4 Lighting circuits

A source of comfort and productivity, lighting represents 15% of the quantity of electricity consumed in industry and 40% in buildings. The quality of lighting (light stability and continuity of service) depends on the quality of the electrical energy thus consumed. The supply of electrical power to lighting networks has therefore assumed great importance.

To help with their design and simplify the selection of appropriate protection devices, an analysis of the different lamp technologies is presented. The distinctive features of lighting circuits and their impact on control and protection devices are discussed. Recommendations relative to the difficulties of lighting circuit implementation are given.

4.1 The different lamp technologies

Artificial luminous radiation can be produced from electrical energy according to two principles: incandescence and electroluminescence.

Incandescence is the production of light via temperature elevation. The most common example is a filament heated to white state by the circulation of an electrical current. The energy supplied is transformed into heat by the Joule effect and into luminous flux.

Luminescence is the phenomenon of emission by a material of visible or almost visible luminous radiation. A gas (or vapors) subjected to an electrical discharge emits luminous radiation (Electroluminescence of gases).

Since this gas does not conduct at normal temperature and pressure, the discharge is produced by generating charged particles which permit ionization of the gas. The nature, pressure and temperature of the gas determine the light spectrum.

Photoluminescence is the luminescence of a material exposed to visible or almost visible radiation (ultraviolet, infrared).

When the substance absorbs ultraviolet radiation and emits visible radiation which stops a short time after energization, this is fluorescence.

Incandescent lamps

Incandescent lamps are historically the oldest and the most often found in common use.
They are based on the principle of a filament rendered incandescent in a vacuum or neutral atmosphere which prevents combustion.

A distinction is made between:

- Standard bulbs

These contain a tungsten filament and are filled with an inert gas (nitrogen and argon or krypton).

- Halogen bulbs

These also contain a tungsten filament, but are filled with a halogen compound and an inert gas (krypton or xenon). This halogen compound is responsible for the phenomenon of filament regeneration, which increases the service life of the lamps and avoids them blackening. It also enables a higher filament temperature and therefore greater luminosity in smaller-size bulbs.

The main disadvantage of incandescent lamps is their significant heat dissipation, resulting in poor luminous efficiency.

Fluorescent lamps

This family covers fluorescent tubes and compact fluorescent lamps. Their technology is usually known as “low-pressure mercury”.

In fluorescent tubes, an electrical discharge causes electrons to collide with ions of mercury vapor, resulting in ultraviolet radiation due to energization of the mercury atoms. The fluorescent material, which covers the inside of the tubes, then transforms this radiation into visible light.

Fluorescent tubes dissipate less heat and have a longer service life than incandescent lamps, but they do need an ignition device called a “starter” and a device to limit the current in the arc after ignition. This device called “ballast” is usually a choke placed in series with the arc.

Compact fluorescent lamps are based on the same principle as a fluorescent tube. The starter and ballast functions are provided by an electronic circuit (integrated in the lamp) which enables the use of smaller tubes folded back on themselves.

Compact fluorescent lamps (see **Fig. N35**) were developed to replace incandescent lamps: They offer significant energy savings (15 W against 75 W for the same level of brightness) and an increased service life.

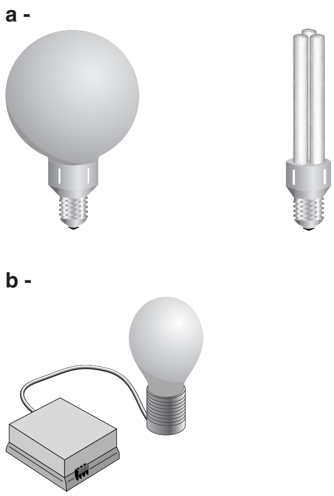


*Fig. N35 : Compact fluorescent lamps **[a]** standard, **[b]** induction*

Lamps known as “induction” type or “without electrodes” operate on the principle of ionization of the gas present in the tube by a very high frequency electromagnetic field (up to 1 GHz). Their service life can be as long as 100,000 hrs.

Discharge lamps (see Fig. N36)

The light is produced by an electrical discharge created between two electrodes within a gas in a quartz bulb. All these lamps therefore require a ballast to limit the current in the arc. A number of technologies have been developed for different applications.
Low-pressure sodium vapor lamps have the best light output, however the color rendering is very poor since they only have a monochromatic orange radiation.
High-pressure sodium vapor lamps produce a white light with an orange tinge.
In high-pressure mercury vapor lamps, the discharge is produced in a quartz or ceramic bulb at high pressure. These lamps are called “fluorescent mercury discharge lamps”. They produce a characteristically bluish white light.
Metal halide lamps are the latest technology. They produce a color with a broad color spectrum. The use of a ceramic tube offers better luminous efficiency and better color stability.

Light Emitting Diodes (LED)

The principle of light emitting diodes is the emission of light by a semi-conductor as an electrical current passes through it. LEDs are commonly found in numerous applications, but the recent development of white or blue diodes with a high light output opens new perspectives, especially for signaling (traffic lights, exit signs or emergency lighting).
LEDs are low-voltage and low-current devices, thus suitable for battery-supply.
A converter is required for a line power supply.
The advantage of LEDs is their low energy consumption. As a result, they operate at a very low temperature, giving them a very long service life. Conversely, a simple diode has a weak light intensity. A high-power lighting installation therefore requires connection of a large number of units in series and parallel.

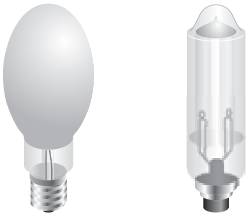


Fig. N36 : Discharge lamps

Technology	Application	Advantages	Disadvantages
Standard incandescent	- Domestic use - Localized decorative lighting	- Direct connection without intermediate switchgear - Reasonable purchase price - Compact size - Instantaneous lighting - Good color rendering	- Low luminous efficiency and high electricity consumption - Significant heat dissipation - Short service life
Halogen incandescent	- Spot lighting - Intense lighting	- Direct connection - Instantaneous efficiency - Excellent color rendering	- Average luminous efficiency
Fluorescent tube	- Shops, offices, workshops - Outdoors	- High luminous efficiency - Average color rendering	- Low light intensity of single unit - Sensitive to extreme temperatures
Compact fluorescent lamp	- Domestic use - Offices - Replacement of incandescent lamps	- Good luminous efficiency - Good color rendering	- High initial investment compared to incandescent lamps
HP mercury vapor	- Workshops, halls, hangars - Factory floors	- Good luminous efficiency - Acceptable color rendering - Compact size - Long service life	- Lighting and relighting time of a few minutes
High-pressure sodium	- Outdoors - Large halls	- Very good luminous efficiency	- Lighting and relighting time of a few minutes
Low-pressure sodium	- Outdoors - Emergency lighting	- Good visibility in foggy weather - Economical to use	- Long lighting time (5 min.) - Mediocre color rendering
Metal halide	- Large areas - Halls with high ceilings	- Good luminous efficiency - Good color rendering - Long service life	- Lighting and relighting time of a few minutes
LED	- Signaling (3-color traffic lights, “exit” signs and emergency lighting)	- Insensitive to the number of switching operations - Low energy consumption - Low temperature	- Limited number of colors - Low brightness of single unit

Technology	Power (watt)	Efficiency (lumen/watt)	Service life (hours)
Standard incandescent	3 – 1,000	10 – 15	1,000 – 2,000
Halogen incandescent	5 – 500	15 – 25	2,000 – 4,000
Fluorescent tube	4 – 56	50 – 100	7,500 – 24,000
Compact fluorescent lamp	5 – 40	50 – 80	10,000 – 20,000
HP mercury vapor	40 – 1,000	25 – 55	16,000 – 24,000
High-pressure sodium	35 – 1,000	40 – 140	16,000 – 24,000
Low-pressure sodium	35 – 180	100 – 185	14,000 – 18,000
Metal halide	30 – 2,000	50 – 115	6,000 – 20,000
LED	0.05 – 0.1	10 – 30	40,000 – 100,000

Fig. N37 : Usage and technical characteristics of lighting devices

4.2 Electrical characteristics of lamps

Incandescent lamps with direct power supply

Due to the very high temperature of the filament during operation (up to 2,500 °C), its resistance varies greatly depending on whether the lamp is on or off. As the cold resistance is low, a current peak occurs on ignition that can reach 10 to 15 times the nominal current for a few milliseconds or even several milliseconds.

This constraint affects both ordinary lamps and halogen lamps: it imposes a reduction in the maximum number of lamps that can be powered by devices such as remote-control switches, modular contactors and relays for busbar trunking.

Extra Low Voltage (ELV) halogen lamps

- Some low-power halogen lamps are supplied with ELV 12 or 24 V, via a transformer or an electronic converter. With a transformer, the magnetization phenomenon combines with the filament resistance variation phenomenon at switch-on. The inrush current can reach 50 to 75 times the nominal current for a few milliseconds. The use of dimmer switches placed upstream significantly reduces this constraint.
- Electronic converters, with the same power rating, are more expensive than solutions with a transformer. This commercial handicap is compensated by a greater ease of installation since their low heat dissipation means they can be fixed on a flammable support. Moreover, they usually have built-in thermal protection.

New ELV halogen lamps are now available with a transformer integrated in their base. They can be supplied directly from the LV line supply and can replace normal lamps without any special adaptation.

Dimming for incandescent lamps

This can be obtained by varying the voltage applied to the lampere

This voltage variation is usually performed by a device such as a Triac dimmer switch, by varying its firing angle in the line voltage period. The wave form of the voltage applied to the lamp is illustrated in **Figure N38a**. This technique known as "cut-on control" is suitable for supplying power to resistive or inductive circuits. Another technique suitable for supplying power to capacitive circuits has been developed with MOS or IGBT electronic components. This techniques varies the voltage by blocking the current before the end of the half-period (see **Fig. N38b**) and is known as "cut-off control".

Switching on the lamp gradually can also reduce, or even eliminate, the current peak on ignition.

As the lamp current is distorted by the electronic switching, harmonic currents are produced. The 3rd harmonic order is predominant, and the percentage of 3rd harmonic current related to the maximum fundamental current (at maximum power) is represented on **Figure N39**.

