Fundamentals of electrical safety

IEC 60364 standard compliance

Ensuring safety in low-voltage installations

EATON

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Introducing Eaton

Eaton's mission is to improve the quality of life and the environment through the use of power management technologies and services. We provide sustainable solutions that help our customers effectively manage electrical, hydraulic, and mechanical power – more safely, more efficiently, and more reliably.

This guide to low-voltage electrical safety forms part of Eaton's 'Fundamentals' series and introduces key electrical installation standards– *in particular – IEC 60364 Electrical installations for buildings* – and latest developments. Reflecting our deep subject knowledge and close involvement through participation on national and international standards committees, it highlights the importance of safety risk awareness of electric shock, protection against fire and the general protection of an electrical installation that puts people and buildings security first. And it does so alongside the need to integrate decarbonisation through renewables and the decentralisation of power sources including energy storage.

We've written the guide to encourage deeper conversation with those with a technical interest such as consultants, designers, electrical installers and panel builders. Detailed related product content and other resources are available through Eaton.com and our expert teams.

Five easy-to-navigate sections take you from buildings electrical safety essentials through to understanding system approaches, meeting the relevant standards for designing an electrical installation, planning and support tools.

Buildings electrical safety essentials

'The highest safety requirements are always applied when an electrical installation or equipment is operated by ordinary 'unskilled' people as they are likely to be less aware of electricity's potential dangers.'

In this section learn about:

- Why buildings electrical safety matters – and who and what it impacts
- 'Hot' current topics influencing electrical safety strategy
- The basics of the regulatory framework protecting people and assets

1.1

Core definitions and safety drivers

What are the important priorities for electrical safety? What is an electrical installation? And how does protection vary for different operators?

1.2

Safety protection and the role of IEC 60364

This standard lies at the heart of all low-voltage electrical safety regulation (excluding the US and Canada) with national adaptation.

Core definitions and safety drivers

Understanding what makes up electrical installations and the importance of protecting those that work with and around them makes a useful starting point for exploring buildings electrical safety – covered here with some introductory 'FAQs':

What is an electrical installation?

An electrical installation consists of electrical equipment that is permanently connected either via an electricity supplier or a generating source such as PV. It might consist of a switchboard, wiring, lighting, socket outlets and other fixed electrical parts. A single item of electrical equipment connected by a plug and socket is not, however, considered part of an electrical installation.

Why is it so important to work safely with or near electricity?

While a low-voltage electrical installation may at first sight appear non-threatening, contact with a live component within it can still cause death. Operating equipment with damage to its cable insulation or other element may also be enough to kill. It means that appropriate personal protective measures must be designed and adopted to keep potential risk to a minimum.

Who can operate electrical installations and equipment?

