Coordination between circuit breakers

Selectivity of modular circuit breakers

Contents

Selectivity between circuit breakers

In the following tables we show the level of selectivity between two LV circuits that are protected by circuit breakers.

This selectivity will be either:

- total: represented by a T (up to the breaking capacity of the downstream device),
- partial: selectivity limit current (Is) indicated. Below this value selectivity is ensured, above this value the upstream device is also involved in breaking,
- ▭ : no selectivity ensured.

A

Selectivity between Compact NSX upstream and modular circuit breakers downstream

Compact NSX circuit breakers have been designed to ensure total selectivity with Acti9 range.

- Total selectivity between Compact NSX 100 A with electronic trip unit and Acti9 circuit breaker up to 40 A.
- Total selectivity between Compact NSX ⩾ 160 A with TMD trip unit ⩾125 A or electronic trip unit and Acti9 up to 63 A.

Selectivity between Compact NSX circuit breakers

Thanks to the Roto-Active breaking principle in the Compact NSX, a combination of Schneider Electric circuit breakers provides an exceptional level of selectivity between protection devices.

This performance is due to the combination and optimization of 3 principles:

- current selectivity,
- energy selectivity,
- time selectivity.

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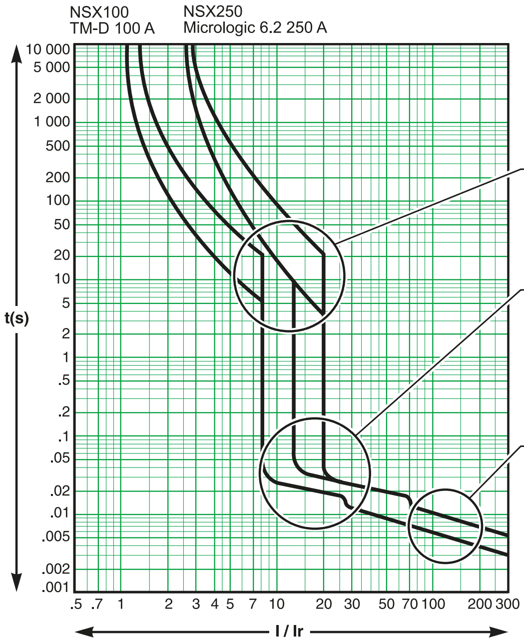

Protection against overloads: current selectivity

The protection is selective if the ratio between the setting thresholds is higher than 1.6 (in the case of two distribution circuit breakers).

Protection against weak short circuits: time selectivity

Tripping of the upstream device has a slight time delay; tripping of the downstream device is faster.

The protection is selective if the ratio between the short-circuit protection thresholds is no less than 1.5.

Protection against high short circuits: energy selectivity

This principle combines the exceptional limiting power of the Compact NSX devices and reflex release, sensitive to the energy dissipated by the short circuit in the device.

When a short circuit is high, if it is seen by two devices, the downstream device limits it greatly. The energy dissipated in the upstream device is insufficient to cause it to trip: there is selectivity whatever the value of the short circuit.

The range has been designed to ensure energy selectivity between NSX630/NSX250/NSX100 or NSX400/NSX160.

Selectivity between Masterpact or Compact NS ⩾ 630 A upstream and Compact NSX downstream

Thanks to their high-performance control units and a very innovative design, Masterpact and Compact NS ⩾ 630 A devices offer, as standard, a very high level of selectivity with downstream Compact NSX up to 630 A

Respect the basic rules of selectivity for overload and short-circuit, or check that curves do not overlap with Ecodial software.

Check the selectivity limit in tables for high short-circuit current or when using limiter circuit breakers (Masterpact MTZ1 L1 or Compact NS L or LB) upstream.

Selectivity between Masterpact or Compact NS ⩾ 630 A upstream and downstream

The utilization category of these devices (excepted limiters ones) is B according to IEC 60947 standard. Selectivity is ensured by a combination of current selectivity and time selectivity.

Respect the basic rules of selectivity for overload and short-circuit, or check that curves do not overlap with Ecodial software.

Check the selectivity limit in tables for high short-circuit current or when using limiter circuit breakers (Masterpact MTZ1 L1 or Compact NS L or LB).

Coordination between circuit breakers

Selectivity

Basic rules of selectivity for overload and short-circuit

Requisite conditions

The values indicated in the tables (for 220, 380, 415 and 440 V) are guaranteed if the following conditions are respected:

Upstream (D1)	Downstream (D2)	Thermal protection Ir up/Ir down	Magnetic protection Im up/Im down
TM	TM or MCB	1.6	2
	Micrologic	1.6	1.5
	MA + Separate overload relay	3	2
	Thermal-magnetic motor circuit breaker	3	2
Micrologic	TM or MCB	1.6	1.5
	Micrologic	1.3	1.5
	MA + Separate overload relay	3	1.5
	Thermal-magnetic motor circuit breaker	3	1.5
TM-DC	TM TM-DC or MCB	3	2

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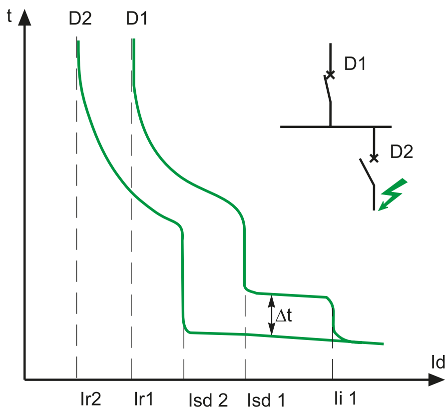


Masterpact MTZ with Micrologic X control unit offer two options for instantaneous trip: "Standard" and "fast". Selectivity tables are provided with "Standard" setting.

See Micrologic X User guide for setting guidelines.

Additional conditions for trip units with adjustable settings

Short time trip pickup current (Isd)

The tables in the following pages show the limit of selectivity assuming the short time trip pickup current “Isd” of upstream circuit-breaker is equal to 10 x Ir.

- When the limit of selectivity indicated in the table is 10 x Ir, the limit of selectivity is in fact the upstream magnetic threshold Isd.
- In many cases, when selectivity is total, a different adjustment of Isd (or Im) may be used provided that the ratio between the magnetic thresholds indicated above is observed and the additional following rules :

When downstream circuit-breaker is a Compact NSX with Micrologic 2.2 or 2.3:

- upstream circuit-breaker magnetic setting “Isd” (or Im) shall be higher than downstream fix instantaneous protection:

Downstream device trip unit	Micrologic 2.2				Micrologic 2.3	
Micrologic Rating	**40A**	**100A**	**160A**	**250A**	**400A**	**630A**
Isd (or Im) minimum value for Compact NSX, Compact NS and Masterpact Micrologic upstream Compact NSX with Mic 2.x	600A	1500A	2400A	3000A	4800A	6900A

- or upstream circuit breaker shall be equipped with Micrologic type 5 with $Isd_{up} \geqslant 1.5\ Isd_{down}$ and Tsd ⩾ 0.1

When downstream circuit breaker is a Compact NS or Masterpact with Micrologic 2.0, upstream circuit breaker shall be equipped with Micrologic type 5, 6 or 7.0 and: $Isd_{up} \geqslant 1.5\ Isd_{down}$ and Tsd ⩾ 0.1.