Note that in practice, the power applied to the lamp by a dimmer switch can only vary in the range between 15 and 85% of the maximum power of the lampere

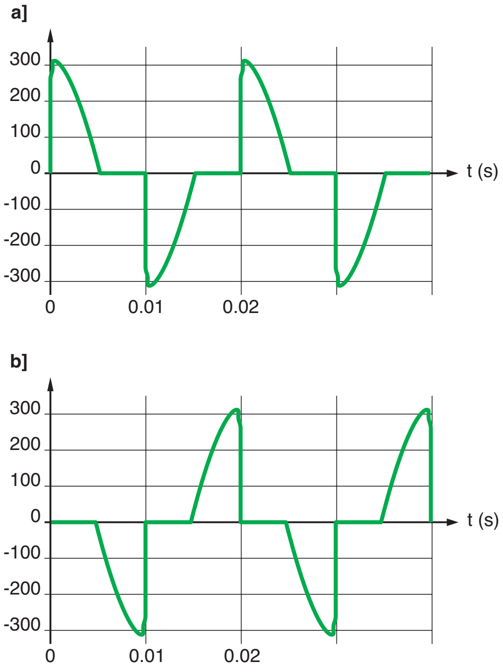


Fig. N38 : Shape of the voltage supplied by a light dimmer at 50% of maximum voltage with the following techniques:
***a]** "cut-on control"*
***b]** "cut-off control"*

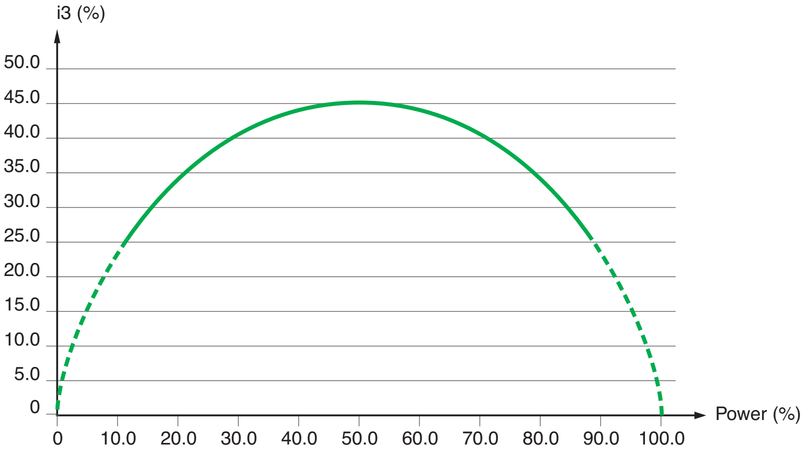


Fig. N39 : Percentage of 3rd harmonic current as a function of the power applied to an incandescent lamp using an electronic dimmer switch

According to IEC standard 61000-3-2 setting harmonic emission limits for electric or electronic systems with current ⩽ 16 A, the following arrangements apply:

- Independent dimmers for incandescent lamps with a rated power less than or equal to 1 kW have no limits applied
- Otherwise, or for incandescent lighting equipment with built-in dimmer or dimmer built in an enclosure, the maximum permissible 3^{rd} harmonic current is equal to 2.30 A

Fluorescent lamps with magnetic ballast

Fluorescent tubes and discharge lamps require the intensity of the arc to be limited, and this function is fulfilled by a choke (or magnetic ballast) placed in series with the bulb itself (see **Fig. N40**).

This arrangement is most commonly used in domestic applications with a limited number of tubes. No particular constraint applies to the switches.

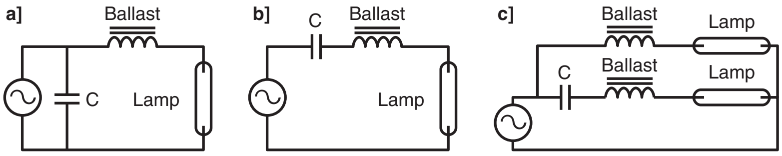
Dimmer switches are not compatible with magnetic ballasts: the cancellation of the voltage for a fraction of the period interrupts the discharge and totally extinguishes the lampere

The starter has a dual function: preheating the tube electrodes, and then generating an overvoltage to ignite the tube. This overvoltage is generated by the opening of a contact (controlled by a thermal switch) which interrupts the current circulating in the magnetic ballast.

During operation of the starter (approx. 1 s), the current drawn by the luminaire is approximately twice the nominal current.

Since the current drawn by the tube and ballast assembly is essentially inductive, the power factor is very low (on average between 0.4 and 0.5). In installations consisting of a large number of tubes, it is necessary to provide compensation to improve the power factor.

For large lighting installations, centralized compensation with capacitor banks is a possible solution, but more often this compensation is included at the level of each luminaire in a variety of different layouts (see **Fig. N41**).



Compensation layout	Application	Comments
Without compensation	Domestic	Single connection
Parallel [a]	Offices, workshops, superstores	Risk of overcurrents for control devices
Series [b]		Choose capacitors with high operating voltage (450 to 480 V)
Duo [c]		Avoids flicker

*Fig. N41 : The various compensation layouts: **a]** parallel; **b]** series; **c]** dual series also called "duo" and their fields of application*

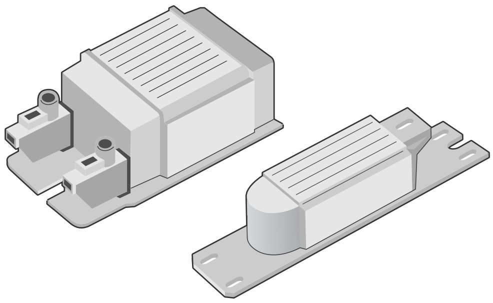


Fig. N40 : Magnetic ballasts

The compensation capacitors are therefore sized so that the global power factor is greater than 0.85. In the most common case of parallel compensation, its capacity is on average 1 µF for 10 W of active power, for any type of lampere However, this compensation is incompatible with dimmer switches.

Constraints affecting compensation

The layout for parallel compensation creates constraints on ignition of the lampere Since the capacitor is initially discharged, switch-on produces an overcurrent. An overvoltage also appears, due to the oscillations in the circuit made up of the capacitor and the power supply inductance.

The following example can be used to determine the orders of magnitude.

Assuming an assembly of 50 fluorescent tubes of 36 W each:

- Total active power: 1,800 W
- Apparent power: 2 kVA
- Total rms current: 9 A
- Peak current: 13 A

With:

- A total capacity: C = 175 µF
- A line inductance (corresponding to a short-circuit current of 5 kA): L = 150 µH

The maximum peak current at switch-on equals:

$$Ic = V_{max}\sqrt{\frac{C}{L}} = 230\sqrt{2}\sqrt{\frac{175 \text{ x } 10^{-6}}{150 \text{ x } 10^{-6}}} = 350 \text{ A}$$

The theoretical peak current at switch-on can therefore reach **27 times** the peak current during normal operation.

The shape of the voltage and current at ignition is given in **Figure N42** for switch closing at the line supply voltage peak.

There is therefore a risk of contact welding in electromechanical control devices (remote-control switch, contactor, circuit-breaker) or destruction of solid state switches with semi-conductors.

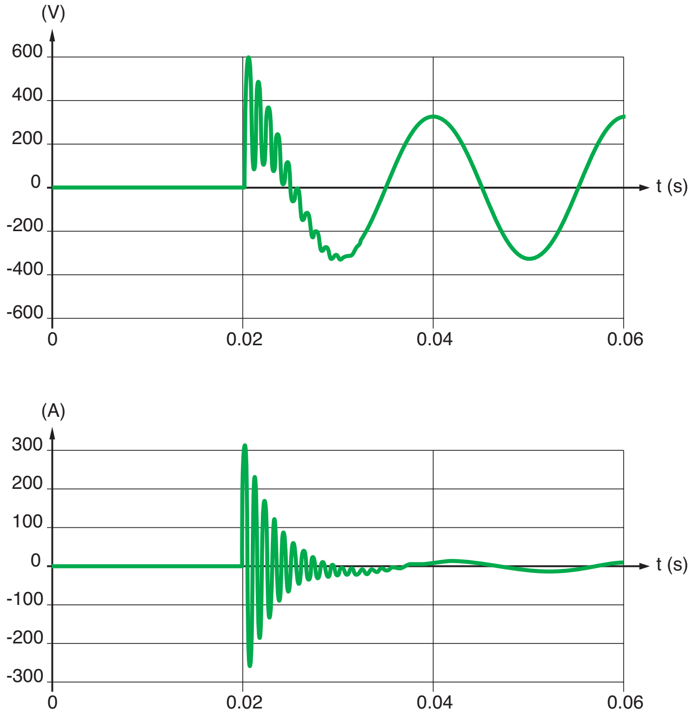


Fig. N42 : Power supply voltage at switch-on and inrush current

In reality, the constraints are usually less severe, due to the impedance of the cables.

Ignition of fluorescent tubes in groups implies one specific constraint. When a group of tubes is already switched on, the compensation capacitors in these tubes which are already energized participate in the inrush current at the moment of ignition of a second group of tubes: they “amplify” the current peak in the control switch at the moment of ignition of the second group.

The table in **Figure N43**, resulting from measurements, specifies the magnitude of the first current peak, for different values of prospective short-circuit current Isc. It is seen that the current peak can be multiplied by 2 or 3, depending on the number of tubes already in use at the moment of connection of the last group of tubes.

Number of tubes already in use	Number of tubes connected	Inrush current peak (A)		
		Isc = 1,500 A	**Isc = 3,000 A**	**Isc = 6,000 A**
0	14	233	250	320
14	14	558	556	575
28	14	608	607	624
42	14	618	616	632

Fig. N43 : Magnitude of the current peak in the control switch of the moment of ignition of a second group of tubes

Nonetheless, sequential ignition of each group of tubes is recommended so as to reduce the current peak in the main switch.

The most recent magnetic ballasts are known as “low-loss”. The magnetic circuit has been optimized, but the operating principle remains the same. This new generation of ballasts is coming into widespread use, under the influence of new regulations (European Directive, Energy Policy Act - USA).

In these conditions, the use of electronic ballasts is likely to increase, to the detriment of magnetic ballasts.