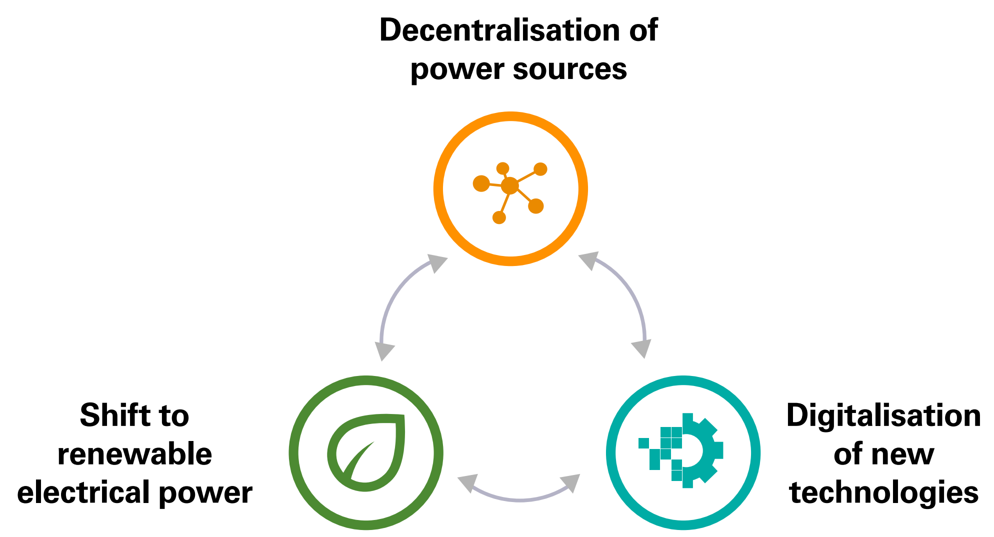
The highest safety requirements are always applied when an electrical installation or equipment is operated by ordinary 'unskilled' people as they are likely to be less aware of electricity's potential dangers. These requirements are expressed in electrotechnical standards, with specific conditions highlighted for the unskilled. For example, the level of protection of electrical devices must be expressed by degree of ingress protection (IP) against accidental touch and moisture, at least to IP20. Another basic safety rule for all outlet sockets up to 32 A that can be operated by unskilled people states that they must be protected by a residual current device sensitive up to 30 mA ($I_{\Delta n} \leq 30$ mA). While other situations may assume that a qualified person has good knowledge of the possible risks, in which case a lower IP degree may be sufficient, risk nevertheless still exists.

What are the other important priorities for safety in electrical installations?

The next important focus for electrical safety after personal protection concerns the protection of equipment and property – incorrect design and use of electricity can cause serious damage to both. This is mainly managed by using overload and short circuit current protection devices. Optimising protection against the risk of electrical fire is also essential. In addition, protection against transient overvoltages is needed in practically all installations, especially if they contain sensitive electronics.

At a time of energy transition, when buildings are becoming energy hubs with local distributed energy resources (DER), three key influences and related safety requirements must be considered when electrical design is devised and implemented:

- **The shift to renewable electrical power:** for example, the use of photovoltaic (PV) energy sources, the installation of heat pumps, electrification of transport with electrical vehicles with demands of new EV charging etc.
- **Decentralisation of power sources:** for example, using individual PV systems in combination with energy storage
- **Digitalisation of new technologies:** a shift that brings new cybersecurity risks.

