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Application of the short-circuit ratings of low-voltage switchgear and controlgear

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National foreword

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— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;

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INTRODUCTION

Low-voltage equipment standards IEC 60947 and IEC 60439 currently include short-circuit ratings for products and assemblies respectively, defined in terms of the ability of the equipment to operate at a level of peak current, an r.m.s. current for a specified time and/or a level of current conditional upon a short-circuit protective device in series. In practice the correct application of the various short-circuit ratings needs to be fully understood by the circuit designer to avoid leaving a circuit or equipment with inadequate short-circuit protection. It is also useful to take full advantage of the capability of devices and systems to avoid over-engineering, with the consequent unnecessary additional cost.

APPLICATION OF THE SHORT-CIRCUIT RATINGS OF LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR

1 Scope

This technical report, which serves as an application guide for the short-circuit ratings given in IEC standards for low-voltage switchgear and controlgear and assemblies, summarises the definitions of the ratings and provides examples of their application.

2 Reference documents

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

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60439-1[1], *Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested and partially type-tested assemblies*

IEC 60439-2[1], *Low-voltage switchgear and controlgear assemblies – Part 2: Particular requirements for busbar trunking systems (busways)*

IEC 60898-1, *Electrical accessories – Circuit-breakers for overcurrent protection for household and similar installations – Part 1: Circuit-breakers for a.c. operation*

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

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 60947-6-2, *Low-voltage switchgear and controlgear – Part 6-2: Multiple function equipment – Control and protective switching devices (or equipment) (CPS)*

IEC 61009-1, *Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs) – Part 1: General rules*

IEC/TR 61459, *Low-voltage fuses – Coordination between fuses and contactors/motor-starters – Application guide*

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[1] A new series of standards is in preparation to replace the IEC 60439 series (provisionally IEC 61439 series).

3 Alphabetical list of definitions and characteristics

	Clause
B	
Breaking capacity of a fuse-link	6.3.1
C	
Circuit-breaker to IEC 60898-1	6.2 b) ii)
Circuit-breaker to IEC 60947-2	6.2 b) ii)
Conditional short-circuit rating (back-up protection)	4
Control and protective switching device (CPS) to IEC 60947-6-2	6.2 b) iv)
Cut-off current of a circuit-breaker to IEC 60947-2	6.3.2
Cut-off current of a fuse-link	6.3.1
F	
Fuse-combination unit to IEC 60947-3	6.2 b) i)
O	
Operating I^2t (Joule integral) of a circuit-breaker to IEC 60947-2	6.3.2
Operating I^2t (Joule integral) of a fuse-link	6.3.1
P	
Peak short-circuit current I_p	4
Prospective (available) short-circuit current I_{cp}	4
Protected starter to IEC 60947-4-1	6.2 b) iii)
Protected switching device to IEC 60947-4-1	6.2 b) iii)
R	
Rated conditional short-circuit current I_q of a contactor or motor starter	7.4.1
Rated conditional short-circuit current I_{cc} of a circuit of an assembly	5
Rated peak withstand current I_{pk} of a circuit of an assembly	5
Rated service short-circuit breaking capacity I_{cs} of a circuit-breaker to IEC 60947-2.	6.3.2
Rated short-circuit breaking capacity I_{cs} of a CPS	6.3.3
Rated short-circuit capacity I_{cn} of a circuit-breaker to IEC 60898-1 and of a residual current operated circuit-breaker with integral overcurrent protection (RCBO) to IEC 61009-1	6.3.4
Rated short-circuit making capacity I_{cm} of a circuit-breaker to IEC 60947-2	6.3.2
Rated short-time withstand current I_{cw} of a circuit of an assembly	5
Rated short-time withstand current I_{cw} of a circuit-breaker to IEC 60947-2	6.3.2
Rated ultimate short-circuit breaking capacity I_{cu} of a circuit-breaker to IEC 60947-2	6.3.2
Residual current operated circuit-breaker with integral overcurrent protection (RCBO) to IEC 61009-1	6.2 b) ii)
S	
Service short-circuit capacity I_{cs} of a circuit-breaker to IEC 60898-1 and of a residual current operated circuit-breaker with integral overcurrent protection (RCBO) to IEC 61009-1	7.5
Short-circuit protective device (SCPD)	4
Steady-state short-circuit current I_k	4
Symmetrical short-circuit breaking current I_b	4

4 Principle of application – The installation

In order to ensure the capability of equipment under short-circuit conditions, the circuit designer must firstly have available the prospective fault level at the point of installation of each item of equipment. This is produced by a system protection study. Short-circuit parameters are defined in terms that include the following:

- **prospective (available) short-circuit current I_{cp}**
  current that would flow if the short-circuit were replaced by an ideal connection of negligible impedance without any change of the supply