Instantaneous trip pickup current (Ii)

The selectivity tables show the limit of selectivity assuming the instantaneous trip pickup current set to its maximum value and when it is inhibited (category B circuit breaker only).

- When the limit of selectivity indicated in the table is 15 x In of the upstream device, the limit of selectivity is in fact the instantaneous trip pickup current of the upstream device.
- When selectivity is total (“T”), a different adjustment of Ii may be used provided that the ratio between the magnetic thresholds indicated above is observed and the additional following rules applied:

Downstream device trip unit:	Micrologic 2/4/5/6/7 .2				Micrologic 2/4/5/6/7.3	
Micrologic Rating	**40A**	**100A**	**160A**	**250A**	**400A**	**630A**
Ii minimum value for Compact NSX, Compact NS and Masterpact Micrologic upstream Compact NSX	2000A	2250A	2500A	4000A	6300A	8000A

Selectivity table

Selectivity of circuit breakers

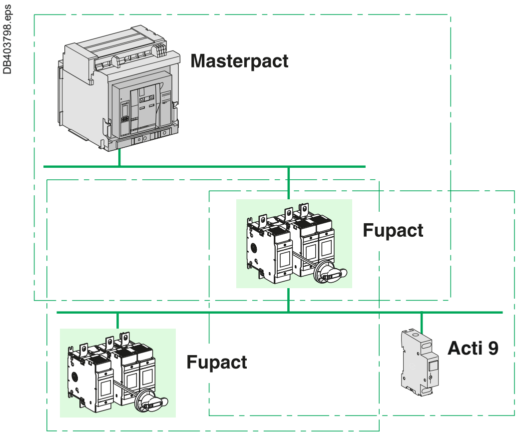
Ue ⩽ 440 V AC

Contents

Selectivity between circuit breakers

In the following tables we show the level of selectivity between two LV circuits that are protected by circuit breakers up to 440 V, 50/60 Hz systems.
This selectivity will be either:
- total: represented by a **T** (up to the breaking capacity of the downstream device),
- partial: selectivity limit current (Is) indicated. Below this value selectivity is ensured, above this value the upstream device is also involved in breaking,
- zero: no selectivity ensured.

Selectivity with fuses - Introduction



Principle

Schneider Electric offers a coordinated protection system

In an electrical installation, protection fuses are never used alone and must always be integrated in a system comprising circuit breakers.
Coordination is required between:

- upstream and downstream fuses
- upstream circuit breakers and downstream fuses
- upstream fuses and downstream circuit breakers.

Upstream fuse / Downstream fuse

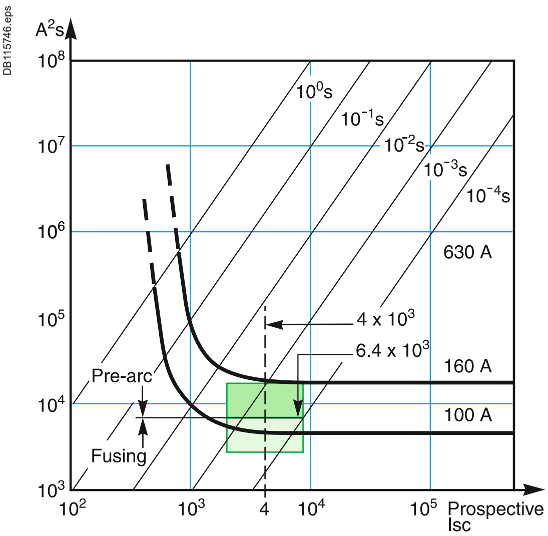
Selectivity is ensured when

Total energy of downstream fuse (Etav) < Pre-arcing energy of upstream fuse (Epam)

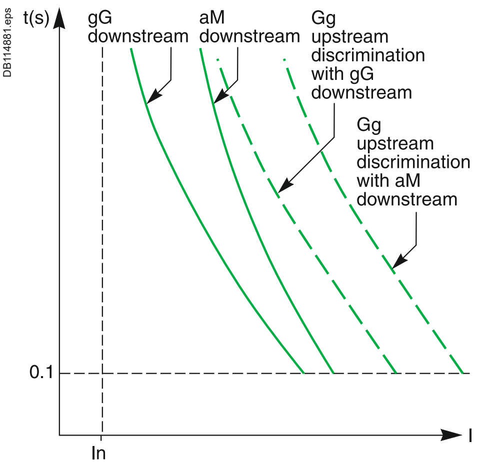
Note: If Etav is higher than 80 % of Epam, the upstream fuse may be derated.

- **Upstream gG fuse-link / downstream gG fuse-link**

Standard IEC 60269-2-1 indicates limit values for pre-arcing and total energies for operation of gG and gM fuse-links, where the operating current is approximately 30 In.



Curves E = f (I) superimposed.



I = f(t) curves.

I²t limit and test currents for verification of selectivity

I_n (A)	Minimum values of pre-arcing I²t		Maximum values of operating I²t	
	Rms values of I prospective (kA)	I²t (A²s)	Rms values of I prospective (kA)	I²t (A²s)
16	0.27	291	0.55	1 210
20	0.40	640	0.79	2 500
25	0.55	1 210	1.00	4 000
32	0.79	2 500	1.20	5 750
40	1.00	4 000	1.50	9 000
50	1.20	5 750	1.85	13 700
63	1.50	9 000	2.30	21 200
80	1.85	13 700	3.00	36 000
100	2.30	21 200	4.00	64 000
125	3.00	36 000	5.10	104 000
160	4.00	64 000	6.80	185 000
200	5.10	104 000	8.70	302 000
250	6.80	185 000	11.80	557 000
315	8.70	302 000	15.00	900 000
400	11.80	557 000	20.00	1 600 000
500	15.00	900 000	26.00	2 700 000
630	20.00	1 600 000	37.00	5 470 000
800	26.00	2 700 000	50.00	10 000 000
1000	37.00	5 470 000	66.00	17 400 000
1250	50.00	10 000 000	90.00	33 100 000

- **Upstream gG fuse-link / downstream aM fuse-link**

The I = f (t) curve for an aM fuse-link is steeper. aM fuse-links are just as fast as gG fuse-links for short-circuit currents, but slower for low overloads.
That is why the selectivity ratio between gG and aM fuse-links is approximately 2.5 to 4.

Selectivity with fuses - Introduction

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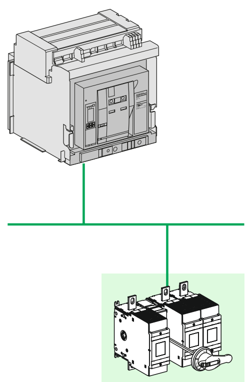

Upstream circuit breaker / Downstream fuse

Upstream circuit breaker with delayed ST (short time) protection function

This is the situation for a MLVS (main low-voltage switchboard) or sub-distribution switchboard protected by an incoming circuit breaker.

