**Table 14 – Thermal stability test specifications**

| Item | 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.<br>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<br>$\Delta_n = (C_n - C_{n-1} - A_n + A_{n-1})/(C_{n-1})$ | |
| Test conditions | Table 8 | |
| EUT temperature | $C_n$, case temperature | Temperature sensing means attached to the outer surface of one semiconductor switching device (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 | a) $\Delta_n \leq 0{,}05$ within 8 h<br>b) No visual evidence of damage (such as smoke, discoloration)<br>c) 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.<br>d) 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. | |

**Table 15 – Initial case temperature requirements**

| Operating cycle number | Initial case temperature, $C_i$<br>°C |
|---|---|
| 1 | Not less than 40 °C |
| 2 | Highest temperature enabling resetting after the first operating cycle of the overload relay of the starter, or the overload relay recommended by the manufacturer to be used together with the controller. |
| 3 and 4 | ≥40 °C plus the maximum case temperature-rise during the temperature-rise test (9.3.3.3) |

If 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, the effectiveness of the interlocking shall be demonstrated in accordance with 8.2.1.6.

#### 9.3.3.6.2 Thermal stability test procedure

Test specifications and acceptance criteria are given in Table 14. The test profiles are illustrated in Figure F.1.

(1) Assign a sequence number, n, to each on-load period in the test series (as $n$ = 0, 1, 2,... N-1, N).

(2) Record initial case temperature $C_0$. Record initial ambient temperature $A_0$.

(3) Set test current, $I_T$, level 1 (see Table 8). Change n to a new value where n = n+1.

(4) The time span of t commences at the instant when the test current reaches the value $I_T$. Therefore, the time for the test current controlled acceleration to reach $I_T$ increases the total test time.

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

NOTE The time span of $T_x$ commences at the instant when the test current reaches the value $X \times I_e$. Therefore, the time for the test current controlled acceleration to reach $X \times I_e$ increases the total test time.

(5) This step needs to be performed with respect to the utilization category.

a) For AC-2a, AC-3a, AC-8a only.

After time interval t (Table 8), change test current, IT, to level 2.

After time interval for level 2, switch EUT to OFF-state.

b) For AC-2b, AC-3b, AC-8b only.

After time interval t (Table 8), 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 (Table 14)

If $\Delta_n > 0{,}05$, total test time is less than 8 h, and results to be obtained (a) and b) of Table 14) are not violated, repeat steps 3 to 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 a), b), c) and d) of Table 14 are not violated, end test. This is successful compliance.

#### 9.3.3.6.3 Overload capability test procedure

(1) Test conditions

a) Refer to Table 10. The test profile is represented in Figure F.2.

b) Controllers and starters, utilizing a current controlled cut-out device in addition to an overload relay to provide 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 highest value of $X$ specified for $I_e$.

c) Where the EUT is a starter, its overload relay shall be disabled. The operating cycle ON-time $t$, shall be set in accordance with c) of Table 10.

NOTE The time span of $t$ commences at the instant when the test current reaches the value $I_T$. Therefore, the time for the test current controlled acceleration 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 motor controller or starter 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 10), switch the EUT to the OFF-state.

e) Repeat steps c) and d) for the number of cycles of Table 10. End test.

In the case of the EUT having a current limit function during motor starting (and possibly stopping), but not in the FULL-ON state, the overload capability test