- **peak short-circuit current I_p**
  maximum possible instantaneous value of the prospective (available) short-circuit current

- **symmetrical short-circuit breaking current I_b**
  r.m.s. value of an integral cycle of the symmetrical a.c. component of the prospective (available) short-circuit current at the instant of contact separation of the first pole of a switching device

- **steady-state short-circuit current I_k**
  r.m.s. value of the short-circuit current which remains, after the decay of the transient phenomena:
  – unlimited
  – limited by an SCPD (short-circuit protective device)

Additional useful definitions:

- **short-circuit protective device (SCPD)**
  device intended to protect a circuit or part of a circuit against short-circuit currents by interrupting them

- **conditional short-circuit rating (back-up protection)**
  short-circuit rating, of a device or an assembly, dependent on an SCPD connected in series with the device or assembly

5 Characteristics – Low-voltage assemblies (switchboard, distribution board, etc.)

An assembly will have a short-circuit rating, assigned by the manufacturer, defined in terms of the maximum prospective short-circuit current applicable at the point it is connected into the system. This will have been determined by test and/or design calculations as specified in the assembly standard, IEC 60439-1, or applicable part thereof.

The terminology to define the short-circuit rating of an assembly is given in the standard as follows:

- **rated short-time withstand current I_{cw} (of a circuit of an assembly)**
  Summarised as: r.m.s value of short-time current that a circuit of an assembly can carry without damage under specified test conditions, defined in terms of a current and time, e.g. 20 kA, 0,2 s.

- **rated peak withstand current I_{pk} (of a circuit of an assembly)**
  Summarised as: value of peak current that a circuit can withstand satisfactorily under specified test conditions.

- **rated conditional short-circuit current I_{cc} (of a circuit of an assembly)**
  Summarised as: r.m.s. value of prospective short-circuit current that a circuit, protected by a specified short-circuit protective device (SCPD), can withstand satisfactorily for the operating time of that device, under specified test conditions.

  NOTE The short-circuit protective device may form an integral part of the assembly or may be a separate unit.

An assembly may be assigned a value of I_{cc} alone.

An assembly may be assigned values of I_{cw} and I_{pk} (but cannot be assigned a value of I_{cw} or I_{pk} alone).

An assembly may be assigned values of I_{cw}, I_{pk} and I_{cc}.

An assembly may be assigned different values of I_{cc} for different circuit protective devices and/or system voltages.

An assembly may be assigned different values of I_{cw} for different short-time periods e.g. 0,2 s, 0,5 s, 1 s.

6 Characteristics – Switching devices

6.1 General

In terms of short-circuit capability, switching devices must be considered in respect of their function in the particular application. A switching device is considered in two respects, self-protection and use as a short-circuit protective device (SCPD) where applicable.

6.2 Switching devices – Self-protection against short-circuit

The following cases are considered:

a) Load and overload switching alone, without any short-circuit switching capability.

   In this case the switching device will be short-circuit rated on a similar basis to a circuit of an assembly (see Clause 5), with a rating of I_{cw} and/or a conditional short-circuit rating, but will in addition have a rated short-circuit making capacity I_{cm}.

b) Load, overload and short-circuit switching capability:

   i) Fuse-combination units to IEC 60947-3 – a fuse-combination unit is normally self-protecting up to the breaking capacity of the fuse. In this case the short-circuit breaking function is provided by the integral fuses and the switching device will have a conditional short-circuit rating.

   ii) Circuit-breakers to IEC 60947-2, circuit-breakers to IEC 60898-1 and residual current operated circuit-breakers with integral overcurrent protection (RCBOs) to IEC 61009-1 – the device will be self-protecting up to its breaking capacity rating (see 6.3.2). At fault levels above the breaking capacity rating, a circuit-breaker may be capable of operating with “back-up” protection by an SCPD (this is in effect a conditional rating, but the term is not generally used in this context).

iii) Protected switching devices and protected starters to IEC 60947-4-1 – a contactor, semiconductor controller or a motor-starter, including overload protection, a manual switching device and an SCPD rated as a unit. These devices have a rated conditional short-circuit current I_q and are self-protecting up to this level.

iv) Control and protective switching devices (CPS) to IEC 60947-6-2 – a switching device (or equipment) capable of operation other than by hand, but with or without local manual operating means. A CPS is capable of making, carrying and breaking currents under normal conditions, including specified operating overload conditions and of making, carrying for a specified time and breaking currents under specified abnormal conditions such as those of short-circuits. A CPS has a rated service short-circuit breaking capacity and is self-protecting up to this level.