The upstream circuit breaker has an electrodynamic withstand capacity Icw and ensures time selectivity.

Rule

Examination of selectivity at the critical points on the LT (long time) and ST (short time) curves results in a selectivity table.

Analysis of the LT critical point indicates whether selectivity between the protection devices is possible or not.

Analysis of the ST (or Icw) critical point indicates whether the selectivity limit is greater than or equal to the ST (or Icw) value.

Note:

- the LT critical point is the most restrictive
- for circuit breakers with a Icw value that is high and/or equal to Icu, the ST critical point is almost never a problem, i.e. selectivity is total.

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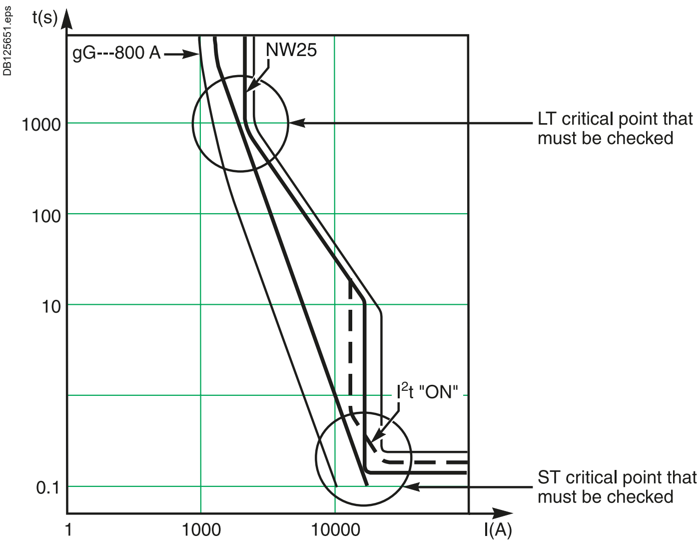

Time-current curves and critical points that must be checked.

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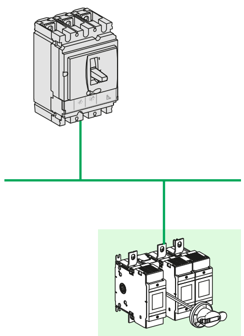

Upstream circuit breaker with non-delayed ST (short time) protection and/or current-limiting function

To make sure the ST critical point is OK, it is necessary to compare:

- the energy curves of the protection devices
- the non-tripping curves of the upstream circuit breaker and the fusing curves of the downstream fuse, and to run tests for the critical values.

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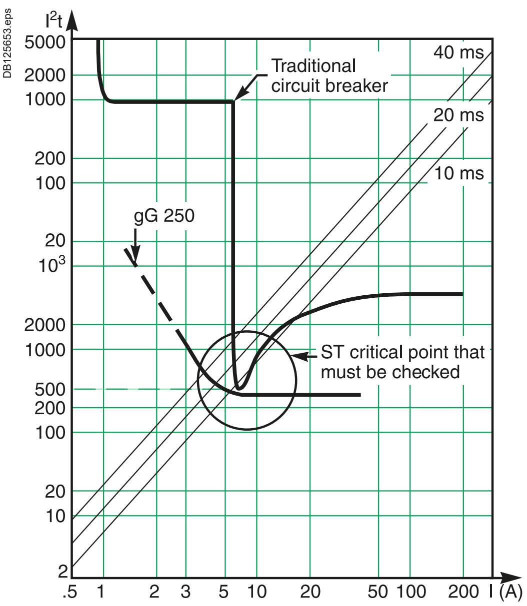
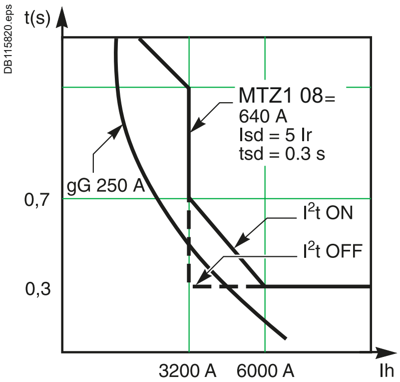


Energy curves and critical points that must be checked.

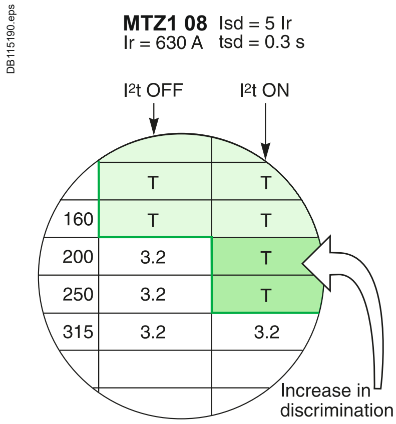
Selectivity with fuses - Introduction

I^2t ON setting

To significantly limit the stresses exerted on the installation (cables installed on trays, power supplied by an engine generator set, etc.), it may be necessary to set the ST protection function to a low value.
The I^2t ON function, a constant-energy tripping curve, maintains the level of selectivity performance and facilitates total selectivity.



I^2t ON curve.



Increase in the selectivity limit.

Selectivity with fuses - Introduction

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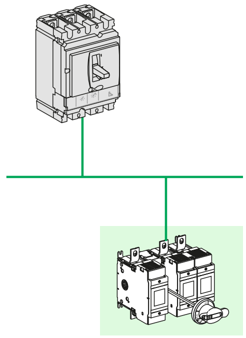

Compact NSX upstream of gG or aM fuse-links

Compact NSX is a current-limiting circuit breaker. Even without an ST (short time) delay setting, selectivity at the ST critical point is significantly improved because Compact NSX has a mini-delay that considerably increases curve values at the ST critical point.

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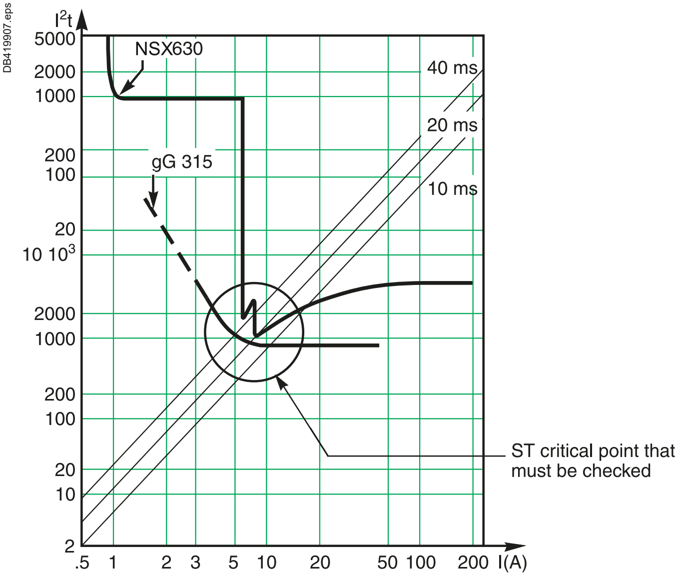

I^2t curve for Compact NSX and a fuse.