Fluorescent lamps with electronic ballast

Electronic ballasts are used as a replacement for magnetic ballasts to supply power to fluorescent tubes (including compact fluorescent lamps) and discharge lamps. They also provide the “starter” function and do not need any compensation capacity.

The principle of the electronic ballast (see **Fig. N44**) consists of supplying the lamp arc via an electronic device that generates a rectangular form AC voltage with a frequency between 20 and 60 kHz.

Supplying the arc with a high-frequency voltage can totally eliminate the flicker phenomenon and strobe effects. The electronic ballast is totally silent.

During the preheating period of a discharge lamp, this ballast supplies the lamp with increasing voltage, imposing an almost constant current. In steady state, it regulates the voltage applied to the lamp independently of any fluctuations in the line voltage.

Since the arc is supplied in optimum voltage conditions, this results in energy savings of 5 to 10% and increased lamp service life. Moreover, the efficiency of the electronic ballast can exceed 93%, whereas the average efficiency of a magnetic device is only 85%.

The power factor is high (> 0.9).

The electronic ballast is also used to provide the light dimming function. Varying the frequency in fact varies the current magnitude in the arc and hence the luminous intensity.

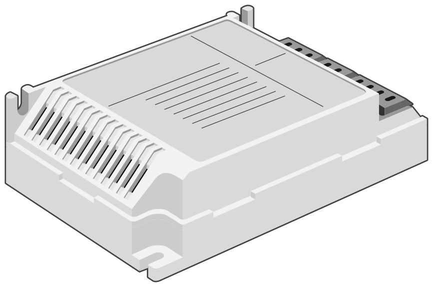


Fig. N44 : Electronic ballast

Inrush current

The main constraint that electronic ballasts bring to line supplies is the high inrush current on switch-on linked to the initial load of the smoothing capacitors (see **Fig. N45**).

Technology	Max. inrush current	Duration
Rectifier with PFC	30 to 100 In	⩽ 1 ms
Rectifier with choke	10 to 30 In	⩽ 5 ms
Magnetic ballast	⩽ 13 In	5 to 10 ms

Fig. N45 : Orders of magnitude of the inrush current maximum values, depending on the technologies used

In reality, due to the wiring impedances, the inrush currents for an assembly of lamps is much lower than these values, in the order of 5 to 10 In for less than 5 ms. Unlike magnetic ballasts, this inrush current is not accompanied by an overvoltage.

Harmonic currents

For ballasts associated with high-power discharge lamps, the current drawn from the line supply has a low total harmonic distortion (< 20% in general and < 10% for the most sophisticated devices). Conversely, devices associated with low-power lamps, in particular compact fluorescent lamps, draw a very distorted current (see **Fig. N46**). The total harmonic distortion can be as high as 150%. In these conditions, the rms current drawn from the line supply equals 1.8 times the current corresponding to the lamp active power, which corresponds to a power factor of 0.55.

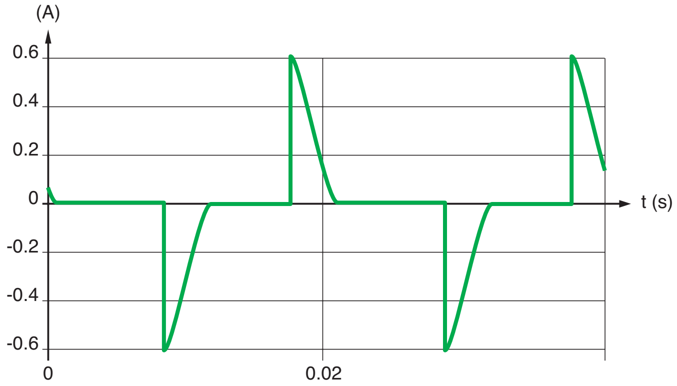


Fig. N46 : Shape of the current drawn by a compact fluorescent lamp

In order to balance the load between the different phases, lighting circuits are usually connected between phases and neutral in a balanced way. In these conditions, the high level of third harmonic and harmonics that are multiple of 3 can cause an overload of the neutral conductor. The least favorable situation leads to a neutral current which may reach $\sqrt{3}$ times the current in each phase.

Harmonic emission limits for electric or electronic systems are set by IEC standard 61000-3-2. For simplification, the limits for lighting equipment are given here only for harmonic orders 3 and 5 which are the most relevant (see **Fig. N47**).

Harmonic order	**Active input power > 25W**	**Active input power ⩽ 25W one of the 2 sets of limits apply:**	
	% of fundamental current	% of fundamental current	Harmonic current relative to active power
3	30	86	3.4 mA/W
5	10	61	1.9 mA/W

Fig. N47 : Maximum permissible harmonic current

Leakage currents

Electronic ballasts usually have capacitors placed between the power supply conductors and the earth. These interference-suppressing capacitors are responsible for the circulation of a permanent leakage current in the order of 0.5 to 1 mA per ballast. This therefore results in a limit being placed on the number of ballasts that can be supplied by a Residual Current Differential Safety Device (RCD).

At switch-on, the initial load of these capacitors can also cause the circulation of a current peak whose magnitude can reach several amps for 10 µs. This current peak may cause unwanted tripping of unsuitable devices.

High-frequency emissions

Electronic ballasts are responsible for high-frequency conducted and radiated emissions.
The very steep rising edges applied to the ballast output conductors cause current pulses circulating in the stray capacities to earth. As a result, stray currents circulate in the earth conductor and the power supply conductors. Due to the high frequency of these currents, there is also electromagnetic radiation. To limit these HF emissions, the lamp should be placed in the immediate proximity of the ballast, thus reducing the length of the most strongly radiating conductors.

The different power supply modes (see **Fig. N48**)

Technology	Power supply mode	Other device
Standard incandescent	Direct power supply	Dimmer switch
Halogen incandescent		
ELV halogen incandescent	Transformer	Electronic converter
Fluorescent tube	Magnetic ballast and starter	Electronic ballast Electronic dimmer + ballast
Compact fluorescent lamp	Built-in electronic ballast	
Mercury vapor	Magnetic ballast	Electronic ballast
High-pressure sodium		
Low-pressure sodium		
Metal halide		

Fig. N48 : Different power supply modes

4.3 Constraints related to lighting devices and recommendations

The current actually drawn by luminaires

The risk

This characteristic is the first one that should be defined when creating an installation, otherwise it is highly probable that overload protection devices will trip and users may often find themselves in the dark.
It is evident that their determination should take into account the consumption of all components, especially for fluorescent lighting installations, since the power consumed by the ballasts has to be added to that of the tubes and bulbs.

The solution

For incandescent lighting, it should be remembered that the line voltage can be more than 10% of its nominal value, which would then cause an increase in the current drawn.

For fluorescent lighting, unless otherwise specified, the power of the magnetic ballasts can be assessed at 25% of that of the bulbs. For electronic ballasts, this power is lower, in the order of 5 to 10%.

The thresholds for the overcurrent protection devices should therefore be calculated as a function of the total power and the power factor, calculated for each circuit.

Overcurrents at switch-on

The risk

The devices used for control and protection of lighting circuits are those such as relays, triac, remote-control switches, contactors or circuit-breakers.

The main constraint applied to these devices is the current peak on energization. This current peak depends on the technology of the lamps used, but also on the installation characteristics (supply transformer power, length of cables, number of lamps) and the moment of energization in the line voltage period. A high current peak, however fleeting, can cause the contacts on an electromechanical control device to weld together or the destruction of a solid state device with semi-conductors.

Two solutions

Because of the inrush current, the majority of ordinary relays are incompatible with lighting device power supply. The following recommendations are therefore usually made:

- Limit the number of lamps to be connected to a single device so that their total power is less than the maximum permissible power for the device
- Check with the manufacturers what operating limits they suggest for the devices. This precaution is particularly important when replacing incandescent lamps with compact fluorescent lamps

By way of example, the table in **Figure N49** indicates the maximum number of compensated fluorescent tubes that can be controlled by different devices with 16 A rating. Note that the number of controlled tubes is well below the number corresponding to the maximum power for the devices.

Tube unit power requirement (W)	**Number of tubes corresponding to the power 16 A x 230 V**	**Maximum number of tubes that can be controlled by**		
		Contactors GC16 A CT16 A	**Remote control switches TL16 A**	**Circuit-breakers C60-16 A**
18	204	15	50	112
36	102	15	25	56
58	63	10	16	34

Fig. N49 : The number of controlled tubes is well below the number corresponding to the maximum power for the devices

But a technique exists to limit the current peak on energization of circuits with capacitive behavior (magnetic ballasts with parallel compensation and electronic ballasts). It consists of ensuring that activation occurs at the moment when the line voltage passes through zero. Only solid state switches with semi-conductors offer this possibility (see **Fig. N50a**). This technique has proved to be particularly useful when designing new lighting circuits.

More recently, hybrid technology devices have been developed that combine a solid state switch (activation on voltage passage through zero) and an electromechanical contactor short-circuiting the solid state switch (reduction of losses in the semi-conductors) (see **Fig. N50b**).

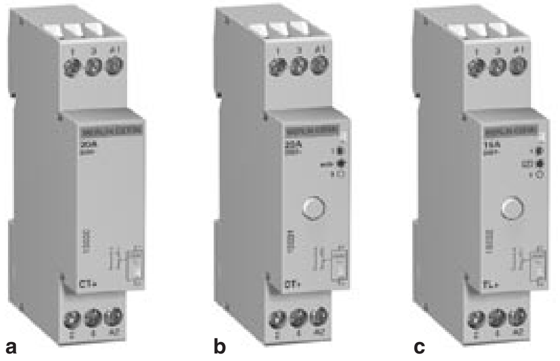


*Fig. N50 : "Standard" CT+ contactor **[a]**, CT+ contactor with manual override, pushbutton for selection of operating mode and indicator lamp showing the active operating mode **[b]**, and TL + remote-control switch **[c]** (Merlin Gerin brand)*

Modular contactors and impulse relays do not use the same technologies. Their rating is determined according to different standards. For example, for a given rating, an impulse relay is more efficient than a modular contactor for the control of light fittings with a strong inrush current, or with a low power factor (non-compensated inductive circuit).