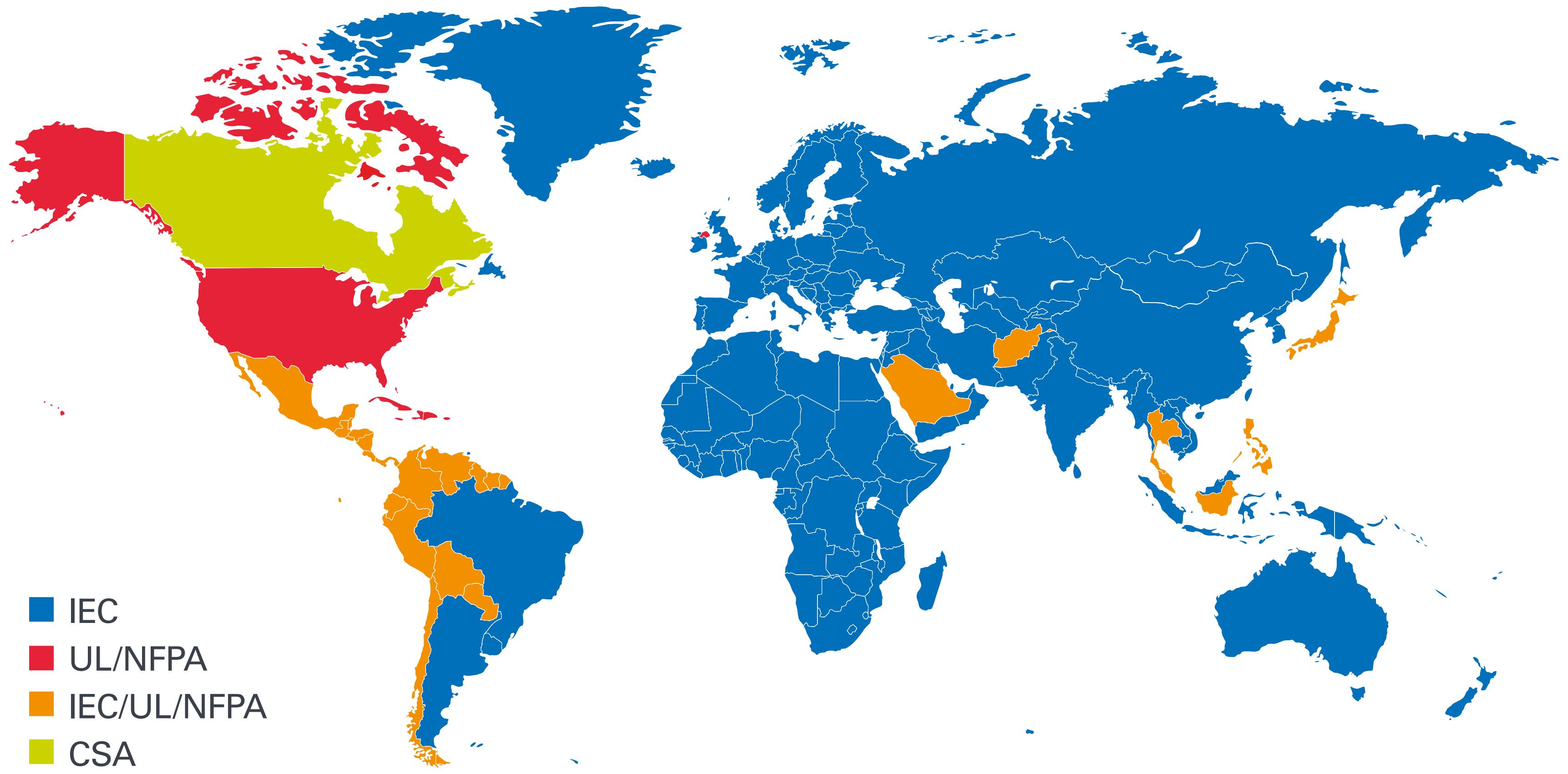


Safety protection and the role of IEC 60364

The basic rules around protection for safety are prescribed in the safety standard IEC 60364 (Low-voltage electrical installations), which is implemented in individual countries through localised versions.

IEC 60364 is mandatory for, but not limited to, all electrical installations in commercial, industrial or residential buildings. However, the way an electrical installation is carried out, inspected and connected to the network in accordance with electrical safety legislation may nevertheless vary country by country.

Standards markets at a glance



Implementation of IEC standards in Europe

IEC standards are implemented in Europe at national level. One identical set applies to products to enable borderless trade. CE declarations then have to be issued by the manufacturer. A further set of standards, IEC 60364, applies to installations and refers to the various products they incorporate. These allow for national adaptation and there must be an initial verification of every fixed installation.

Standards for products		Standards for installations
Example: IEC 60947-2 IEC 60898-1	IEC	**IEC 60364-X-XX** eg. IEC 60364-4-41
↓ Identical (idt) or Modified (mod)		↓ Identical (idt) or Modified (mod)
Example: EN 60947-2 EN 60898-1	CENELEC	**HD 60364-X-XX** + special national conditions HD = Harmonised Document eg. HD 60364-4-41
↓ Identical (idt)		↓ Identical (idt) ↑
Example: VDE EN 60947-2 (Germany) BS EN 60947-2 (United Kingdom)	**Country**	**National standard** with special national conditions eg. DIN VDE 0100-410 (Germany) BS 7176 (United Kingdom) ČSN 33 2000-4-41 (Czech republic) and etc.

Understanding system approaches

'IEC 60364 applies to low-voltage installations and refers to the various products they incorporate. These regulations allow for national adaptation.'