6.3 Switching devices – Application as SCPD

6.3.1 Fuse-combination units and fuses as SCPD

Since the short-circuit breaking function in fuse-combination units is provided by the fuses, it is the fuse characteristics that are considered. These are given in IEC 60269-1 as follows:

- **breaking capacity of a fuse-link**
  Summarised as: value (for a.c. the r.m.s. value of the a.c. component) of prospective current that a fuse-link is capable of breaking at a stated voltage under prescribed conditions of use.

- **cut-off current of a fuse-link**
  Summarised as: maximum instantaneous value reached by the current during the breaking operation of a fuse-link when it operates to prevent the current reaching the prospective peak.

- **operating I^2t (Joule integral) of a fuse-link**
  Summarised as: integral of the square of the current over the operating time of the fuse-link under short-circuit conditions.

  Sometimes referred to as “let-through energy”. When expressed in A^2s gives the energy dissipated per ohm and thus represents the thermal effect on the circuit.

  See Figure 1: example of the I^2t characteristic of a fuse.

6.3.2 Circuit-breakers to IEC 60947-2 as SCPD

The short-circuit breaking function is provided by the circuit-breaker itself and the following characteristics should be considered.

Moulded-case circuit-breakers (MCCBs) and air circuit-breakers (ACBs) are rated according to IEC 60947-2 as follows:

- **rated short-circuit making capacity I_{cm}**
  Summarised as: maximum peak prospective current that the circuit-breaker can make on to satisfactorily.

  Rated short-circuit breaking capacities:

- **rated ultimate short-circuit breaking capacity I_{cu}**
  Summarised as: r.m.s prospective current that the circuit-breaker is capable of breaking at a specified voltage, under defined test conditions which include one break operation and one make/break operation.

The I_{cu} rating of a circuit-breaker should be equal to or exceed the prospective (available) short-circuit current at the point of installation. The exception being where the circuit-breaker is itself protected by another SCPD, the combination being rated for a higher short-circuit current.

See Figure 3: example of SCPDs in combination.

- **rated service short-circuit breaking capacity I_{cs}**
  Summarised as: r.m.s prospective current that the circuit-breaker is capable of breaking at a specified voltage, under defined test conditions which include one break operation and two make/break operations.

  The standard specifies fixed relationships to I_{cs}/I_{cu} of 25 %, 50 %, 75 % or 100 %.

  The I_{cs} rating of a circuit-breaker is applied where assurance of continuity of service is required after a short-circuit fault.

- **rated short-time withstand current I_{cw}**
  Summarised as: r.m.s value of short-time current assigned by the manufacturer, based on specified test conditions.

  Minimum values are given in the standard.

A circuit-breaker can only be assigned a rated short-time withstand current I_{cw} if it is equipped with a time-delay short-circuit release.

All circuit-breakers to IEC 60947-2 have values of I_{cu} and I_{cs}.

Circuit-breaker characteristics not specified in IEC 60947-2 but having application to short-circuit protection:

- **cut-off current of a circuit-breaker**
  Summarised as: maximum instantaneous value reached by the current during the breaking operation of a circuit-breaker when it operates to prevent the current reaching the prospective peak.

  NOTE A current limiting circuit-breaker exhibits cut-off under short-circuit conditions. A non-current limiting circuit-breaker does not exhibit cut-off.

- **operating I^2t (Joule integral) of a circuit-breaker**
  Summarised as: integral of the square of the current over the operating time of the circuit-breaker under short-circuit conditions.

  Sometimes referred to as “let-through energy”. When expressed in A^2s gives the energy dissipated per ohm and thus represents the thermal effect on the circuit.

  See Figure 2: example of the I^2t characteristic of a circuit-breaker.

6.3.3 Control and protective switching devices (CPS) to IEC 60947-6-2 as SCPD

A CPS has a rated short-circuit breaking capacity I_{cs} and the application of the CPS as an SCPD is the same as that for a circuit-breaker (see 6.3.2).

6.3.4 Circuit-breakers to IEC 60898-1 (MCBs) and residual current operated circuit-breaker with integral overcurrent protection (RCBOs) to IEC 61009-1 as SCPD

The short-circuit breaking function is provided by the circuit-breaker/RCBO itself and the following characteristic should be considered:

- **rated short-circuit capacity I_{cn}**
  Summarised as: the ultimate short-circuit breaking capacity of the circuit-breaker.

An MCB/RCBO is also tested for a service short-circuit capacity I_{cs}, which has a fixed relationship to I_{cn} (see Table 1).

7 Examples of the practical application of the product characteristics

7.1 General

In simple studies only the r.m.s value of steady-state prospective short-circuit current I_k is quoted. The peak current is assumed to be in a standard relationship to the r.m.s current, determined by the overall power factor, and taken into account in the rating of SCPDs to the respective IEC standards.