Choice of relay rating according to lamp type

- **Figure 51** below shows the maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp. As an indication, the total acceptable power is also mentioned.
- These values are given for a 230 V circuit with 2 active conductors (single-phase phase/neutral or two-phase phase/phase). For 110 V circuits, divide the values in the table by 2.
- To obtain the equivalent values for the whole of a 230 V three-phase circuit, multiply the number of lamps and the total acceptable power:
  - ☐ by $\sqrt{3}$ (1.73) for circuits without neutral;
  - ☐ by 3 for circuits with neutral.

Note: The power ratings of the lamps most commonly used are shown in bold.

Type of lamp	Unit power and capacitance of power factor correction capacitor		Maximum number of light fittings for a single-phase circuit and maximum power output per circuit											
			TL impulse relay				**CT contactor**							
			16 A		32 A		16 A		25 A		40 A		63 A	
Basic incandescent lamps LV halogen lamps Replacement mercury vapour lamps (without ballast)														
	40 W		40	1500 W to 1600 W	106	4000 W to 4200 W	38	1550 W to 2000 W	57	2300 W to 2850 W	115	4600 W to 5250 W	172	6900 W to 7500 W
	60 W		25		66		30		45		85		125	
	75 W		20		53		25		38		70		100	
	100 W		16		42		19		28		50		73	
	150 W		10		28		12		18		35		50	
	200 W		8		21		10		14		26		37	
	300 W		5	1500 W	13	4000 W	7	2100 W	10	3000 W	18	5500 W to 6000 W	25	7500 W to 8000 W
	500 W		3		8		4		6		10		15	
	1000 W		1		4		2		3		6		8	
	1500 W		1		2		1		2		4		5	
ELV 12 or 24 V halogen lamps														
With ferromagnetic transformer	**20 W**		70	1350 W to 1450 W	180	3600 W to 3750 W	15	300 W to 600 W	23	450 W to 900 W	42	850 W to 1950 W	63	1250 W to 2850 W
	50 W		28		74		10		15		27		42	
	75 W		19		50		8		12		23		35	
	100 W		14		37		6		8		18		27	
With electronic transformer	**20 W**		60	1200 W to 1400 W	160	3200 W to 3350 W	62	1250 W to 1600 W	90	1850 W to 2250 W	182	3650 W to 4200 W	275	5500 W to 6000 W
	50 W		25		65		25		39		76		114	
	75 W		18		44		20		28		53		78	
	100 W		14		33		16		22		42		60	
Fluorescent tubes with starter and ferromagnetic ballast														
1 tube without compensation (1)	15 W		83	1250 W to 1300 W	213	3200 W to 3350 W	22	330 W to 850 W	30	450 W to 1200 W	70	1050 W to 2400 W	100	1500 W to 3850 W
	18 W		70		186		22		30		70		100	
	20 W		62		160		22		30		70		100	
	36 W		35		93		20		28		60		90	
	40 W		31		81		20		28		60		90	
	58 W		21		55		13		17		35		56	
	65 W		20		50		13		17		35		56	
	80 W		16		41		10		15		30		48	
	115 W		11		29		7		10		20		32	
1 tube with parallel compensation (2)	15 W	5 µF	60	900 W	160	2400 W	15	200 W to 800 W	20	300 W to 1200 W	40	600 W to 2400 W	60	900 W to 3500 W
	18 W	5 µF	50		133		15		20		40		60	
	20 W	5 µF	45		120		15		20		40		60	
	36 W	5 µF	25		66		15		20		40		60	
	40 W	5 µF	22		60		15		20		40		60	
	58 W	7 µF	16		42		10		15		30		43	
	65 W	7 µF	13		37		10		15		30		43	
	80 W	7 µF	11		30		10		15		30		43	
	115 W	16 µF	7		20		5		7		14		20	
2 or 4 tubes with series compensation	2 x **18 W**		56	2000 W	148	5300 W	30	1100 W to 1500 W	46	1650 W to 2400 W	80	2900 W to 3800 W	123	4450 W to 5900 W
	4 x **18 W**		28		74		16		24		44		68	
	2 x **36 W**		28		74		16		24		44		68	
	2 x **58 W**		17		45		10		16		27		42	
	2 x 65 W		15		40		10		16		27		42	
	2 x 80 W		12		33		9		13		22		34	
	2 x 115 W		8		23		6		10		16		25	
Fluorescent tubes with electronic ballast														
1 or 2 tubes	**18 W**		80	1450 W to 1550 W	212	3800 W to 4000 W	74	1300 W to 1400 W	111	2000 W to 2200 W	222	4000 W to 4400 W	333	6000 W to 6600 W
	36 W		40		106		38		58		117		176	
	58 W		26		69		25		37		74		111	
	2 x **18 W**		40		106		36		55		111		166	
	2 x **36 W**		20		53		20		30		60		90	
	2 x **58 W**		13		34		12		19		38		57	

Fig. N51 : Maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp (Continued on opposite page)

Type of lamp	Unit power and capacitance of power factor correction capacitor		Maximum number of light fittings for a single-phase circuit and maximum power output per circuit											
			TL impulse relay				**CT contactor**							
			16 A		32 A		16 A		25 A		40 A		63 A	
Compact fluorescent lamps														
With external electronic ballast	**5 W**		240	1200 W to 1450 W	630	3150 W to 3800 W	210	1050 W to 1300 W	330	1650 W to 2000 W	670	3350 W to 4000 W	not tested	
	7 W		171		457		150		222		478			
	9 W		138		366		122		194		383			
	11 W		118		318		104		163		327			
	18 W		77		202		66		105		216			
	26 W		55		146		50		76		153			
With integral electronic ballast (replacement for incandescent lamps)	**5 W**		170	850 W to 1050 W	390	1950 W to 2400 W	160	800 W to 900 W	230	1150 W to 1300 W	470	2350 W to 2600 W	710	3550 W to 3950 W
	7 W		121		285		114		164		335		514	
	9 W		100		233		94		133		266		411	
	11 W		86		200		78		109		222		340	
	18 W		55		127		48		69		138		213	
	26 W		40		92		34		50		100		151	
High-pressure mercury vapour lamps with ferromagnetic ballast without ignitor **Replacement high-pressure sodium vapour lamps** with ferromagnetic ballast with integral ignitor (3)														
Without compensation (1)	50 W		not tested, infrequent use				15	750 W to 1000 W	20	1000 W to 1600 W	34	1700 W to 2800 W	53	2650 W to 4200 W
	80 W						10		15		27		40	
	125 / 110 W (3)						8		10		20		28	
	250 / 220 W (3)						4		6		10		15	
	400 / 350 W (3)						2		4		6		10	
	700 W						1		2		4		6	
With parallel compensation (2)	50 W	7 µF					10	500 W to 1400 W	15	750 W to 1600 W	28	1400 W to 3500 W	43	2150 W to 5000 W
	80 W	8 µF					9		13		25		38	
	125 / 110 W (3)	10 µF					9		10		20		30	
	250 / 220 W (3)	18 µF					4		6		11		17	
	400 / 350 W (3)	25 µF					3		4		8		12	
	700 W	40 µF					2		2		5		7	
	1000 W	60 µF					0		1		3		5	
Low-pressure sodium vapour lamps with ferromagnetic ballast with external ignitor														
Without compensation (1)	**35 W**		not tested, infrequent use				5	270 W to 360 W	9	320 W to 720 W	14	500 W to 1100 W	24	850 W to 1800 W
	55 W						5		9		14		24	
	90 W						3		6		9		19	
	135 W						2		4		6		10	
	180 W						2		4		6		10	
With parallel compensation (2)	**35 W**	20 µF	38	1350 W	102	3600 W	3	100 W to 180 W	5	175 W to 360 W	10	350 W to 720 W	15	550 W to 1100 W
	55 W	20 µF	24		63		3		5		10		15	
	90 W	26 µF	15		40		2		4		8		11	
	135 W	40 µF	10		26		1		2		5		7	
	180 W	45 µF	7		18		1		2		4		6	
High-pressure sodium vapour lamps **Metal-iodide lamps**														
With ferromagnetic ballast with external ignitor, without compensation (1)	35 W		not tested, infrequent use				16	600 W	24	850 W to 1200 W	42	1450 W to 2000 W	64	2250 W to 3200 W
	70 W						8		12		20		32	
	150 W						4		7		13		18	
	250 W						2		4		8		11	
	400 W						1		3		5		8	
	1000 W						0		1		2		3	
With ferromagnetic ballast with external ignitor and parallel compensation (2)	35 W	6 µF	34	1200 W to 1350 W	88	3100 W to 3400 W	12	450 W to 1000 W	18	650 W to 2000 W	31	1100 W to 4000 W	50	1750 W to 6000 W
	70 W	12 µF	17		45		6		9		16		25	
	150 W	20 µF	8		22		4		6		10		15	
	250 W	32 µF	5		13		3		4		7		10	
	400 W	45 µF	3		8		2		3		5		7	
	1000 W	60 µF	1		3		1		2		3		5	
	2000 W	85 µF	0		1		0		1		2		3	
With electronic ballast	35 W		38	1350 W to 2200 W	87	3100 W to 5000 W	24	850 W to 1350 W	38	1350 W to 2200 W	68	2400 W to 4000 W	102	3600 W to 6000 W
	70 W		29		77		18		29		51		76	
	150 W		14		33		9		14		26		40	

(1) Circuits with non-compensated ferromagnetic ballasts consume twice as much current for a given lamp power output. This explains the small number of lamps in this configuration.

(2) The total capacitance of the power factor correction capacitors in parallel in a circuit limits the number of lamps that can be controlled by a contactor. The total downstream capacitance of a modular contactor of rating 16, 25, 40 or 63 A should not exceed 75, 100, 200 or 300 µF respectively. Allow for these limits to calculate the maximum acceptable number of lamps if the capacitance values are different from those in the table.

(3) High-pressure mercury vapour lamps without ignitor, of power 125, 250 and 400 W, are gradually being replaced by high-pressure sodium vapour lamps with integral ignitor, and respective power of 110, 220 and 350 W.