In this section learn about:

- The regulation framework for products and installations and the twelve steps to ensuring low-voltage installation compliance under IEC 60364
- How low-voltage switchboards must conform to IEC 61439
- How installations featuring new technologies demand specific safety attention

2.1

Designing low-voltage electrical installations to IEC 60364

This includes taking both normal conditions and fault conditions into account.

2.2

Meeting IEC 61439 standard for low-voltage switchboards

These specific requirements apply to essential parts of every electrical installation because they include protective, switching and control devices combined.

2.3

Risk considerations in buildings with new technologies

Understand the issues around the integration of renewable power sources, EV chargers and energy storage.

Designing low-voltage electrical installations to IEC 60364

2.1.1 Structure of IEC 60364 – Electrical installations for buildings

Part 1: Fundamental principles, assessment of general characteristics, definitions		
Part 2: Terms (cancelled) Explanation clauses are covered by Part 1, Terminology is subject of IEV (International Electrotechnical Vocabulary)		
Part 3: Provisions of general characteristics (cancelled) Transferred to Part 1 and 5		
Part 4 : Protection for safety	**Part 5 : Selection and erection of electrical equipment**	**Part 6 : Verification**
41: Protections against electric shock	51: General provisions	Visit, testing and measuring
42: Protection against thermal effects	52: Cable and wire systems	Insulation resistance
43: Protection against overcurrent	53: Switching and control devices	SELV, PELV check
44: Protection against overvoltage	54: Earthing installations, protective conductors	Resistance of floors, walls
45: Protection against undervoltages	55: Other electrical equipments	Automatic disconnection
46: Isolation and switching	56: Facilities for securities purposes	Additional protection etc.
Part 7: Requirements for special installations and locations		
701, 702, 703, … Part 753		
Part 8: Energy efficiency, intelligent low-voltage systems		
8-1 *Functional aspect* - Energy efficiency		
8-82 Prosumer’s low-voltage electrical installations		
IEC TS 60364-8-3 Operation of prosumer’s electrical installations		

Note: Part 8-1 of IEC 60364 is not related to electrical safety. Please refer to separate Fundamentals guide about Energy efficiency to follow the 60364-8-1 approach.

Designing low-voltage electrical installations to IEC 60364

IEC 60364 Part 1 *Fundamental principles, assessment of general characteristics, definitions* provides a general overview about the requirements for electrical installations. This ensures the safety of people and property from danger and damage which may arise in the reasonable use of electrical installations.

This includes the following main hazards:

- Electric shock likely to cause injury or death
- Excessive temperatures likely to cause burns or fires
- Overvoltages and electromagnetic influences likely to cause or result in injury or damage
- Power supply interruptions likely to cause property and data damage
- Arcing likely to cause excessive temperature and pressure, blinding effects and toxic gases
- Undervoltage that can expose electrical devices to problems such as overheating, malfunction, premature failure and shutdown
- The ignition of a potentially explosive atmosphere

All of the above can be minimised by the use of appropriate protective measures, as detailed in IEC 60364 Part 4 and Part 5, which provide details on the correct selection of individual components. The safety of an electrical installation is verified initially just before first use and later by regular verifications, as required IEC 60364-6 *Verification.*

Switchboards are an essential part of any electrical installation and act as carriers for the switching and protective devices needed. Specific details of product standard IEC 61439 *Low voltage switchgear and control gear assemblies* ensure switchboards are designed, tested and assembled in the correct way.

Each product used in the electrical installation and switchboards must conform to a respective product standard, its safety confirmed by the manufacturer in a statement of conformity referencing a specification or standard.

IEC 60364-6 Verifications (New and operation phase)

Two levels of verification are used for low-voltage installation safety assessment:

- Mandatory initial verification of the electrical installation before commissioning.
- Periodical verification carried out during normal operation within specified intervals. Depending on the type of installation and operating conditions, this can be between one to five years.