See pages A-146 and A-152 for the selectivity tables.

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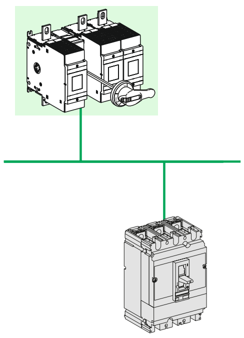

Compact NSX downstream of gG or aM fuse-links

Compact NSX offers an extremely high level of current-limiting performance due to the piston-based reflex tripping system. Again, selectivity is significantly improved with an upstream fuse.

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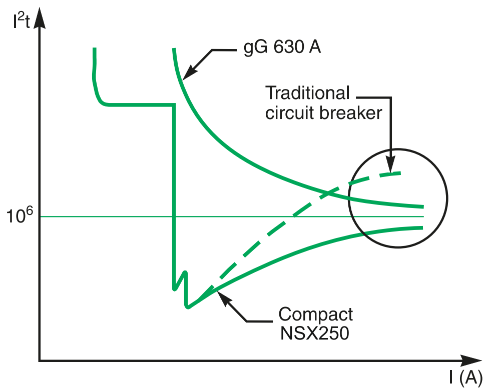

See page A-152 for the selectivity tables.

Selectivity with fuses - Introduction

Upstream: Fupact (gG fuse-link)
Downstream: Fupact (gG or aM fuse-link)

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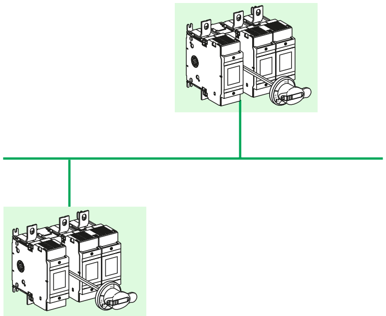

The tables below indicate the necessary ratings for the upstream and downstream fuse-links to achieve **total selectivity**. They take into account the standardised values stipulated in IEC 60269-1 and IEC 60269-2-1 for:

- the pre-arcing energies of the upstream fuse-links
- the total fusing energies of the downstream fuse-links.

Upstream fuse-link gG (In) / gM (Ich)	Downstream fuse-link gG (In) / gM (Ich)	aM (In)
Rating (A)		
16	6	4
20	10	6
25	16	8
32	20	10
40	25	12
50	32	16
63	40	20
80	50	25
100	63	32
125	80	40
160	100	63
200	125	80
250	160	125
315	200	125
400	250	160
500	315	200
630	400	250
800	500	315
1000	630	400
1250	8000	500

Examples:

- an upstream 125 A gG fuse-link ensures total selectivity with an 80 A gG fuse-link and/or a 40 A aM fuse-link situated downstream
- an upstream 125 A gG fuse-link ensures total selectivity with a 63 A gG 63M80 fuse-link (with an 80 A characteristic) situated downstream.

Cascading tables
Contents

Selectivity enhanced by cascading

Cascading tables

Contents

Selectivity enhanced by cascading

A

Using the cascading tables

This table takes in account all types of faults: between phases, phase and neutral, phase and earth in all earthing systems.
In IT the following cascading tables can not be used to evaluate performances in case of "double fault" between two different phases and earth in two different locations of the installation. Each breaker shall comply to IEC60947-2 Annex H to be used in such a system.
Depending on the network and the type of downstream circuit breaker, the selection table below indicates which table should be consulted to find out the cascading value.

Selection table

		Upstream network					
		DB123996.eps L1 N		DB123998.eps L1 L2 L3 N		DB123997.eps L1 L2 L3	
Type of Downstream network	**Type of Downstream protection device**	**Type of circuit breaker upstream device: 1P, 2P, 3P or 4P circuit breaker**					
		Ph/N 110-130 V	**Ph/N 220-240 V**	**Ph/N 110-130 V Ph/Ph 220-240 V**	**Ph/N 220-240 V Ph/Ph 380-415 V**	**Ph/Ph 220-240 V**	**Ph/Ph 380-415 V**
DB124079.eps N L1	DB123991.eps 2P	See table Ue: 220-240 V	[1] See table Ue: 380-415 V	See table Ue: 220-240 V	[1] See table Ue: 380-415 V		
	DB124191.eps 1P; DB123992.eps 1P + N	See table Ue: 220-240 V	[2] See table Ue: 380-415 V	See table Ue: 220-240 V	[2] See table Ue: 380-415 V		
DB124192.eps L1 L2	DB123991.eps 2P			See table Ue: 220-240 V	See table Ue: 380-415 V	See table Ue: 220-240 V	See table Ue: 380-415 V
DB124080.eps L1 L2 L3	DB123993.eps 3P			See table Ue: 220-240 V	See table Ue: 380-415 V	See table Ue: 220-240 V	See table Ue: 380-415 V
DB124081.eps N L1 L2 L3	DB123994.eps 4P			See table Ue: 220-240 V	See table Ue: 380-415 V		
	DB123993.eps 3P; DB123995.eps 3P+N			See table Ue: 220-240 V	See table Ue: 380-415 V		

[1] For fault phase-neutral with upstream protection of neutral, please consult the table Ue: 220-240 V.
[2] For iC60 1P+N circuit breaker connected between phase and neutral under 220-240 V, consult the table Ue: 220-240 V (only for faults between phase and neutral).

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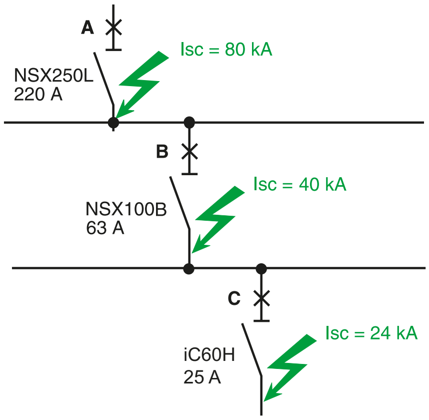


Example of three level cascading

Consider three circuit breakers A, B and C connected in series. The criteria for cascading are fulfilled in the following two cases:

- the upstream device A is coordinated for cascading with both devices B and C (even if the cascading criteria are not fulfilled between B and C). It is simply necessary to check that the combinations A + B and A + C have the required breaking capacity
- each pair of successive devices is coordinated, i.e. A with B and B with C (even if the cascading criteria are not fulfilled between A and C). It is simply necessary to check that the combinations A + B and B + C have the required breaking capacity.

The upstream breaker A is a NSX250L (breaking capacity 150 kA) for a prospective Isc of 80 kA across its output terminals.
A NSX100B (breaking capacity 25 kA) can be used for circuit breaker B for a prospective Isc of 40 kA across its output terminals, since the "reinforced" breaking capacity provided by cascading with the upstream NSX250L is 50 kA.
A iC60H (breaking capacity 15 kA) can be used for circuit breaker C for a prospective Isc of 24 kA across its output terminals since the "reinforced" breaking capacity provided by cascading with the upstream NSX250L is 25 kA.
Note that the "reinforced" breaking capacity of the iC60H with the NSX100B upstream is only 20 kA, but:

- A + B = 50 kA
- A + C = 25 kA.