Fig. N51 : Maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp (Concluded)

Protection of lamp circuits: Maximum number of lamps and MCB rating versus lamp type, unit power and MCB tripping curve

During start up of discharge lamps (with their ballast), the inrush current drawn by each lamp may be in the order of:

- 25 x circuit start current for the first 3 ms
- 7 x circuit start current for the following 2 s

For fluorescent lamps with High Frequency Electronic control ballast, the protective device ratings must cope with 25 x inrush for 250 to 350 µs.
However due to the circuit resistance the total inrush current seen by the MCB is lower than the summation of all individual lamp inrush current if directly connected to the MCB.
The tables below (see **Fig. N52** to **NXX**) take into account:

- Circuits cables have a length of 20 meters from distribution board to the first lamp and 7 meters between each additional fittings.
- MCB rating is given to protect the lamp circuit in accordance with the cable cross section, and without unwanted tripping upon lamp starting.
- MCB tripping curve (C = instantaneous trip setting 5 to 10 In, D = instantaneous trip setting 10 to 14 In).

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	MCB rating C & D tripping curve																			
14/18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14 x3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
14 x4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
18 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
18 x4	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
21/24	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
21/24 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
35/36/39	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10
38/39 x2	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10
40/42	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
40/42 x2	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10	16
49/50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
49/50 x2	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16
54/55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10
54/55 x2	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16
60	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10

Fig. N52 : Fluorescent tubes with electronic ballast - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	MCB rating C & D tripping curve																			
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
11	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
15	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
20	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
21	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
23	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
25	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10

Fig. N53 : Compact fluorescent lamps - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
80	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
125	6	6	6	10	10	10	10	10	10	10	10	16	16	16	16	16	16	16	20	20
250	6	10	10	16	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	16	20	25	25	32	32	32	32	32	32	40	40	40	50	50	50	50	63	63
1000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
MCB rating D tripping curve																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
80	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
125	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16	20	20
250	6	6	10	10	10	10	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63
1000	10	20	25	32	40	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-

Fig. N54 : High pressure mercury vapour (with ferromagnetic ballast and PF correction) - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
Ferromagnetic ballast																				
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
26	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
91	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16	16
131	6	6	6	10	10	10	10	10	10	10	10	10	16	16	16	16	16	16	16	20
135	6	6	6	10	10	10	10	10	10	10	10	16	16	16	16	16	16	20	20	20
180	6	6	10	10	10	10	10	10	16	16	16	16	20	20	20	20	25	25	25	25
Electronic ballast																				
36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
66	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
91	6	6	6	6	6	10	10	10	10	10	10	10	10	10	10	10	16	16	16	16
MCB rating D tripping curve																				
Ferromagnetic ballast																				
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
26	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10
91	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16
131	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16	20
135	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	20	20	20
180	6	6	6	6	10	10	10	10	16	16	16	16	20	20	20	20	25	25	25	25
Electronic ballast																				
36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
66	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
91	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16	16

Fig. N55 : Low pressure sodium (with PF correction) - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
Ferromagnetic ballast																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
100	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16
150	6	6	10	10	10	10	10	10	6	16	16	16	16	16	16	20	20	20	25	25
250	6	10	16	16	16	20	20	20	20	20	20	25	25	25	32	32	32	32	40	40
400	10	16	20	25	32	32	32	32	32	32	32	40	40	40	50	50	50	50	63	63
1000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
Electronic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
50	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
100	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16
MCB rating D tripping curve																				
Ferromagnetic ballast																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
100	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16
150	6	6	6	6	6	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25
250	6	6	10	10	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63
1000	10	20	32	32	40	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-
Electronic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
50	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
100	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16

Fig. N56 *: High pressure sodium (with PF correction) - Vac = 230 V*

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
Ferromagnetic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
150	6	6	10	10	10	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25
250	6	10	16	16	16	20	20	20	20	20	20	25	25	25	32	32	32	32	40	40
400	6	16	20	25	25	32	32	32	32	32	32	40	40	40	50	50	50	50	63	63
1000	16	32	40	50	50	50	50	63	63	63	63	63	63	63	63	63	63	63	63	63
1800/2000	25	50	63	63	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electronic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
70	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10
150	6	6	6	10	10	10	10	10	10	10	16	16	16	16	16	16	16	20	20	20
MCB rating D tripping curve																				
Ferromagnetic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
70	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16
150	6	6	6	6	6	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25
250	6	6	10	10	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63
1000	16	20	32	32	40	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
1800	16	32	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2000	20	32	40	50	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electronic ballast																				
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
70	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10
150	6	6	6	6	6	6	6	10	10	10	16	16	16	16	16	16	16	20	20	20

Fig. N57 *: Metal halide (with PF correction) - Vac = 230 V*

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
1800	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
2000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
MCB rating D tripping curve																				
1800	16	20	32	32	32	32	50	63	63	-	-	-	-	-	-	-	-	-	-	-
2000	16	25	32	32	32	32	50	63	-	-	-	-	-	-	-	-	-	-	-	-

Fig. N58 *: Metal halide (with ferromagnetic ballast and PF correction) - Vac = 400 V*

Overload of the neutral conductor

The risk

In an installation including, for example, numerous fluorescent tubes with electronic ballasts supplied between phases and neutral, a high percentage of 3rd harmonic current can cause an overload of the neutral conductor. **Figure N59** below gives an overview of typical H3 level created by lighting.

Lamp type	Typical power	Setting mode	Typical H3 level
Incandescend lamp with dimmer	100 W	Light dimmer	5 to 45 %
ELV halogen lamp	25 W	Electronic ELV transformer	5 %
Fluorescent tube	100 W	Magnetic ballast	10 %
	< 25 W	Electronic ballast	85 %
	> 25 W	+ PFC	30 %
Discharge lamp	100 W	Magnetic ballast	10 %
		Electrical ballast	30 %

Fig. N59 : Overview of typical H3 level created by lighting

The solution

Firstly, the use of a neutral conductor with a small cross-section (half) should be prohibited, as requested by Installation standard IEC 60364, section 523–5–3.

As far as overcurrent protection devices are concerned, it is necessary to provide 4-pole circuit-breakers with protected neutral (except with the TN-C system for which the PEN, a combined neutral and protection conductor, should not be cut).
This type of device can also be used for the breaking of all poles necessary to supply luminaires at the phase-to-phase voltage in the event of a fault.

A breaking device should therefore interrupt the phase and Neutral circuit simultaneously.

Leakage currents to earth

The risk

At switch-on, the earth capacitances of the electronic ballasts are responsible for residual current peaks that are likely to cause unintentional tripping of protection devices.

Two solutions

The use of Residual Current Devices providing immunity against this type of impulse current is recommended, even essential, when equipping an existing installation (see **Fig. N60**).

For a new installation, it is sensible to provide solid state or hybrid control devices (contactors and remote-control switches) that reduce these impulse currents (activation on voltage passage through zero).

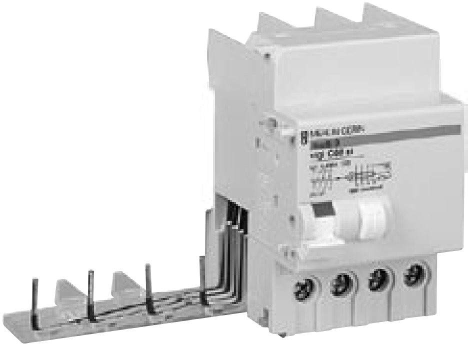


*Fig. N60 : **s.i.** residual current devices with immunity against impulse currents (Merlin Gerin brand)*

Overvoltages

The risk

As illustrated in earlier sections, switching on a lighting circuit causes a transient state which is manifested by a significant overcurrent. This overcurrent is accompanied by a strong voltage fluctuation applied to the load terminals connected to the same circuit. These voltage fluctuations can be detrimental to correct operation of sensitive loads (micro-computers, temperature controllers, etc.)

The Solution

It is advisable to separate the power supply for these sensitive loads from the lighting circuit power supply.

Sensitivity of lighting devices to line voltage disturbances

Short interruptions

- The risk

Discharge lamps require a relighting time of a few minutes after their power supply has been switched off.

- The solution

Partial lighting with instantaneous relighting (incandescent lamps or fluorescent tubes, or “hot restrike” discharge lamps) should be provided if safety requirements so dictate. Its power supply circuit is, depending on current regulations, usually distinct from the main lighting circuit.

Voltage fluctuations

- The risk

The majority of lighting devices (with the exception of lamps supplied by electronic ballasts) are sensitive to rapid fluctuations in the supply voltage. These fluctuations cause a flicker phenomenon which is unpleasant for users and may even cause significant problems. These problems depend on both the frequency of variations and their magnitude.

Standard IEC 61000-2-2 (“compatibility levels for low-frequency conducted disturbances”) specifies the maximum permissible magnitude of voltage variations as a function of the number of variations per second or per minute.

These voltage fluctuations are caused mainly by high-power fluctuating loads (arc furnaces, welding machines, starting motors).

- The solution

Special methods can be used to reduce voltage fluctuations. Nonetheless, it is advisable, wherever possible, to supply lighting circuits via a separate line supply. The use of electronic ballasts is recommended for demanding applications (hospitals, clean rooms, inspection rooms, computer rooms, etc).

Developments in control and protection equipment

The use of light dimmers is more and more common. The constraints on ignition are therefore reduced and derating of control and protection equipment is less important. New protection devices adapted to the constraints on lighting circuits are being introduced, for example Merlin Gerin brand circuit-breakers and modular residual current circuit-breakers with special immunity, such as s.i. type ID switches and Vigi circuit-breakers. As control and protection equipment evolves, some now offer remote control, 24-hour management, lighting control, reduced consumption, etc.

4.4 Lighting of public areas

Normal lighting

Regulations governing the minimum requirements for buildings receiving the public in most European countries are as follows:

- Installations which illuminates areas accessible to the public must be controlled and protected independently from installations providing illumination to other areas
- Loss of supply on a final lighting circuit (i.e. fuse blown or CB tripped) must not result in total loss of illumination in an area which is capable of accommodating more than 50 persons
- Protection by Residual Current Devices (RCD) must be divided amongst several devices (i.e. more than on device must be used)

Emergency lighting and other systems

When we refer to emergency lighting, we mean the auxiliary lighting that is triggered when the standard lighting fails.