7.2 Circuit protection

The application of short-circuit protective devices (SCPD) to circuit protection, i.e. the protection of cables, is detailed in the installation rules IEC 60364 and is given by

$$(I^2t)_{SCPD} \leq (k^2S^2)_{cable}$$

where

k is a factor depending upon the materials of the cable (conductivity and insulation), and

S is the nominal cross-sectional area of the conductor.

In general it is accepted that selection of the protective device on the basis of overload protection of a cable automatically provides short-circuit protection up to the breaking capacity of the SCPD, in the case of non-time-delayed devices.

7.3 Short-circuit protection for LV assemblies

7.3.1 Switchgear and controlgear assemblies (switchboard/motor-control centre (MCC))

The prospective short-circuit current, given as an r.m.s. value, at the input to the switchboard is obtained from a system protection study.

a) If the switchboard/MCC has an I_{cw} current value higher than the prospective current level, then the only requirement is to limit the time for which a short-circuit could persist to within the short-time value. This is achieved by the time-delay setting of short-circuit releases upstream or at the incomer to the switchboard/MCC.

b) If the switchboard/MCC has an I_{cc} rating higher than the prospective current level, then the only requirement is to include the specified SCPD in the circuit. This may be added in the circuit upstream or may already be included as an incomer to the switchboard.

7.3.2 Busbar trunking systems (BTS)

The prospective short-circuit current, given as an r.m.s. value, at the input to the BTS, is obtained from a system protection study.

a) If the BTS has an I_{cw} current value higher than the prospective current level, then the only requirement is to limit the time for which a short-circuit could persist to within the short-time value. This is achieved by the time-delay setting of short-circuit releases upstream.

b) If the BTS has an I_{cw} current lower than the prospective current level I_k but has an I_{cc} rating higher than I_k, then the only requirement is to include the specified SCPD in the circuit upstream or in the busbar trunking feeder unit. The suitability of any given SCPD may be derived from the cut-off current and Joule-integral characteristics by comparison with type test parameters.

See Figure 4: example of the derivation of a conditional rating from type-test parameters.

7.4 Short-circuit protection for controlgear

7.4.1 General

Motor-starters and contactors are not generally self-protecting against the effects of short-circuit and therefore need to be associated with an SCPD. In this particular case, test procedures to IEC 60947-4-1 recognise the difficulty of protecting sensitive devices from damage under heavy short-circuit conditions. Thus a special case of conditional rating is obtained which allows two types of co-ordination with an SCPD:

– Type “1” co-ordination requires that, under short-circuit conditions, the contactor or starter shall cause no damage to persons or installation and may not be suitable for further service without repair or replacement of parts.

– Type “2” co-ordination requires that, under short-circuit conditions, the contactor or starter shall cause no damage to persons or installation and shall be suitable for further use. The risk of contact welding is recognised, in which case the manufacturer shall indicate the measures to be taken as regards the maintenance of the equipment.

These ratings can only be obtained by type-testing and thus the data for the selection of the SCPD must be obtained from the manufacturer of the controlgear, taking into account the rated operational current, rated operational voltage and the corresponding utilisation category.

The rated conditional short-circuit current of contactors and starters backed up by short-circuit protective device(s) (SCPD(s)), combination starters and protected starters is verified by short-circuit tests at two levels of prospective current:

a) at the rated conditional short-circuit current I_q; and

b) an additional test is made at a current “*r*” as shown in Table 2. The test current “*r*” is considered a critical current for a contactor and the test ensures the performance of the contactor at this level.

NOTE Further information about co-ordination between fuses and contactors/motor-starters is given in IEC/TR 61459.

7.4.2 Protected switching device and protected starter

These devices according to IEC 60947-4-1 have a rated conditional short-circuit current I_q.

I_q shall be equal to or greater than the prospective short-circuit current at the point of installation.

The rated conditional short-circuit current I_q is derived under test conditions which include the method of mounting of the devices, including any enclosure. Within the test procedure to IEC 60947-4-1, it is established that the SCPD takes over the current interruption at a level of current within the breaking capacity of the contactor or controller or motor-starter, as applicable.

See Figure 5: illustration of co-ordination between motor-starter and SCPD.

7.4.3 Control and protective switching device (CPS) to IEC 60947-6-2

The ability of a CPS to operate on short-circuit is stated in terms of the rated service short-circuit capacity I_{cs} and the CPS is self-protecting up to this level.

Additional tests are made on a CPS at two levels of critical current:

a) conventional current "*r*", as for contactors and motor-starters (see 7.4.1);

b) conventional current I_{cr}, at between 15 – 30 times rated current I_e according to rating.

A CPS effectively provides a level of co-ordination which provides continuity of service in the event of a short-circuit, the test conditions for which do not allow contact welding.

7.5 Short-circuit protection using circuit-breakers for household and similar installations to IEC 60898-1 (usually known as MCBs) and residual current operated circuit-breakers with integral overcurrent protection (RCBOs) to IEC 61009-1

NOTE This document does not concern itself with household (domestic) installations.

