

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

**Appareillage à basse tension –
Partie 4-2: Contacteurs et démarreurs de moteurs – Gradateurs, démarreurs et
démarreurs progressifs à semiconducteurs de moteurs**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

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

FOREWORD

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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.

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

FDIS	Report on voting
121A/353/FDIS	121A/360/RVD

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

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 publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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 speed¹;
- 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 circuits¹;
- adjustable speed electrical power drive systems (see IEC 61800 series);
- use of the product within explosive atmospheres (see IEC 60079 series);
- software and firmware requirements¹;

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;

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, *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*

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]

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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.

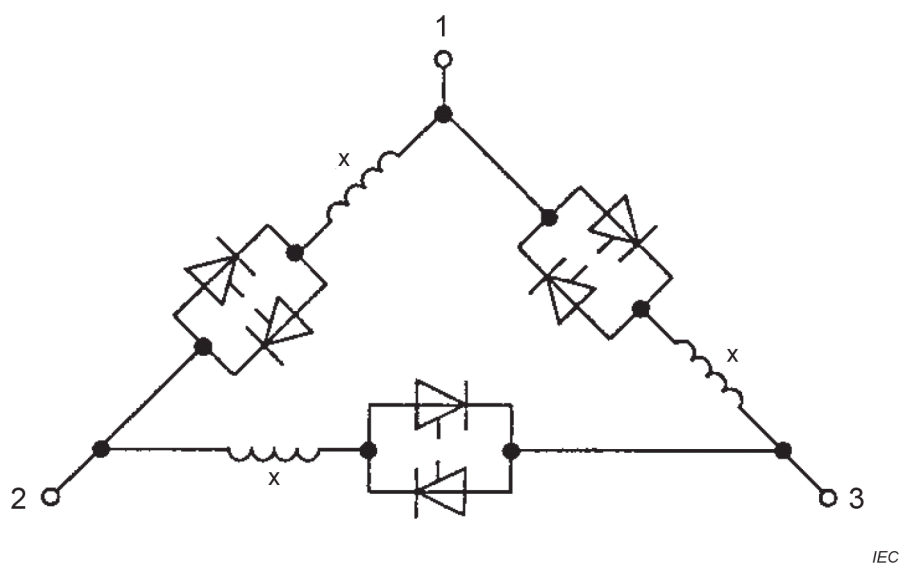


Figure 2a – Motor in delta – Thyristors in series with a winding

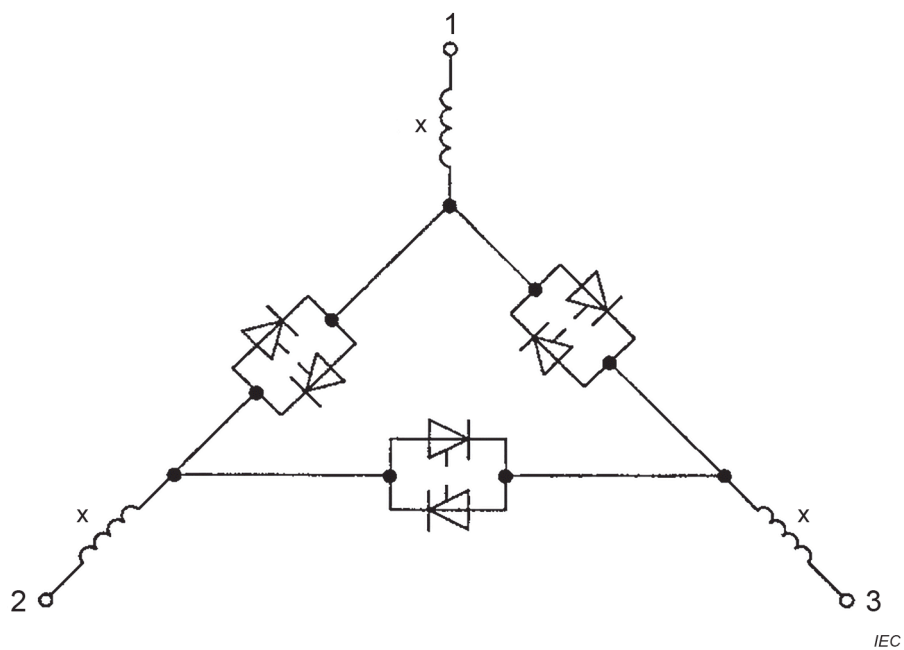
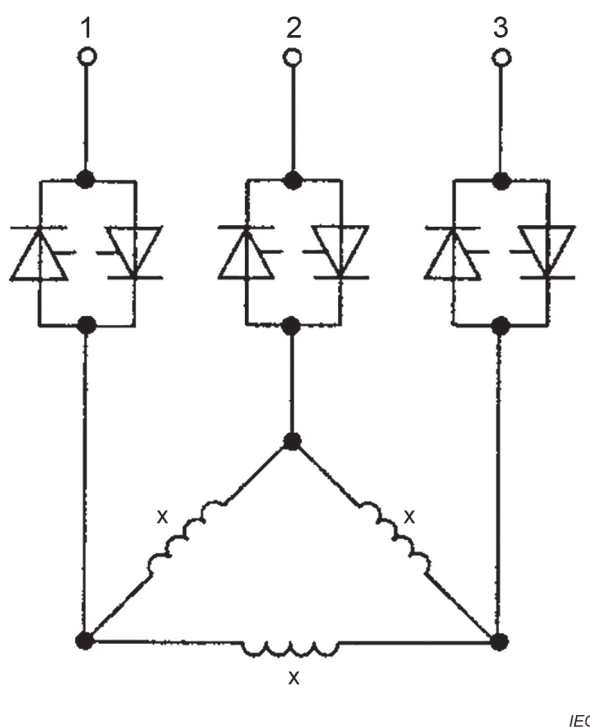


Figure 2b – Motor in star – Thyristors in delta



IEC

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.

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:

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

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:

- 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;
- 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.

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 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.

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	Highest value of $(XI_e)^2 \cdot T_x$	Highest value of $F \cdot S$
	AC-3a		
	AC-8a		
	AC-2b	Highest value of $(XI_e)^2 \cdot T_x$	Lowest value of OFF-time
	AC-3b		
	AC-8b		