Emergency lighting is subdivided as follows (EN-1838):

Safety lighting

It originates from the emergency lighting and is intended to provide lighting for people to evacuate an area safely or for those who try to finish a potentially dangerous operation before leaving the area. It is intended to illuminate the means of evacuation and ensure continuous visibility and ready usage in safety when standard or emergency lighting is needed.

Safety lighting may be further subdivided as follows:

Safety lighting for escape routes

It originates from the safety lighting, and is intended to ensure that the escape means can be clearly identified and used safely when the area is busy.

Anti-panic lighting in extended areas

It originates from the safety lighting, and is intended to avoid panic and to provide the necessary lighting to allow people to reach a possible escape route area.

Emergency lighting and safety signs for escape routes

The emergency lighting and safety signs for escape routes are very important for all those who design emergency systems. Their suitable choice helps improve safety levels and allows emergency situations to be handled better.

Standard EN 1838 ("Lighting applications. Emergency lighting") gives some fundamental concepts concerning what is meant by emergency lighting for escape routes:
"The intention behind lighting escape routes is to allow safe exit by the occupants, providing them with sufficient visibility and directions on the escape route …"
The concept referred to above is very simple:
The safety signs and escape route lighting must be two separate things.

Functions and operation of the luminaires

The manufacturing specifications are covered by standard EN 60598-2-22, "Particular Requirements - Luminaires for Emergency Lighting", which must be read with EN 60598-1, "Luminaires – Part 1: General Requirements and Tests".

Duration

A basic requirement is to determine the duration required for the emergency lighting. Generally it is 1 hour but some countries may have different duration requirements according to statutory technical standards.

Operation

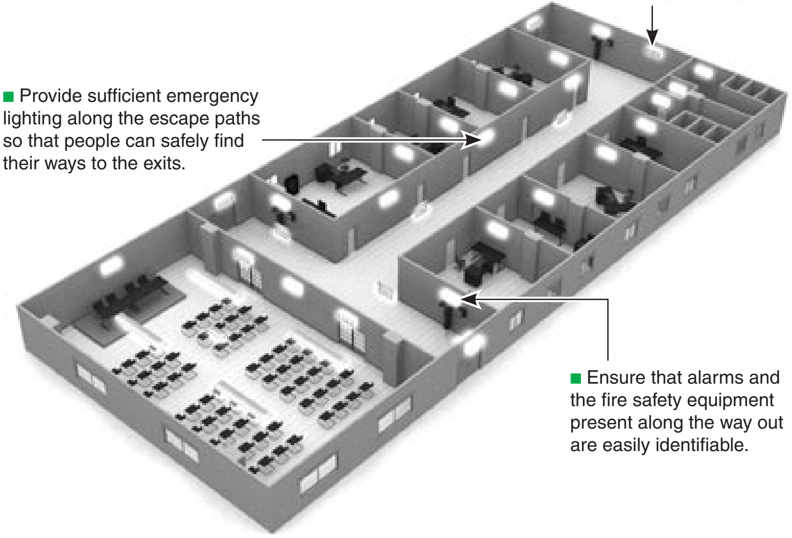
We should clarify the different types of emergency luminaires:

- Non-maintained luminaires
  - The lamp will only switch on if there is a fault in the standard lighting
  - The lamp will be powered by the battery during failure
  - The battery will be automatically recharged when the mains power supply is restored
- Maintained luminaires
  - The lamp can be switched on in continuous mode
  - A power supply unit is required with the mains, especially for powering the lamp, which can be disconnected when the area is not busy
  - The lamp will be powered by the battery during failure.

Design

The integration of emergency lighting with standard lighting must comply strictly with electrical system standards in the design of a building or particular place.
All regulations and laws must be complied with in order to design a system which is up to standard (see **Fig. N61**).

The main functions of an emergency lighting system when standard lighting fails are the following:



- Clearly show the escape route using clear signs.
- Provide sufficient emergency lighting along the escape paths so that people can safely find their ways to the exits.
- Ensure that alarms and the fire safety equipment present along the way out are easily identifiable.

Fig. N61 *: The main functions of an emergency lighting system*

European standards

The design of emergency lighting systems is regulated by a number of legislative provisions that are updated and implemented from time to time by new documentation published on request by the authorities that deal with European and international technical standards and regulations.
Each country has its own laws and regulations, in addition to technical standards

which govern different sectors. Basically they describe the places that must be provided with emergency lighting as well as its technical specifications. The designer's job is to ensure that the design project complies with these standards.

EN 1838

A very important document on a European level regarding emergency lighting is the Standard EN 1838, "Lighting applications. Emergency lighting".
This standard presents specific requirements and constraints regarding the operation and the function of emergency lighting systems.

CEN and CENELEC standards

With the CEN (Comité Européen de Normalisation) and CENELEC standards (Comité Européen de Normalisation Electrotechnique), we are in a standardised environment of particular interest to the technician and the designer. A number of sections deal with emergencies. An initial distinction should be made between luminaire standards and installation standards.

EN 60598-2-22 and EN-60598-1

Emergency lighting luminaires are subject to European standard EN 60598-2-22, "Particular Requirements - Luminaires for Emergency Lighting", which is an integrative text (of specifications and analysis) of the Standard EN-60598-1, Luminaires – "Part 1: General Requirements and Tests".

5 Asynchronous motors

The asynchronous (i.e. induction) motor is robust and reliable, and very widely used. 95% of motors installed around the world are asynchronous. The protection of these motors is consequently a matter of great importance in numerous applications.

The consequence of an incorrectly protected motor can include the following:

- For persons:
  - Asphyxiation due to the blockage of motor ventilation
  - Electrocution due to insulation failure in the motor
  - Accident due to non stopping of the motor following the failure of the control circuit in case of incorrect overcurrent protection
- For the driven machine and the process
  - Shaft couplings and axles, etc, damaged due to a stalled rotor
  - Loss of production
  - Manufacturing time delayed
- For the motor
  - Motor windings burnt out due to stalled rotor
  - Cost of dismantling and reinstalling or replacement of motor
  - Cost of repairs to the motor

Therefore, the safety of persons and goods, and reliability and availability levels are highly dependant on the choice of protective equipment.

In economic terms, the overall cost of failure must be considered. This cost is increasing with the size of the motor and with the difficulties of access and replacement. Loss of production is a further, and evidently important factor.

Specific features of motor performance influence the power supply circuits required for satisfactory operation

A motor power-supply circuit presents certain constraints not normally encountered in other (common) distribution circuits, owing to the particular characteristics, specific to motors, such as:

- High start-up current (see **Fig. N62**) which is mostly reactive, and can therefore be the cause of important voltage drop
- Number and frequency of start-up operations are generally high
- The high start-up current means that motor overload protective devices must have operating characteristics which avoid tripping during the starting period

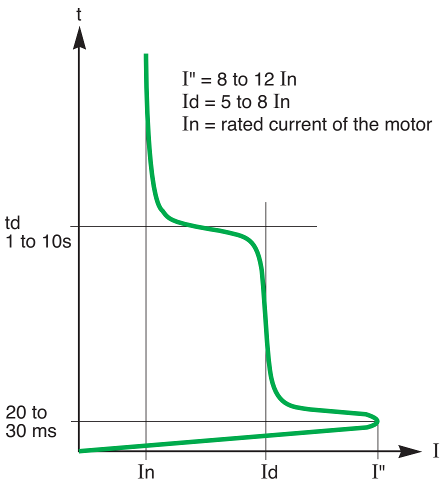


Fig. N62 *: Direct on-line starting current characteristics of an induction motor*

5.1 Functions for the motor circuit

Functions generally provided are:

- Basic functions including:
  - Isolating facility
  - Motor control (local or remote)
  - Protection against short-circuits
  - Protection against overload
- Complementary protections including:
  - Thermal protection by direct winding temperature measurement
  - Thermal protection by indirect winding temperature determination
  - Permanent insulation-resistance monitoring
  - Specific motor protection functions
- Specific control equipment including:
  - Electromechanical starters
  - Control and Protective Switching devices (CPS)
  - Soft-start controllers
  - Variable speed drives

Basic functions

Isolating facility

It is necessary to isolate the circuits, partially or totally, from their power supply network for satety of personnel during maintenance work. “Isolation” function is provided by disconnectors. This function can be included in other devices designed to provide isolation such as disconnector/circuit-breaker.

Motor control

The motor control function is to make and break the motor current. In case of manual control, this function can be provided by motor-circuit-breakers or switches.
In case of remote control, this function can be provided by contactors, starters or CPS.

The control function can also be initiated by other means:

- Overload protection
- Complementary protection
- Under voltage release (needed for a lot of machines)

The control function can also be provided by specific control equipment.

Protection against short-circuits

- Phase-to-phase short-circuit

This type of fault inside the machine is very rare. It is generally due to mechanical incident of the power supply cable of the motor.

- Phase-to-earth short-circuit

The deterioration of winding insulation is the main cause. The resulting fault current depends on the system of earthing. For the TN system, the resulting fault current is very high and in most cases the motor will be deteriorated. For the other systems of earthing, protection of the motor can be achieved by earth fault protection.

For short-circuit protection, it is recommended to pay special attention to avoid unexpected tripping during the starting period of the motor. The inrush current of a standard motor is about 6 to 8 times its rated current but during a fault the current can be as high as 15 times the rated current. So, the starting current must not be seen as a fault by the protection. In addition, a fault occuring in a motor circuit must not disturb any upstream circuit. As a consequence, discrimination/selectivity of magnetic protections must be respected with all parts of the installation.

Protection against overload

Mechanical overloads due to the driven machine are the main origins of the overload for a motor application. They cause overload current and motor overheating. The life of the motor can be reduced and sometimes, the motor can be deteriorated. So, it is necessary to detect motor overload. This protection can be provided by:

- Specific thermal overload relay
- Specific thermal-magnetic circuit-breaker commonly referred to as “motor circuit-breaker”
- Complementary protection (see below) like thermal sensor or electronic multifunction relay
- Electronic soft start controllers or variable speed drives (see below)

Complementary protections

- Thermal protection by direct winding temperature measurement

Provided by thermal sensors incorporated inside the windings of the motor and associated relays.