MCBs/RCBOs have a rated short-circuit capacity I_{cn}, summarised as: r.m.s prospective current that the circuit-breaker is capable of breaking at a specified voltage, under defined test conditions which include one break operation and one make/break operation.

MCBs/RCBOs also have a service short-circuit capacity I_{cs}, summarised as: r.m.s. prospective current that the device is capable of breaking at a specified voltage, under defined test conditions which include two break operations and one make/break operation. The product standard specifies a fixed relationship between I_{cs} and I_{cn} (see Table 1).

MCBs and RCBOs are marked with the values of I_{cn} but not with the I_{cs} values as these are predefined as stated above.

The I_{cn} rating of an MCB/RCBO should equal or exceed the prospective (available) short-circuit current at the point of installation.

When applied in other than domestic (household) situations, the MCB may need to be "backed-up" by another SCPD. Only testing of the required combination is satisfactory and thus the data must be obtained from the manufacturer of the SCPD or the manufacturer of the MCB.

For application outside the scope of IEC 60898-1, i.e. over 125 A rating and/or 440 V rating, MCBs can be rated in accordance with IEC 60947-2 and applied accordingly (see 6.3.2).

Table 1 – Ratio *k* between service short-circuit capacity (I_{cs}) and rated short-circuit capacity (I_{cn})

I_{cn}	*k*
$I_{cn} \leq 6\,000$ A	1
6 000 A < $I_{cn} \leq 10\,000$ A	0,75 [a]
$I_{cn} > 10\,000$ A	0,5 [b]
[a] Minimum value of I_{cs}: 6 000 A [b] Minimum value of I_{cs}: 7 500 A	

Table 2 – Value of the prospective test current according to the rated operational current

Rated operational current I_e (AC-3)[a] A	**Prospective test current "*r*"** kA
$0 < I_e \leq 16$	1
$16 < I_e \leq 63$	3
$63 < I_e \leq 125$	5
$125 < I_e \leq 315$	10
$315 < I_e \leq 630$	18
$630 < I_e \leq 1\,000$	30
$1\,000 < I_e \leq 1\,600$	42
$1\,600 < I_e$	Subject to agreement between manufacturer and user
[a] If the contactor or starter is not specified according to utilization category AC-3, the prospective current "*r*" shall correspond to the highest rated operational current for any utilization category claimed by the manufacturer.	