Selectivity enhanced by cascading

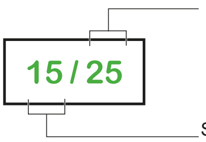
With traditional circuit breakers, cascading between two devices generally results in the loss of selectivity.
With Compact circuit breakers, the selectivity characteristics in the tables remain applicable and are in some cases even enhanced. Protection selectivity is ensured for short-circuit currents greater than the rated breaking capacity of the circuit breaker and even, in some cases, for its enhanced breaking capacity. In the later case, **protection selectivity is total**, i.e. only the downstream device trips for any and all possible faults at its point in the installation.

Example
Consider a combination between:
- a Compact NSX250H with trip unit TM250D
- a Compact NSX100F with trip unit TM25D.

The selectivity tables indicate total selectivity. Protection selectivity is therefore ensured up to the breaking capacity of the NSX100F, i.e. **36 kA**.
The cascading tables indicate an enhanced breaking capacity of **70 kA**.
The enhanced selectivity tables indicate that in a cascading configuration, selectivity is ensured up to **70 kA**, i.e. for any and all possible faults at that point in the installation.

Enhanced selectivity tables - 380-415 V

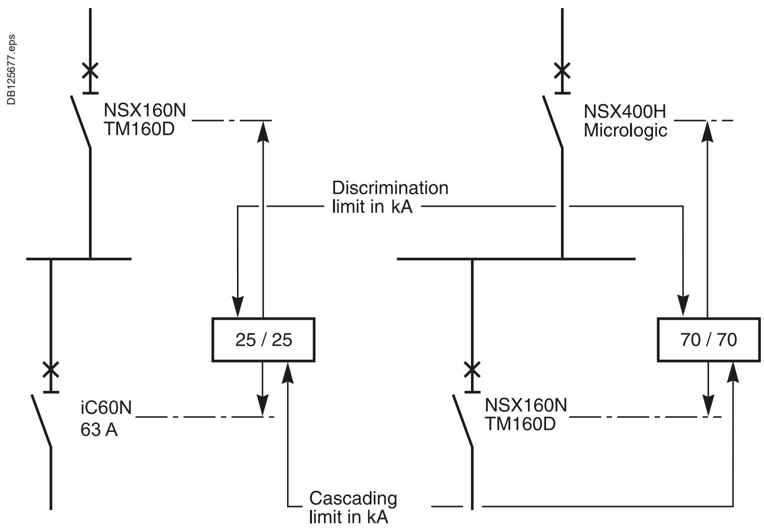
For each combination of two circuit breakers, the tables indicate the:



In a table, a box containing two equal values indicates that selectivity is provided up to the reinforced breaking capacity of the downstream device.
These tables apply only to cases with combined selectivity and cascading between two devices. For all other cases, refer to the normal cascading and selectivity tables.

Technical principle

Enhanced selectivity is the result of the exclusive Compact NSX Roto-active breaking technique which operates as follows:
- due to the short-circuit current (electrodynamic forces), the contacts in both devices simultaneously separate. The result is major limitation of the short-circuit current
- the dissipated energy provokes the reflex tripping of the downstream device, but is insufficient to trip the upstream device.



Note: respect the basic rules of selectivity, in terms of overload, short-circuit, see page A-2 and A-12.

Motor protection selectivity

Motor protection selectivity tables

See introduction page A7 for condition of use of selectivity tables.

<table>
<tr><th>Upstream</th><th colspan="8">Compact</th></tr>
<tr><th></th><th>NSXm</th><th colspan="4">NSX</th><th colspan="3">NS</th></tr>
<tr><th></th><th>16-160</th><th>100-250</th><th>100 -160</th><th>250</th><th>400-630</th><th>630b-1600</th><th>630b-1000</th><th>1600-3200</th></tr>
<tr><th></th><th colspan="5">All breaking capacities</th><th>N/H</th><th>L</th><th>N</th></tr>
<tr><th>Downstream</th><th>TM-D & Micrologic 4.1</th><th>TMD</th><th colspan="3">Micrologic</th><th colspan="3">Micrologic</th></tr>
<tr><td>Tesys GV2 ME01...ME32</td><td rowspan="6">page B-3</td><td rowspan="9">page B-5</td><td rowspan="9">page B-7</td><td rowspan="9">page B-9</td><td rowspan="9">page B-9</td><td rowspan="22">page B-11</td><td rowspan="22">page B-12</td><td rowspan="22">page B-13</td></tr>
<tr><td>Tesys GV2 P01...P32</td></tr>
<tr><td>Tesys U LUB12 + LUC●6...12</td></tr>
<tr><td>Tesys U LUB32 + LUC●6...32</td></tr>
<tr><td>Tesys GV3 P13...P65</td></tr>
<tr><td>Tesys GV4 P/PE/PEM 02-115</td></tr>
<tr><td>Compact NSX100 F/N/H/S/L/R Micrologic 2.2M 6.2M</td><td rowspan="5"></td></tr>
<tr><td>Compact NSX160 F/N/H/S/L Micrologic 2.2M 6.2M</td></tr>
<tr><td>Compact NSX250 F/N/H/S/L/R Micrologic 2.2M 6.2M</td></tr>
<tr><td>Compact NSX400F/N/H/S/L/R Micrologic 2.3 6.3M 320</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Compact NSX630F/N/H/S/L/R Micrologic 2.3M 6.3M</td></tr>
<tr><td>iC60 L MA1.6…MA40 + LRD</td><td rowspan="5">page B-10</td><td rowspan="7">page B-6</td><td rowspan="7">page B-8</td><td rowspan="9">page B-10</td><td rowspan="9">page B-10</td></tr>
<tr><td>NG125L MA2.5...MA63 + LRD</td></tr>
<tr><td>Tesys GV2 L03...L32 + LRD</td></tr>
<tr><td>Tesys GV3 L25...L65 + LRD</td></tr>
<tr><td>Tesys GV4 L/LE 02-115 +LRD</td></tr>
<tr><td>Compact NSX100F/N/H/S/L MA 2.5...MA6.3 + LRD</td><td rowspan="6"></td></tr>
<tr><td>Compact NSX100F/N/H/S/L/R MA12.5...MA100 + LRD</td></tr>
<tr><td>Compact NSX160F/N/H/S/L MA150 + LR9D/F</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>Compact NSX250F/N/H/S/L/R MA220+LR9D/F</td></tr>
<tr><td>Compact NSX400F/N/H/S/L/R 1.3M +LR9F</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Compact NSX630 F/N/H/S/L/R 1.3M +LR9F</td></tr>
</table>