- Thermal protection by indirect winding temperature determination

Provided by multifunction relays through current measurement and taking into account the characteristics of the motors (e.g.: thermal time constant).

- Permanent insulation-resistance monitoring relays or residual current differential relays

They provide detection and protection against earth leakage current and short-circuit to earth, allowing maintenance operation before destruction of the motor.

- Specific motor protection functions

Such as protection against too long starting period or stalled rotor, protection against unbalanced, loss or permutation of phases, earth fault protection, no load protection, rotor blocked (during start or after)…; pre alarm overheating indication, communication, can also be provided by multifunction relays.

Specific control equipment

- Electromechanical starters (star-delta, auto-transformer, rheostatic rotor starters,…)

They are generally used for application with no load during the starting period (pump, fan, small centrifuge, machine-tool, etc.)

- Advantages

Good torque/current ratio; great reduction of inrush current.

- Disadvantages

Low torque during the starting period; no easy adjustment; power cut off during the transition and transient phenomenon; 6 motor connection cables needed.

- Control and Protective Switching devices (CPS)

They provide all the basic functions listed before within a single unit and also some complementary functions and the possibility of communication. These devices also provide continuity of service in case of short-circuit.

- Soft-start controllers

Used for applications with pump, fan, compressor, conveyor.

- Advantages

Reduced inrush current, voltage drop and mechanical stress during the motor start; built-in thermal protection; small size device; possibility of communication

- Disadvantages

Low torque during the starting period; thermal dissipation.

- Variable speed drives

They are used for applications with pump, fan, compressor, conveyor, machine with high load torque, machine with high inertia.

  - Advantages

Continuous speed variation (adjustment typically from 2 to 130% of nominal speed), overspeed is possible; accurate control of acceleration and deceleration; high torque during the starting and stopping periods; low inrush current, built-in thermal protection, possibility of communication.

  - Disadvantages

Thermal dissipation, volume, cost.

5.2 Standards

The motor control and protection can be achieved in different way:

- By using an association of a SCPD (Short-Circuit-Protective-Device) and electromechanical devices such as
  - An electromechanical starters fulfilling the standard IEC 60947-4-1
  - A semiconductor starter fulfilling the standard IEC 60947-4-2
  - A variable speed drives fulfilling the standard series IEC 61800
- By using a CPS, single device covering all the basic functions, and fulfilling the standard IEC 60947-6-2

In this document, only the motor circuits including association of electromechanical devices such as, starters and protection against short-circuit, are considered. The devices meeting the standard 60947-6-2, the semiconductor starters and the variable speed drives will be considered only for specific points.

A motor circuit will meet the rules of the IEC 60947-4-1 and mainly:

- The co-ordination between the devices of the motor circuit
- The tripping class of the thermal relays
- The category of utilization of the contactors
- The insulation co-ordination

Note: The first and last points are satisfied inherently by the devices meeting the IEC 60947-6-2 because they provide a continuity of service.

Standardization of the association circuit-breaker + contactor + thermal relay

Utilization category of the contactors

Standard IEC 60947-4-1 gives utilization categories which considerably facilitate the choice of a suitable contactor for a given service duty. The utilization categories advise on:

- A range of functions for which the contactor must be adapted
- The required current breaking and making capabilities
- Standard values for on-load durability tests, according to the utilization category.

Figure N63 gives some typical examples of the utilization categories covered.

Utilization category	Application characteristics
AC-1	Non-inductive (or slightly inductive) loads: $\cos \varphi \geqslant 0.95$ (heating, distribution)
AC-2	Starting and switching off of slip-ring motors
AC-3	Cage motors: Starting, and switching off motors during running
AC-4	Cage motors: Starting, plugging, inching

Fig. N63 : Utilization categories for contactors

Note: These utilization categories are adapted to the devices meeting the other standards. For example AC-3 becomes AC-53 for the semiconductor starters (IEC 60947-4-2) and becomes AC-43 for CPS's (IEC 60947-6-2).

The types of co-ordination

For each association of devices, a type of co-ordination is given, according to the state of the constituant parts following a circuit-breaker trip out on fault, or the opening of a contactor on overload.

The standard IEC 947-4-1 defines two types of co-ordination, type 1 and type 2, which set maximum allowable limits of deterioration of switchgear, in case of short-circuit.

Whatever the type of co-ordination, it is required that the contactor or the starter must never present a danger for the personnel and for the installation. The specificities of each type are:

■ Type 1
Deterioration of the starter is acceptable after a short-circuit and the operation of the starter may be recovered after reparing or replacing some parts.

■ Type 2
Burning and the risk of welding of the contacts of the contactor are the only risks allowed.

Which type to choose?

The type of co-ordination to adopt depends on the parameters of exploitation and must be chosen to satisfy (optimally) the needs of the user and the cost of installation.

■ Type 1
□ Qualified maintenance service
□ Volume and cost of switchgear reduced
□ May not be suitable for further service without repair or replacement of parts after a short-circuit
■ Type 2
□ Only light maintenance measures for further use after a short-circuit

5.3 Applications

The control and protection of a motor can consist of one, two, three or four different devices which provide one or several functions.

In the case of the combination of several devices, co-ordination between them is essential in order to provide optimized protection of the motor application.

To protect a motor circuit, many parameters must be taken into account. They depend on:

■ The application (type of driven machine, safety of operation, number of operations, etc.)

■ The continuity performance requested by the application

■ The standards to be enforced to provide security and safety.

The electrical functions to be provided are quite different:
■ Start, normal operation and stop without unexpected tripping while maintaining control requirements, number of operations, durability and safety requirements (emergency stops), as well as circuit and motor protection, disconnection (isolation) for safety of personnel during maintenance work.

Among the many possible methods of protecting a motor, the association of a circuit breaker + contactor + thermal relay(1) *provides many advantages*

Basic protection schemes: circuit-breaker + contactor + thermal relay

Avantages

The combination of devices facilitates installation work, as well as operation and maintenance, by:

■ The reduction of the maintenance work load: the circuit-breaker avoids the need to replace blown fuses and the necessity of maintaining a stock (of different sizes and types)

■ Better continuity performance: the installation can be re-energized immediately following the elimination of a fault and after checking of the starter

■ Additional complementary devices sometimes required on a motor circuit are easily accomodated

■ Tripping of all three phases is assured (thereby avoiding the possibility of “single phasing”)

■ Full load current switching possibility (by circuit-breaker) in the event of contactor failure, e.g. contact welding

■ Interlocking

■ Diverse remote indications

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(1) The combination of a contactor with a thermal relay is commonly referred to as a “discontactor”

- Better protection for the starter in case of overcurrent and in particular for impedant short-circuit (1) corresponding to currents up to about 30 times In of motor (see **Fig. N64**).
- Possibility of adding RCD:
  - Prevention of risk of fire (sensitivity 500 mA)
  - Protection against destruction of the motor (short-circuit of laminations) by the early detection of earth fault currents (sensitivity 300 mA to 30 A)

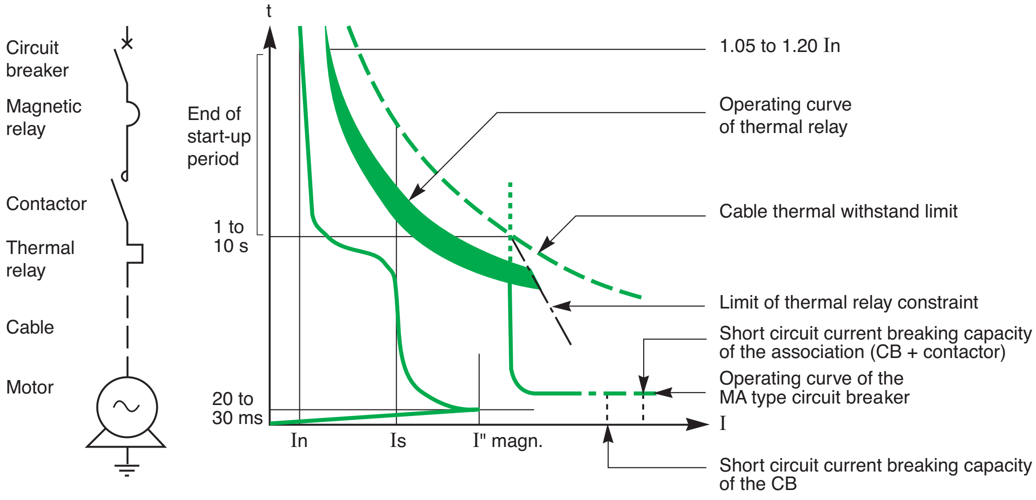

Fig. N64 : Tripping characteristics of a circuit-breaker + contactor + thermal relay (1)

Conclusion

The combination of a circuit-breaker + contactor + thermal relay for the control and protection of motor circuits is eminently appropriate when:

- The maintenance service for an installation is reduced, which is generally the case in tertiary and small and medium sized industrial sites
- The job specification calls for complementary functions
- There is an operational requirement for a load breaking facility in the event of need of maintenance.

Key points in the successful combination of a circuit-breaker and a discontactor

Standards define precisely the elements which must be taken into account to achieve a correct coordination of type 2:

- Absolute compatibility between the thermal relay of the discontactor and the magnetic trip of the circuit-breaker. In **Figure N65** the thermal relay is protected if its limit boundary for thermal withstand is placed to the right of the circuit-breaker magnetic trip characteristic curve. In the case of a motor control circuit-breaker incorporating both magnetic and thermal relay devices, coordination is provided by design.