Note: Several of the conditions stated in IEC 60364-6 are included in other standards in a similar way. For example, IEC 61439, which is the dedicated product standard for LV switchboard assemblies, requires routine verification at the end of the switchboard assembly process. This is because the purpose of all standards is the same – to ensure a safe solution.

IEC 60364-7	Requirements for special installations or locations
IEC 60364-7-701	Locations containing a bath or shower
IEC 60364-7-702	Swimming pools and fountains
IEC 60364-7-703	Rooms and cabins containing sauna heaters
IEC 60364-7-704	Construction and demolition site installations
IEC 60364-7-705	Agricultural and horticultural premises
IEC 60364-7-706	Conducting locations with restricttive movement
IEC 60364-7-708	Caravan parks, camping parks and similar locations
IEC 60364-7-709	Marinas and similar locations
IEC 60364-7-710	Medical locations
IEC 60364-7-711	Exhibitions, shows and stands
IEC 60364-7-712	Solar photovoltaic (PV) power supply systems
IEC 60364-7-713	Furniture
IEC 60364-7-714	External lighting installations
IEC 60364-7-715	Extra-low-voltage lighting installations
IEC 60364-7-717	Mobile or transportable units
IEC 60364-7-718	Communal facilities and workplaces
IEC 60364-7-721	Electrical installations in caravans and motor caravans
IEC 60364-7-729	Operating or maintenance gangways
IEC 60364-7-740	Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses
IEC 60364-7-753	Heating cables and embedded heating systems

Designing low-voltage electrical installations to IEC 60364

2.1.2 Taking a logical approach to the design process

Electrical installation design starts from the load to source side. IEC 60364 describes it with logical steps, as shown in Figure 1. Each step must be evaluated in accordance with the relevant part of the IEC 60364 standard resulting in a decision, for example to modify the design.