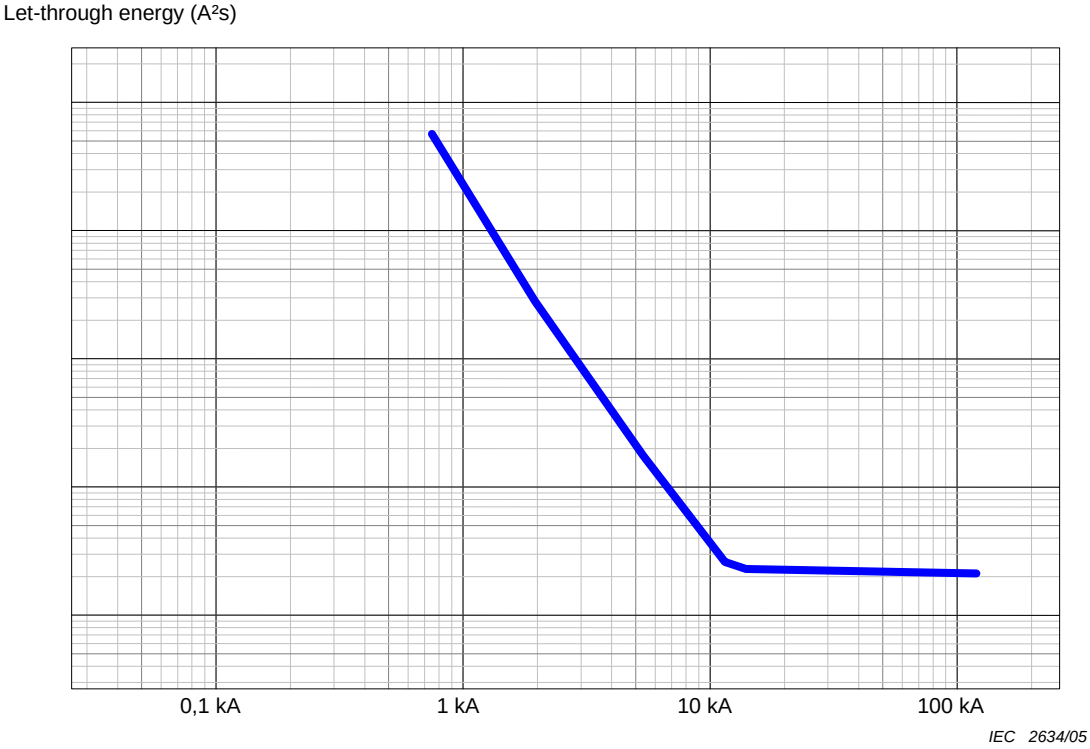


Figure 1 – Example of the I^2t characteristic of a fuse

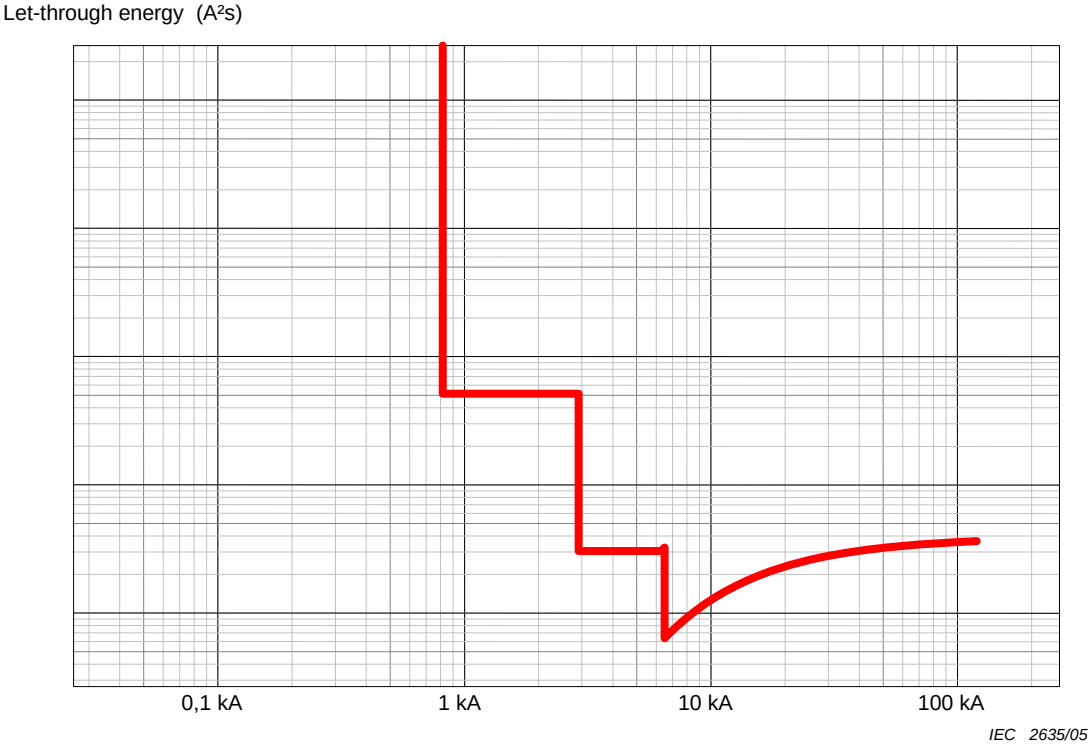
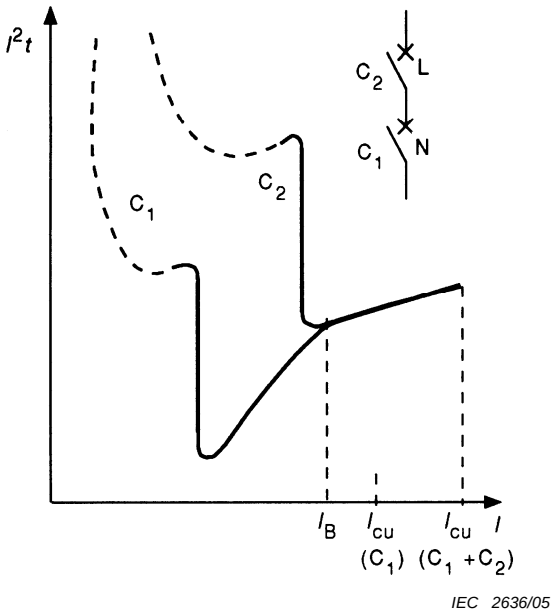