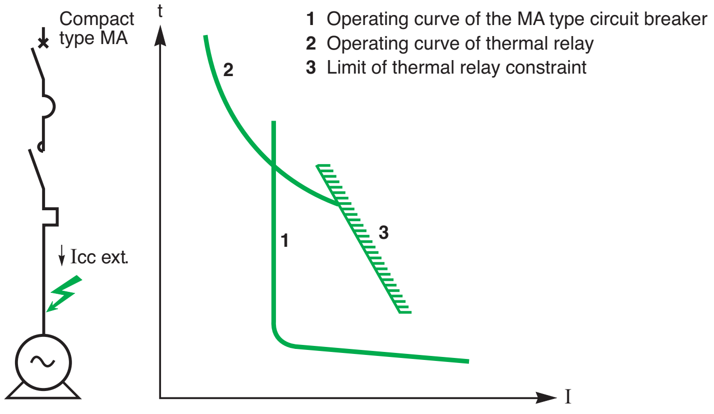

Fig. N65 : The thermal-withstand limit of the thermal relay must be to the right of the CB magnetic-trip characteristic

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(1) In the majority of cases, short-circuit faults occur at the motor, so that the current is limited by the cable and the wiring of the starter and are called impedant short-circuits

- The overcurrent breaking capability of the contactor must be greater than the current corresponding to the setting of the circuit-breaker magnetic trip relay.
- When submitted to a short-circuit current, the contactor and its thermal relay must perform in accordance with the requirements corresponding to the specified type of co-ordination.

It is not possible to predict the short-circuit current-breaking capacity of a circuit-breaker + contactor combination. Only laboratory tests by manufacturers allow to do it. So, Schneider Electric can give table with combination of Multi 9 and Compact type MA circuit-breakers with different types of starters

Short-circuit current-breaking capacity of a circuit-breaker + contactor combination

At the selection stage, the short-circuit current-breaking capacity which must be compared to the prospective short-circuit current is:

- Either, that of the circuit-breaker + contactor combination if the circuit-breaker and the contactor are physically close together (see **Fig. N66**) (same drawer or compartment of a motor control cabinet). A short-circuit downstream of the combination will be limited to some extent by the impedances of the contactor and the thermal relay. The combination can therefore be used on a circuit for which the prospective short-circuit current level exceeds the rated short-circuit current-breaking capacity of the circuit-breaker. This feature very often presents a significant economic advantage
- Or that of the circuit-breaker only, for the case where the contactor is separated (see **Fig. N67**) with the risk of short-circuit between the contactor and the circuit-breaker.

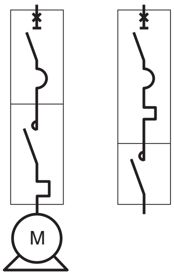

Fig. N66 : *Circuit-breaker and contactor mounted side by side*

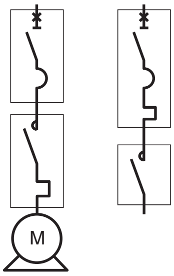

Fig. N67 : *Circuit-breaker and contactor mounted separately*

Choice of instantaneous magnetic-trip relay for the circuit-breaker

The operating threshold must never be less than 12 In for this relay, in order to avoid unexpected tripping due to the first current peak during motor starting.

Complementary protections

Complementary protections are:

- Thermal sensors in the motor (windings, bearings, cooling-air ducts, etc.)
- Multifunction protections (association of functions)
- Insulation-failure detection devices on running or stationary motor

Thermal sensors

Thermal sensors are used to detect abnormal temperature rise in the motor by direct measurement. The thermal sensors are generally embedded in the stator windings (for LV motors), the signal being processed by an associated control device acting to trip the contactor or the circuit-breaker (see **Fig. N68**).

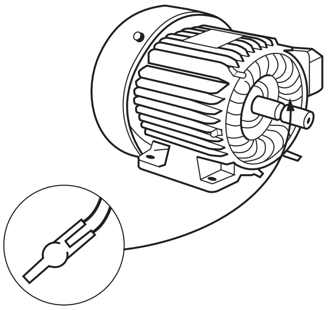

Fig. N68 : *Overheating protection by thermal sensors*

Mutifunction motor protection relay

The multifunction relay, associated with a number of sensors and indication modules, provides protection for motor and also for some functions, protection of the driven machine such as:

- Thermal overload
- Stalled rotor, or starting period too long
- Overheating
- Unbalanced phase current, loss of one phase, inverse rotation
- Earth fault (by RCD)
- Running at no-load, blocked rotor on starting

The avantages are essentially:

- A comprehensive protection, providing a reliable, high performance and permanent monitoring/control function
- Efficient monitoring of all motor-operating schedules
- Alarm and control indications
- Possibility of communication via communication buses

Example: Telemecanique LT6 relay with permanent monitoring/control function and communication by bus, or multifunction control unit LUCM and communication module for TeSys model U.

Preventive protection of stationary motors

This protection concerns the monitoring of the insulation resistance level of a stationary motor, thereby avoiding the undesirable consequences of insulation failure during operation such as:

- Failure to start or to perform correctly for motor used on emergency systems
- Loss of production

This type of protection is essential for emergency systems motors, especially when installed in humid and/or dusty locations. Such protection avoids the destruction of a motor by short-circuit to earth during starting (one of the most frequently-occuring incidents) by giving a warning informing that maintenance work is necessary to restore the motor to a satisfactory operationnal condition.

Example of application:
Motors driving pumps for “sprinklers” fire-protection systems or irrigation pumps for seasonal operation.

A Vigilohm SN21 (Merlin Gerin) monitors the insulation of a motor, and signals audibly and visually any abnormal reduction of the insulation resistance level. Furthermore, this relay can prevent any attempt to start the motor, if necessary (see **Fig. N69**).

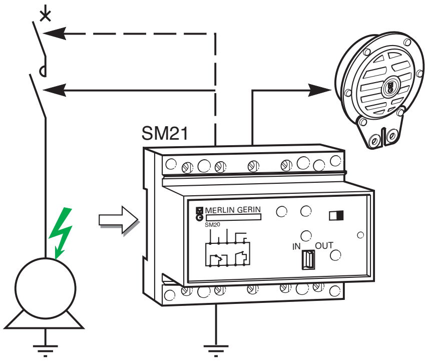

Fig. N69 : Preventive protection of stationary motors

Limitative protections

Residual current diffential protective devices (RCDs) can be very sensitive and detect low values of leakage current which occur when the insulation to earth of an installation deteriorates (by physical damage, contamination, excessive humidity, and so on). Some versions of RCDs, with dry contacts, specially designed for such applications, provide the following:

- To avoid the destruction of a motor (by perforation and short-circuiting of the laminations of the stator) caused by an eventual arcing fault to earth. This protection can detect incipient fault conditions by operating at leakage currents in the range of 300 mA to 30 A, according to the size of the motor (approx sensitivity: 5% In)
- To reduce the risk of fire: sensitivity ⩽ 500 mA

For example, RH99M relay (Merlin Gerin) provides (see **Fig. N70**):

- 5 sensitivities (0.3; 1; 3; 10; 30 A)
- Possibility of discrimination or to take account of particular operation by virtue of 3 possible time delays (0, 90, 250 ms)
- Automatic breaking if the circuit from the current transformer to the relay is broken
- Protection against unwanted trippings
- Protection against DC leakage currents (type A RCD)

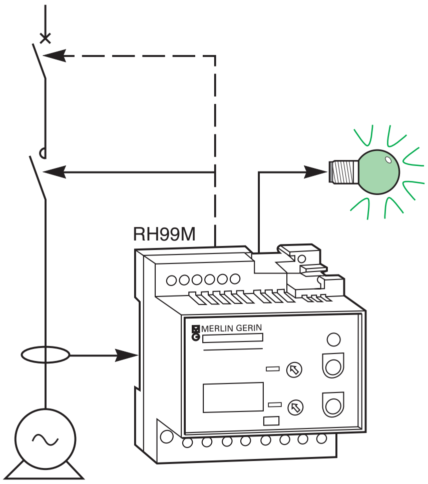

Fig. N70 : Example using relay RH99M

The importance of limiting the voltage drop at the motor terminals during start-up

In order to have a motor starting and accelerating to its normal speed in the appropriate time, the torque of the motor must exceed the load torque by at least 70%. However, the starting current is much higher than the full-load current of the motor. As a result, if the voltage drop is very high, the motor torque will be excessively reduced (motor torque is proportional to U^2) and it will result, for extreme case, in failure to start.

Example:

- With 400 V maintained at the terminals of a motor, its torque would be 2.1 times that of the load torque
- For a voltage drop of 10% during start-up, the motor torque would be 2.1 x 0.9^2 = 1.7 times the load torque, and the motor would accelerate to its rated speed normally
- For a voltage drop of 15% during start-up, the motor torque would be 2.1 x 0.85^2 = 1.5 times the load torque, so that the motor starting time would be longer than normal

In general, a maximum allowable voltage drop of 10% is recommended during start-up of the motor.

5.4 Maximum rating of motors installed for consumers supplied at LV

The disturbances caused on LV distribution networks during the start-up of large direct-on-line AC motors can cause considerable nuisance to neighbouring consumers, so that most power-supply utilities have strict rules intended to limit such disturbances to tolerable levels. The amount of disturbance created by a given motor depends on the "strength" of the network, i.e. on the short-circuit fault level at the point concerned. The higher the fault level, the "stronger" the system and the lower the disturbance (principally voltage drop) experienced by neibouring consumers. For distribution networks in many countries, typical values of maximum allowable starting currents and corresponding maximum power ratings for direct-on-line motors are shown in **Figures N71** and **N72** below.

Type of motor	**Location**	**Maximum starting current (A)**	
		Overhead-line network	**Underground-cable network**
Single phase	Dwellings	45	45
	Others	100	200
Three phase	Dwellings	60	60
	Others	125	250

Fig. N71 : Maximum permitted values of starting current for direct-on-line LV motors (230/400 V)

Location		**Type of motor**		
		Single phase 230 V (kW)	**Three phase 400 V**	
			Direct-on-line starting at full load (kW)	**Other methods of starting (kW)**
Dwellings		1.4	5.5	11
Others	Overhead line network	3	11	22
	Underground cable network	5.5	22	45

Fig. N72 : Maximum permitted power ratings for LV direct-on-line starting motors

Since, even in areas supplied by one power utility only, "weak" areas of the network exist as well as "strong" areas, it is always advisable to secure the agreement of the power supplier before acquiring the motors for a new project.

Other (but generally more costly) alternative starting arrangements exist, which reduce the large starting currents of direct-on-line motors to acceptable levels; for example, star-delta starters, slip-ring motor, "soft start" electronic devices, etc.

5.5 Reactive-energy compensation (power-factor correction)

The method to correct the power factor is indicated in chapter L.