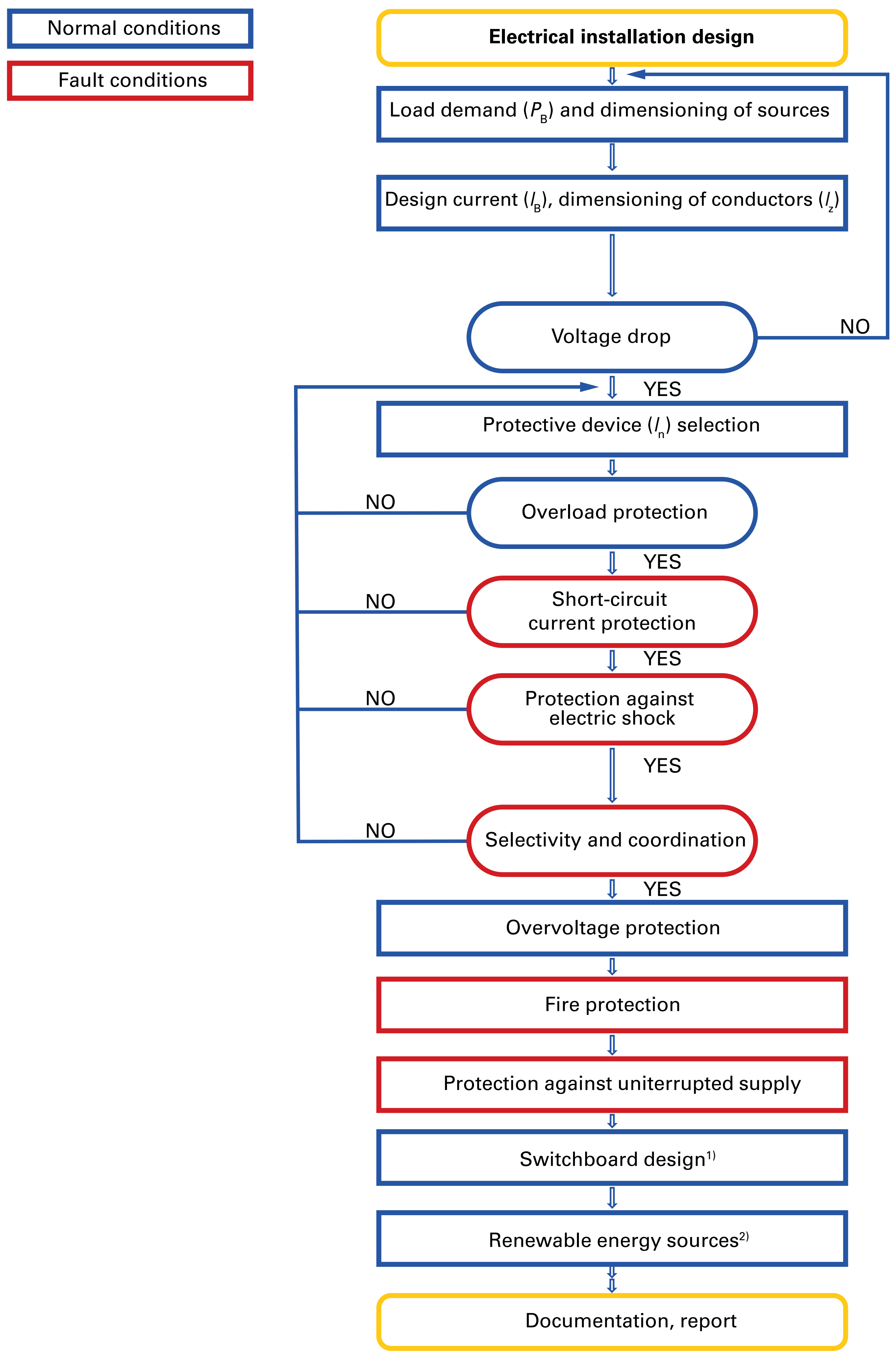
The step sequence can vary from application to application depending on priorities. For example, voltage drop can be checked at the end of the procedure instead of at the beginning. In the event of a design modification, such as a change in cable or protection device setting, evaluation of the relevant process step needs to be repeated. For example, a change in conductor size and/or its length has direct influence on voltage drop during normal operation and on short circuit current magnitude during fault conditions.

Additionally, there are various applications with very specific demands – for example electrical installations in medical locations and industrial settings. Such projects must be undertaken by specialist designers.

The short circuit current value in selected node (Step 7) is especially important as it's the starting point for evaluating other safety parameters. These impact decisions around protection against electric shock, the short circuit current strength of protective conductors, and the breaking capacity of protective devices including back up protection, etc.

Notes to Figure 1: 1) The design of the switchboard should take into account the risk of internal arcing.

2) Renewable energy sources with small powers can be evaluated as a load (with respect to dimensioning of conductors and overload protection); high power sources must be evaluated at beginning of design with respect to their way of operation.



Step	Selection criteria	Standards	Clause
1	**Load demand (P_B) and power supply**	IEC 60364-1	311
2-3	**Design current of circuits (I_B)** current carrying capacity (I_z)	IEC 60364-4-43 IEC 60364-5-52	433,1 523
	Dimensioning conductors (L1, L2, L3), (N), (PE) harmonics (N)	IEC 60364-5-52 IEC 60364-4-52	523 523,6
4	**Voltage drop**	IEC 60364-5-52	525
5	**Protective device selection (I_n)**	IEC 60364-4-43	433,1
6	**Overload protection** rated current rule/tripping current rule	IEC 60364-4-43 IEC 60364-4-43	433 433,1
7	**Short-circuit protection** maximum short circuit current (thermal load)	IEC 60364-4-43 IEC 60364-4-43	434 434.5.1; 434.5.2
8	**Protection against electric shock** fault current in TN, IT maximal cable lenghts cross section of PE, PEN (thermal load) fault current in TT, selection of RCD	IEC 60364-4-41 IEC 60364-4-41 IEC 60364-53 IEC 60364-5-54 IEC 60364-4-41	411 411.4.4; 411.6.4 533.3, 533.3.2.3 543,1 411.5.3; 532.2.4
9	**Selectivity**	IEC 60364-5-53	
10	**Overvoltage protection**	IEC 60364-4-44	
11	**Fire protection**	IEC 60364-4-42	
12	**Protection against uniterrupted supply**	IEC 60364-5-56	
13	**Switchboards design 1)**	IEC 60364-1 (IEC 61439)	
14	**Renewable energy sources 2)**	IEC 60364-8	
15	**Documentation, report**	IEC 60364-1, IEC 60364-6	