Figure 2 – Example of the I^2t characteristic of a circuit-breaker



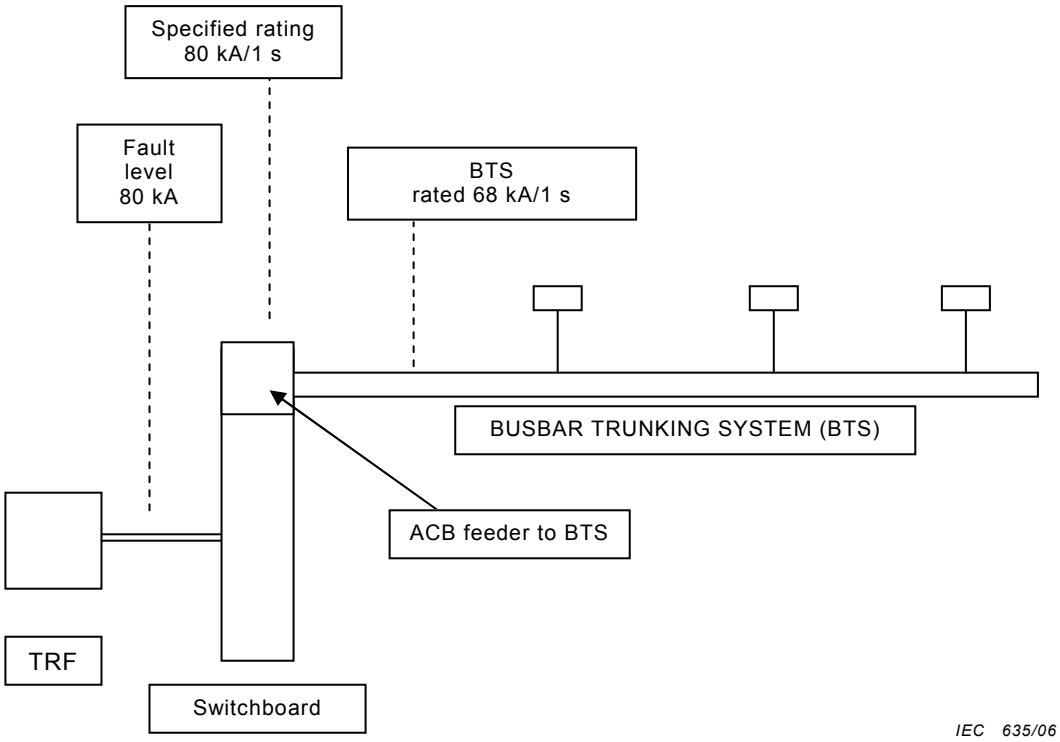
Key

I_B Take-over current

C_1 Non current-limiting circuit-breaker (N)

C_2 Current-limiting circuit-breaker (L)

Figure 3 – Example of SCPDs in combination



Peak current withstand of BTS (I_{pk}), from type-test to IEC 60439-2
= 68 x 2,2 x 10^3 = 150 kA

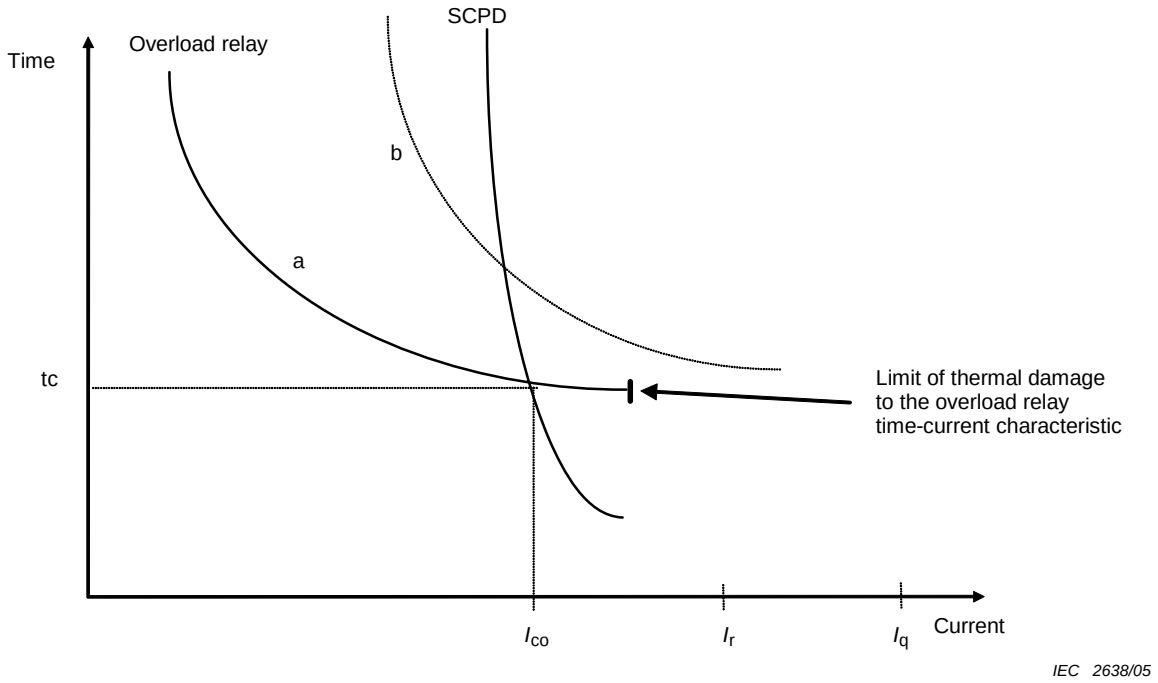
Cut-off peak current of typical ACB rated thermally for the BTS = 120 kA