Motor protection selectivity

Upstream	Masterpact						
	MTZ1		MTZ2			MTZ3	
	06-16	06-10	08-20	25-40	25-40	40-63	40-63
	H1/H2/H3	L1	N1/H1/H2/L1	H1/H2	H3	H1	H2
Downstream	Micrologic		Micrologic		Micrologic		
Tesys GV2 ME01...ME32	page B-14	page B-15	page B-16	page B-17	page B-18	page B-17	page B-18
Tesys GV2 P01...P32							
Tesys U LUB12 + LUC●6...12							
Tesys U LUB32 + LUC●6...32							
Tesys GV3 P13...P65							
Tesys GV4 P/PE/PEM 02-115							
Compact NSX100 F/N/H/S/L/R Micrologic 2.2M 6.2M							
Compact NSX160 F/N/H/S/L Micrologic 2.2M 6.2M							
Compact NSX250 F/N/H/S/L/R Micrologic 2.2M 6.2M							
Compact NSX400F/N/H/S/L/R Micrologic 2.3 6.3M 320							
Compact NSX630F/N/H/S/L/R Micrologic 2.3M 6.3M							
iC60 L MA1.6…MA40 + LRD							
NG125L MA2.5...MA63 + LRD							
GV2 L03...L32 + LRD							
GV3 L25...L65 + LRD							
GV4 L/LE 02-115 +LRD							
Compact NSX100F/N/H/S/L MA 2.5...MA6.3 + LRD							
Compact NSX100F/N/H/S/L/R MA12.5...MA100 + LRD							
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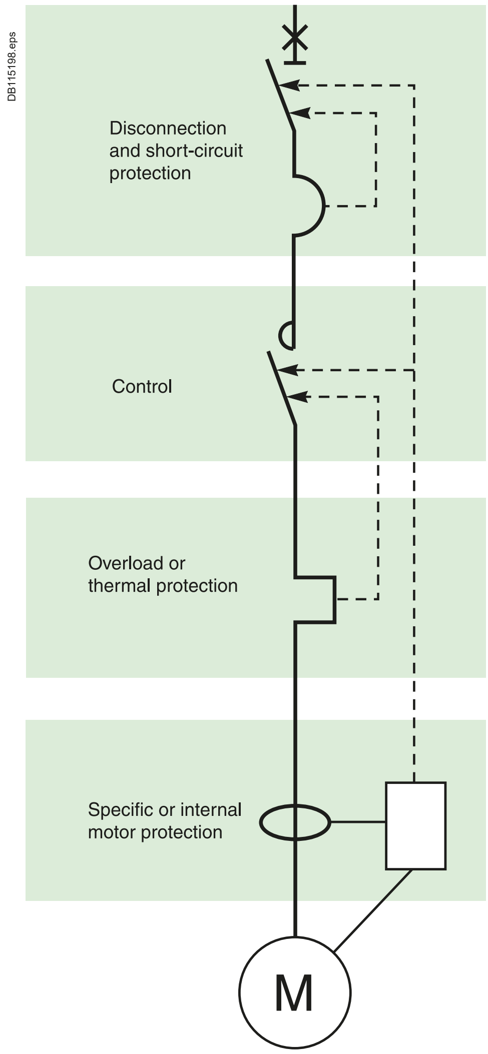
Compact NSX250F/N/H/S/L/R MA220+LR9D/F							
Compact NSX400F/N/H/S/L/R 1.3M +LR9F							
Compact NSX630 F/N/H/S/L/R 1.3M +LR9F							

Motor protection coordination

Protection of motor circuit with circuit-breaker



Introduction

A circuit supplying a motor may include one, two, three or four switchgear or controlgear devices fulfilling one or more functions.

When a number of devices are used, they must be coordinated to ensure optimum operation of the motor.

Protection of a motor circuit involves a number of parameters that depend on:
- the application (type of machine driven, operating safety, starting frequency, etc.)
- the level of service continuity imposed by the load or the application
- the applicable standards to ensure protection of life and property.

The necessary electrical functions are of very different natures:
- protection (motor-dedicated for overloads)
- control (generally with high endurance levels)
- isolation.

Protection functions

Disconnection functions:
- Isolate a motor circuit prior to maintenance operations.

Short-circuit protection:
Protect the starter and the cables against major overcurrents (> 10 In).

Control:
Start and stop the motor, and, if applicable:
- gradual acceleration
- speed control.

Overload protection:
Protect the starter and the cables against minor overcurrents (< 10 In).

Additional specific protection:
- limitative fault protection (while the motor is running)
- preventive fault protection (monitoring of motor insulation with motor off).

Overloads (I < 10 In).
An overload may be caused by:
- an electrical problem, for instance on the mains (loss of a phase, voltage outside tolerances, etc.)
- a mechanical problem, for instance excessive torque due to abnormally high demands by the process or motor damage (bearing vibrations, etc.)

A further consequence of these two origins is excessively long starting.

Impedant short-circuit (10 < I < 50 In)
Deterioration of motor-winding insulation is the primary cause.

Short-circuit (I > 50 In)
This type of fault is relatively rare. A possible cause may be a connection error during maintenance.

Overload protection
Thermal relays provide protection against this type of fault. They may be:
- integrated in the short-circuit protective device
- separate.

Short-circuit protection
This type of protection is provided by a circuit breaker.

Protection against insulation faults
This type of protection may be provided by:
- a residual current device (RCD)
- an insulation monitoring device (IMD).

Motor protection coordination

Protection of motor circuit with circuit-breaker

Applicable standards

A circuit supplying a motor must comply with the general rules set out in IEC standard 60947-4-1 and in particular with those concerning contactors, motor starters and their protection as stipulated in IEC 60947-4-1, notably:
- coordination of the components of the motor circuit
- trip class for thermal relays
- contactor utilisation categories
- coordination of insulation.

Coordination of the components of the motor circuit

Two types of coordination

The standard defines tests at different current levels. The purpose of these tests is to place the switchgear and controlgear in extreme conditions. Depending on the state of the components following the tests, the standard defines two types of coordination:
- **type 1:**

Deterioration of the contactor and the relay is acceptable under two conditions:
- □ no danger to operating personnel
- □ no danger to any components other than the contactor and the relay
- **type 2:**

Only minor welding of the contactor or starter contacts is permissible and the contacts must be easily separated.

□ following type-2 coordination tests, the switchgear and controlgear functions must be fully operational.

Which type of coordination is needed?

Selection of a type of coordination depends on the operating conditions encountered.

The goal is to achieve the best balance between the user's needs and the cost of the installation.
- **type 1:**
  - □ qualified maintenance service
  - □ low cost of switchgear and controlgear
  - □ continuity of service is not imperative or may be ensured by simply replacing the faulty motor drawer
- **type 2:**
  - □ continuity of service is imperative
  - □ limited maintenance service
  - □ specifications stipulating type 2.

Motor protection coordination

Protection of motor circuit with circuit-breaker

The different test currents

"Ic", "r" and "Iq" test currents

To qualify for type-2 coordination, the standard requires three fault-current tests to check that the switchgear and controlgear operates correctly under overload and short-circuit conditions.

"Ic" current (overload I < 10 In)

The thermal relay provides protection against this type of fault, up to the Ic value (a function of Im or Isd) defined by the manufacturer.
IEC standard 60947-4-1 stipulates two tests that must be carried out to guarantee coordination between the thermal relay and the short-circuit protective device:

- at 0.75 Ic, only the thermal relay reacts
- at 1.25 Ic, the short-circuit protective device reacts.