Figure 1. LV electrical installation design steps (as specified by IEC 60364)

Designing low-voltage electrical installations to IEC 60364

2.1.3 Design steps in close up

Step 1: Load demand and power supply

IEC 60364-1 ***Fundamental principles, assessment of general characteristics, definitions***

IEC 60364-4-43 ***Protection for safety – Protection against overcurrent***

The installed power of all loads is the first thing to consider for every project. But because the majority of installed loads and outlet sockets are not usually operated continuously, and also not at 100% of rated power, only the actual load of each circuit need be applied as a basic parameter.

Should bigger loads or outlet sockets not be operated continuously in some parts of the installation, including loads not with their rated power, a simultaneity factor (k_s) and utilisation factor (k_u) will need to be applied. As the installation will be designed for usual conditions, using these factors will ensure the installation is suitable for normal operation and avoid over-dimensioning. Both factors are applied in combination accordingly.

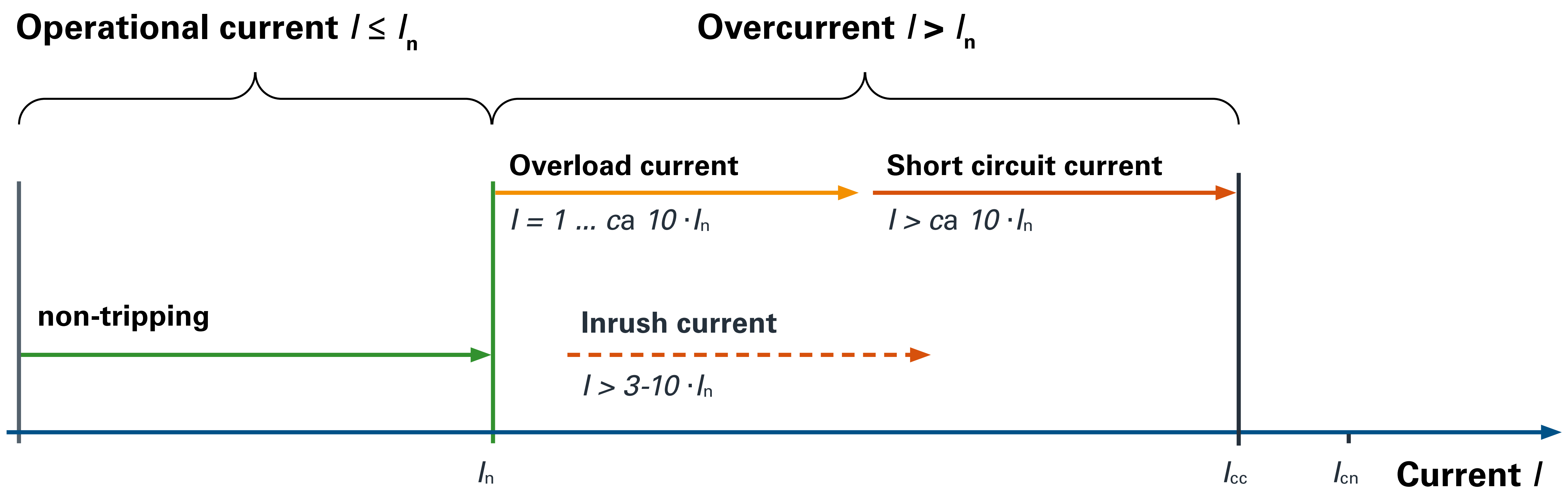
Definitions of utilisation and simultaneous factors usually used in electrical installations are as follows:

- **Utilisation factor k_u (or use factor):** the ratio of the time that a piece of equipment is in use relative to the total time that it could be in use.
- **Simultaneity factor k_s (or diversity factor):** the ratio of the sum of the individual non-coincident maximum loads of various subdivisions of the system relative to the maximum demand of the complete system.