^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 and Table 4, column D ^a	Tripping time T_p under the conditions specified in 8.2.1.5.1.1 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.		
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, 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: $6 \times I_e$ -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: $3 \times I_e$ -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) (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.

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.

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

For each relevant potential hazard, the manufacturer shall provide safety signs, graphical symbols or safety notes of the hazard for example by using e.g. IEC 60417-5036:2002. 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 need 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.

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 taking into account:

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

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

7.1.3 Atmospheric conditions

7.1.3.1 Humidity

Subclause 7.1.3.1 of IEC 60947-1:2020 applies.

7.1.3.2 Degrees of pollution

Unless otherwise stated by the manufacturer, 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. Components or assemblies of components, for which no relevant product standard exists, shall be tested according to the requirements of this document. Where mechanical switching devices are used, they should meet the requirements of their own IEC product standard, and the additional requirements of this document.

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

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

The user manual shall give details of all safety-relevant 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 IEC 60445.

8.1.9 Additional requirements for equipment provided with a neutral pole

Vacant.

8.1.10 Provisions for protective earthing

Subclause 8.1.10 of IEC 60947-1:2020 applies.

8.1.11 Enclosures for equipment

Subclause 8.1.11 of IEC 60947-1:2020 applies.

8.1.12 Degrees of protection of enclosed equipment

Subclause 8.1.12 of IEC 60947-1:2020 applies.

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

Subclause 8.1.13 of IEC 60947-1:2020 applies.