Following the tests at 0.75 and 1.25 Ic, the trip characteristics of the thermal relay must be unchanged. Type-2 coordination thus enhances continuity of service. The contactor may be closed automatically following clearing of the faul.

"r" current

(Impedant short-circuit 10 < I < 50 In)
The primary cause of this type of fault is the deterioration of insulation. IEC standard 60947-4-1 defines an intermediate short-circuit current “r”. This test current is used to check that the protective device provides protection against impedant short-circuits.
There must be no modification in the original characteristics of the contactor and the thermal relay following the test.
The circuit breaker must trip in ⩽ 10 ms for a fault current ⩾ 15 In.

Operational current Ie (AC3) of the motor (in A)	"r" current (kA)
Ie ⩽ 16	1
16 < Ie ⩽ 63	3
63 < Ie ⩽ 125	5
125 < Ie ⩽ 315	10
315 < Ie < 630	18

“Iq” current

(short-circuit I > 50 In)
This type of fault is relatively rare. A possible cause may be a connection error during maintenance.
Short-circuit protection is provided by devices that open quickly.
IEC standard 60947-4-1 defines the “Iq” current as generally ⩾ 50 kA.
The “Iq” current is used to check the coordination of the switchgear and controlgear installed on a motor supply circuit.
Following this test under extreme conditions, all the coordinated switchgear and controlgear must remain operational.

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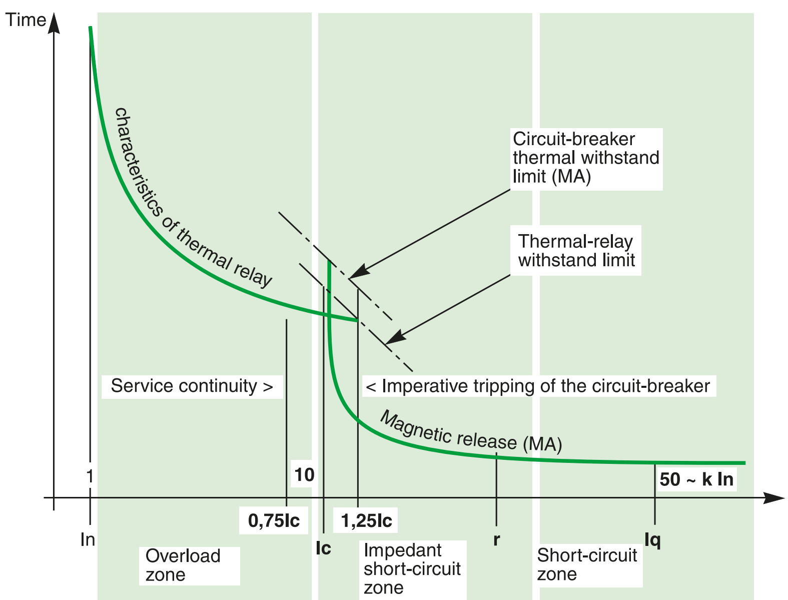
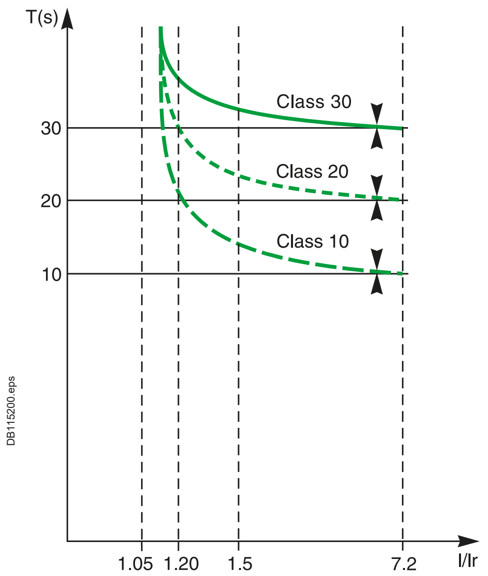


Motor protection coordination

Protection of motor circuit with circuit-breaker



Trip class of a thermal relay.

Trip class of a thermal relay

The four trip class of a thermal relay are 10 A, 10, 20 and 30 (maximum tripping times at 7.2 Ir).
Classes 10 and 10 A are the most commonly used. Classes 20 and 30 are reserved for motors with difficult starting conditions.
The diagram and the table opposite can be used to select a thermal relay suited to the motor starting time.

Class	1.05 Ir	1.2 Ir	1.5 Ir	7.2 Ir
10 A	t > 2 h	t < 2 h	t < 2 min.	2 ≤ t ≤ 10 s
10	t > 2 h	t < 2 h	t < 4 min.	4 ≤ t ≤ 10 s
20	t > 2 h	t < 2 h	t < 8 min.	6 ≤ t ≤ 20 s
30	t > 2 h	t < 2 h	t < 12 min.	9 ≤ t ≤ 30 s

Motor protection coordination

Protection of motor circuit with circuit-breaker

The four utilisation categories of contactors (AC1 to AC4)

The four utilisation categories of contactors (AC1 to AC4)The utilisation category determines the operating frequency and endurance of a contactor. The category depends on the type of load. If the load is a motor; the category also depends on the service classification.

Main characteristics of the controlled electrical circuits and applications

Category	Type of load	Contactor usage	Typical applications
AC1	No-inductive (cos φ 0.8)	Energisation	Heating, distribution
AC2	Slip-ring motors (cos φ 0.65)	Starting Switching off during running Regenerative braking Inching	Wire drawing machines
AC3	Squirrel-cage motors (cos φ 0.45 for le ≤ 100A) (cos φ 0.35 for le > 100A)	Starting Switching off during running	Compressors, lifts, mixing Pumps, escalators, fans, Conveyers, air-conditioning
AC4	Squirrel-cage motors (cos φ 0.45 for le ≤ 100A) (cos φ 0.35 for le > 100A)	Starting Switching off during running Regenerative braking Plugging Inching	Printing machines, wire

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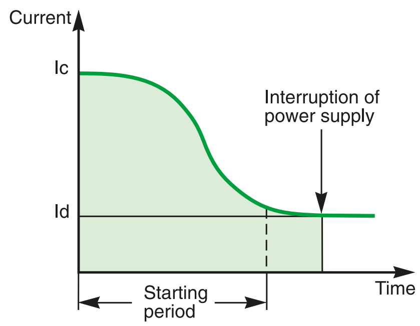

AC3 utilisation category. The contactor interrupts the rated current of the motor.

AC3 utilisation category

This category covers asynchronous squirrel-cage motors that are switched off during running. This is the most common situation (85 % of all cases).
The control device establishes the starting current and interrupts the rated current at a voltage equal to approximately one-sixth of the rated value.
Current interruption is carried out with no difficulty.