Withstand let-through energy (I^2t) of BTS at 68 kA, from type-test to IEC 60439-2
= [68 x 10^3] ^{2} x 1 = 4 624 x 10^6 A^2s

Let-through energy at 80 kA of ACB rated thermally for the BTS = 70 x 10^6 A^2s

Therefore the system is protected against short-circuit

Figure 4 – Example of the derivation of a conditional rating from type-test parameters

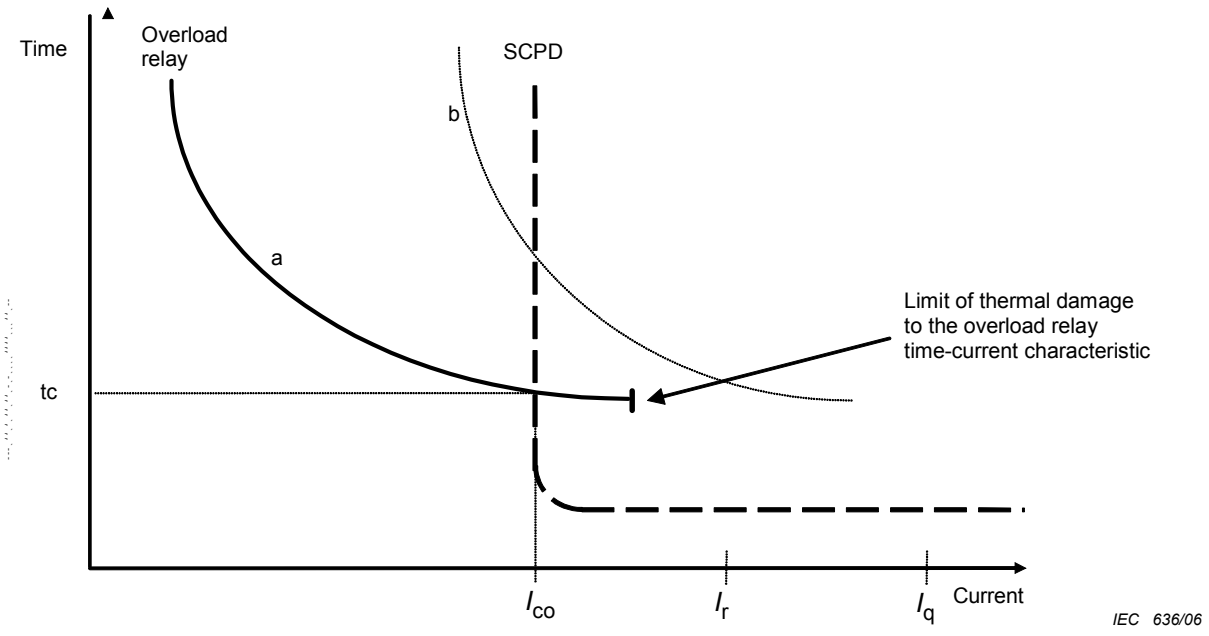


Key

a mean overload relay time-current characteristic from cold state

b time-current characteristic withstand capability of contactor

Figure 5a – Co-ordination of a motor-starter with a fuse



Key

a mean overload relay time-current characteristic from cold state

b time-current characteristic withstand capability of contactor

Figure 5b – Co-ordination of a motor-starter with circuit-breaker

Figure 5 – Illustration of co-ordination between motor-starter and SCPD

Annex A
(informative)

Interpolation of the suitability of an alternative SCPD for the protection of controlgear (substitution)

Conditions for valid interpolation from tested arrangement:

a) The SCPD only may be substituted.

b) Like types of SCPD only may be substituted, i.e. a fuse for a fuse or a circuit-breaker for a circuit-breaker.

c) Substitution of the SCPD will be valid for type 1 and type 2 co-ordination for an overload relay or a contactor.

The verification is based on information provided by the manufacturer from the results of tests to IEC 60947-4-1.

The method is composed of three parts:

- Substitution verification

  The values of rated operational voltage, rated operational current and rated conditional short-circuit current (I_q) for the substitute application shall not be higher than the reference tested data.

- Substitute I_p and I^2t verification

  Considering the characteristics of the substitute SCPD, the I_p and I^2t values shall be determined for the rated conditional short-circuit current I_q and rated operational voltage.

- Contactor/overload verification

  The values of I_p and I^2t determined as above shall be not greater than the reference test values.

Conformity with the above shows that the SCPD substitution is valid and no further verification tests are required.

blank

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