8.1.14 Limited energy source

8.1.14.1 General

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

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

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

8.1.14.2 Limited energy source with galvanic separation

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

- a) the output is inherently limited in compliance with Table 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		Output current ^{b, d}	Maximum power ^c
U_{oc}			
V AC	V DC	I_{sc} A	S VA
≤ 30 RMS	≤ 30 V	≤ 8	100
-	$30 < U_{oc} \leq 60$ ^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 I_{sc} is made 5 s after application of the load if protection is by an electronic circuit or a positive temperature coefficient device (e.g. PTC 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		Output current ^{b, d}	Maximum power ^{c, d}	Current rating of over-current protective device ^e
U_{oc}				
V AC	V DC	I_{sc} A	S VA	A
≤ 20	≤ 20	$\leq \frac{1000}{U_{oc}}$	250	≤ 5,0
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$ ^f			$\leq \frac{100}{U_{oc}}$
-	$30 < U_{oc} \leq 60$ ^f			$\leq \frac{100}{U_{oc}}$

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

NOTE 2 This table will be moved into 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:

- the output voltage is limited in compliance with Table 21, and
- 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} A	Maximum power ^c S VA
V AC	V DC		
≤ 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 I_{sc} is made 5 s after application of the short-circuit.			

8.1.15 Stored charge energy circuit

Parts including stored charge (capacitors) that are accessible (such as coil 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.

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

8.1.17 Short-circuit and overload protection of ports

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

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

8.2 Performance requirements

8.2.1 Operating conditions

8.2.1.1 General

Auxiliary devices used in 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, 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 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 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 $2 \times T_p$ (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 $7,2 \times I_e$;
- 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.

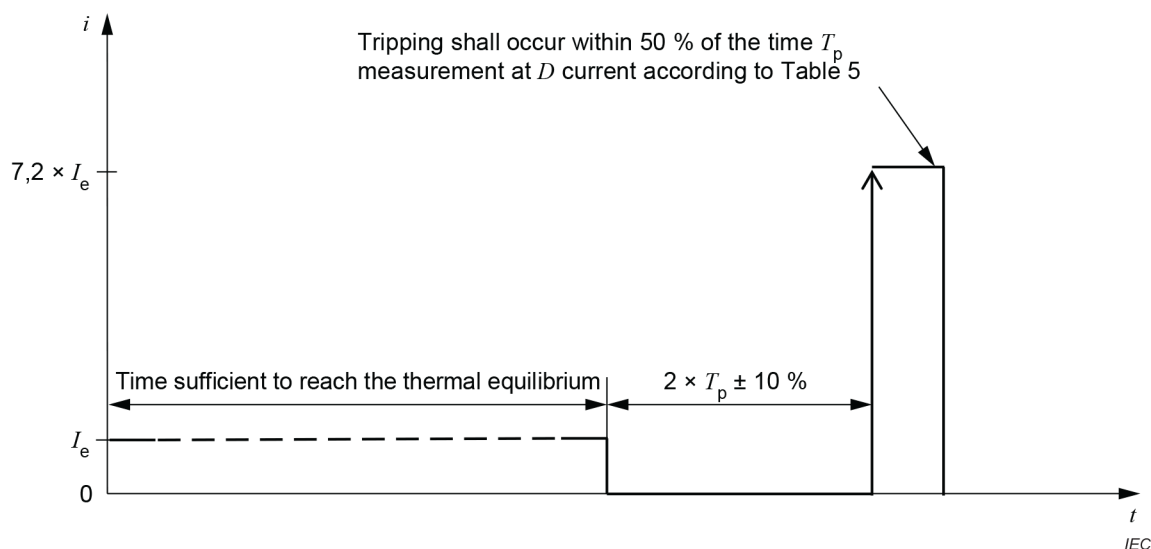


Figure 3 – Thermal memory test

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 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 Not phase loss sensitive	3 poles 1,0	2 poles 1,32 1 pole 0	+20 °C
Thermal, not compensated for ambient air temperature variations Not phase loss sensitive	3 poles 1,0	2 poles 1,25 1 pole 0	+40 °C
Thermal, compensated for ambient air temperature variations or electronic Phase loss sensitive	2 poles 1,0 1 pole 0,9	2 poles 1,15 1 pole 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: $\pm 10\%$. The relay is tripping within 5,4 s and 6,6 s when the current is equal to or greater than $100 \text{ A} \times 1,2 = 120 \text{ A}$.

- 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.

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 commute, to carry designated levels of overload currents, and to establish and sustain an OFF-state condition without failure or any type of damage when tested 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).