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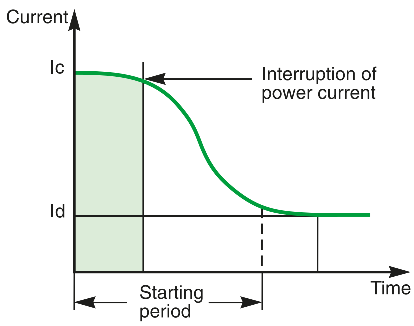

AC4 utilisation category. The contactor must be capable of interrupting the starting current id.

AC4 utilisation category

This category covers asynchronous squirrel-cage or slip-ring motors capable of operating under regenerative-braking or inching (jogging) conditions.
The control device establishes the starting current and is capable of interrupting the starting current at a voltage that may be equal to that of the mains.
Such difficult conditions require oversizing of the control and protective devices with respect to category AC3.

Motor protection coordination

Using the circuit breaker/contactor coordination tables

B

Subtransient phenomena related to direct on-line starting of asynchronous motors

Subtransient phenomena occurring when starting squirrel-cage motors:
A squirrel-cage motor draws a high inrush current during starting. This current is related to the combined influence of two parameters:

- the high inductance of the copper stator winding
- the magnetisation of the iron core of the stator.

In motor: current drawn by the motor at full rated load (in A rms)
Id: current drawn by the motor during starting (in A ms)
Id”: subtransient current generated by the motor when it is energised. This very short subtransient phenomenon is expressed as k x Id x r 2 (in A peak).
td: motor starting time, from 0.5 to 30 seconds depending on the application.
td”: duration of the subtransient current, from 0.010 to 0.015 seconds when the motor is energised.
Irm: magnetic setting of the circuit breakers.

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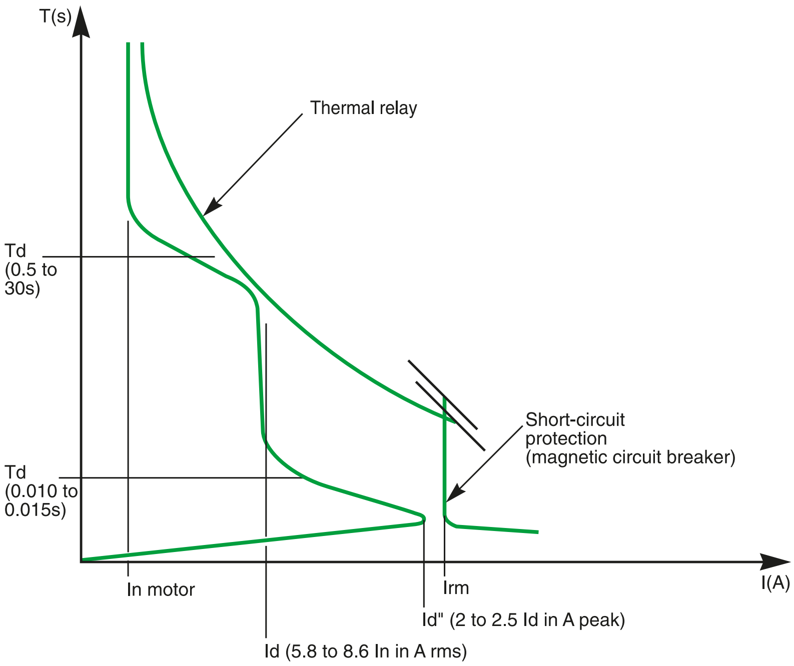

Typical upper and lower limits for these subtransient currents:
These values, not covered by standards, also depend on the type of motor technology used:

- ordinary motors Id” = 2 Id to 2.1 Id (in A peak)
- high-efficiency motors Id” = 2.2 Id to 2.5 Id (in A peak).
- variation of Id” as a function of Id:

Type of motor	d (in A rms)	Id” (in A peak)
Ordinary motor	5.8 to 8.6 In motor	Id” = 2 Id = 11.5 In (A peak) to Id” = 2.1 Id = 18 In (A peak)
High-efficiency motor	5.8 to 8.6 In motor	Id” = 2.2 Id = 12.5 In (A peak) to Id” = 2.5 Id = 21.5 In (A peak)

Example: Upon energisation, a high-efficiency motor with an Id of 7.5 In produces a subtransient current with a value between (depending on its characteritics):
- minimum = 16.5 In (in A peak)
- maximum = 18.8 In (in A peak).

Motor protection coordination

Using the circuit breaker/contactor coordination tables

Subtransient currents and protection settings:

- as illustrated in the above table, subtransient currents can be very high.
- If they approach their upper limits, they can trip short-cicuit protection devices (nuisance tripping)
- circuit breakers are rated to provide optimum short-circuit protection for motor starters (type 2 coordination with thermal relay and contactor)
- combinations made up of circuit breakers and contactors and thermal relays are designed to allow starting of motors generating high subtransient currents (up to 19 In motor peak)
- the tripping of short-circuit protective devices when starting with a combination listed in the coordination tables means:
  - the limits of certain devices may be reached
  - the use of the starter under type 2 coordination conditions on the given motor may lead to premature wear of one of the components of the combination.

In event of such a problem, the ratings of the starter and the associated protective devices must be redesigned.

European regulation EC640 has been introduced in January 2015 to enforce usage of premium efficiency motor classified as IE3.

One consequence of the improvement of induction motor's efficiency may be an increase of starting current value.

TeSys and Compact ranges can handle IE3 motor higher inrush and starting current. However, due to the spread of starting current values of the motors on the market, it's recommended to check the value of subtransient starting current in Direct-On-Line application when Istart > 7.5 In or Ipeak inrush > 19 x In.

Using the coordination tables for circuit breaker and contactors:

- **ordinary motor:**
The starter components can be selected directly from the coordination tables, whatever the values of the starting current (Id from 5.8 to 8.6 In) and the subtransient current
- **high-efficiency motors with Id ≤ 7.5 In:**
The starter components can be selected directly from the coordination tables, whatever the values of the starting current and the subtransient current
- **high-efficiency motors with Id > 7.5 In:**
When circuit breakers are used for motor currents in the neighbourhood of their rated current, they are set to provide minimum short-circuit protection at **19 In motor (A peak)**.
There are two possibilities:
- the subtransient starting current is known (indicated by the motor manufacturer) and is less than **19 In motor (A peak)**.
In this case, the starter components can be selected directly from the coordination tables, whatever the value of the starting current (for Id > 7.5 In).
Example: for a 110 kW 380-415 V 3-phase motor, the selected components are: NSX250-MA220/LC1-F225/LR9-F5371.
- the subtransient starting current is unknown or greater than 19 In motor (A peak).
In this case, the value used for the motor power in the coordination tables should be increased by 20 % to satisfy optimum starting and coordination conditions.
Example: for a 110 kW 380-415 V 3-phase motor, the selected components are those for a motor power of 110 + 20 % = 132 kW:
NSX400 Micrologic 4.3M/LC1-F265/LR9-F5371

Reversing starters and coordination

The starter components can be selected using the tables for direct-on-line starting.
Replace contactors LC1 by LC2.

Star-delta starting and coordination

- the components should be sized according to the current flowing in the motor windings
- the mounting locations and connections of the various components of star-delta starters should be selected according to the type of coordination required and the protective devices implemented.