The best possible estimate must be calculated depending on the type of installation and, based on experience, available tables and parameters taken from actual installations.

Notes on terminology

The IEC 60364 design process allows for operation under both normal and fault conditions. Normal operation is in the range of operational current up to the rated current value, within which the protected device should not trip – see Figure 2. Operation under fault conditions means the presence of overcurrent in the circuit, namely any current higher than rated current. It is important to be clear on the following definitions, as illustrated in Figure 2. An overload current is defined as up to approximately ten times the rated current. A short circuit current is defined as higher than approximately 10 times the rated current.



I_n - rated current
I_{cc} - prospective short circuit current in the installation
I_{cn} - breaking capacity of protective device (I_{cn}, I_{cu}, I_{cs}, I_1 - various symbols according to product standard)

Figure 2. Terms used in protected circuits

Designing low-voltage electrical installations to IEC 60364

2.1.4 Design steps in close up

Step 2: Design current of circuits

IEC 60364-4-43 ***Protection for safety – Protection against overcurrent***

The design solution is based on appliances that determine overall power consumption. However, it is not possible to use a simple sum of the installed power outputs (P_i) of all available devices. Only the output of those devices that are operated simultaneously must be used, thus a simultaneity factor (k_s) is applied. This actual output is therefore called the design power (P_B), which is used to determine the design current (I_B). The following applies to three-phase networks:

$$I_B = \frac{P_B}{\sqrt{3} \, . \, U \, . \, \cos\phi}$$

Where:

U line-to-line voltage in the power supply network (400 V)
$\cos\phi$ power factor for a given group of appliances

Step 3: Sizing conductors

IEC 60364-4-43 ***Protection for safety – Protection against overcurrent***

IEC 60364 5-52 ***Selection and erection of electrical equipment – Wiring systems***

Conductors such as cables, lines and busbars must meet requirements for safe and reliable operation over the normally expected lifespan of 30 years given normal external influences. Design can also consider local conditions such as a specific industry setting.

The design current (I_B) of the circuit determines the current carrying capacity (I_Z) of the cables, lines, busbars: $I_B \leq I_Z$

The current carrying capacity value of a conductor (I_Z) is not fixed. For conventional conditions, such as an air temperature of 30°C or 20°C for ground installation, it's the result of calculating rated current multiplied by coefficients as defined in IEC 60364-5-52 for local variables such as ambient temperature, method of installation, selected type of insulation (PVC, EPR, XLPE), etc.

Well-balanced, three-phase loads generate no or relatively little current with a neutral conductor. This is why cables can use a reduced cross section for a neutral conductor. Should harmonics be significant, the neutral conductor cable must be the same cross section size as the others.

Step 4: Protective devices – selection of rated current (I_n)

IEC 60364-4-43 ***Protection for safety - Protection against overcurrent,***

IEC 60364-5-53 ***Selection and erection of electrical equipment - Devices for protection for safety, isolation, switching, control and monitoring***

The design current (I_B) of a cable or line must be lower than the rated current of the protective device (I_n): $k_B \leq I_n$

This simple rule avoids unwanted tripping during normal operation.

Step 5: Voltage drop

IEC 60364-5-52 ***Selection and erection of electrical equipment – Wiring systems***

Voltage drop is the voltage loss that occurs through an electrical circuit due to its resistance. This is calculated under normal operating conditions. The standard specifies maximum voltage limits for example 3% for lightning.

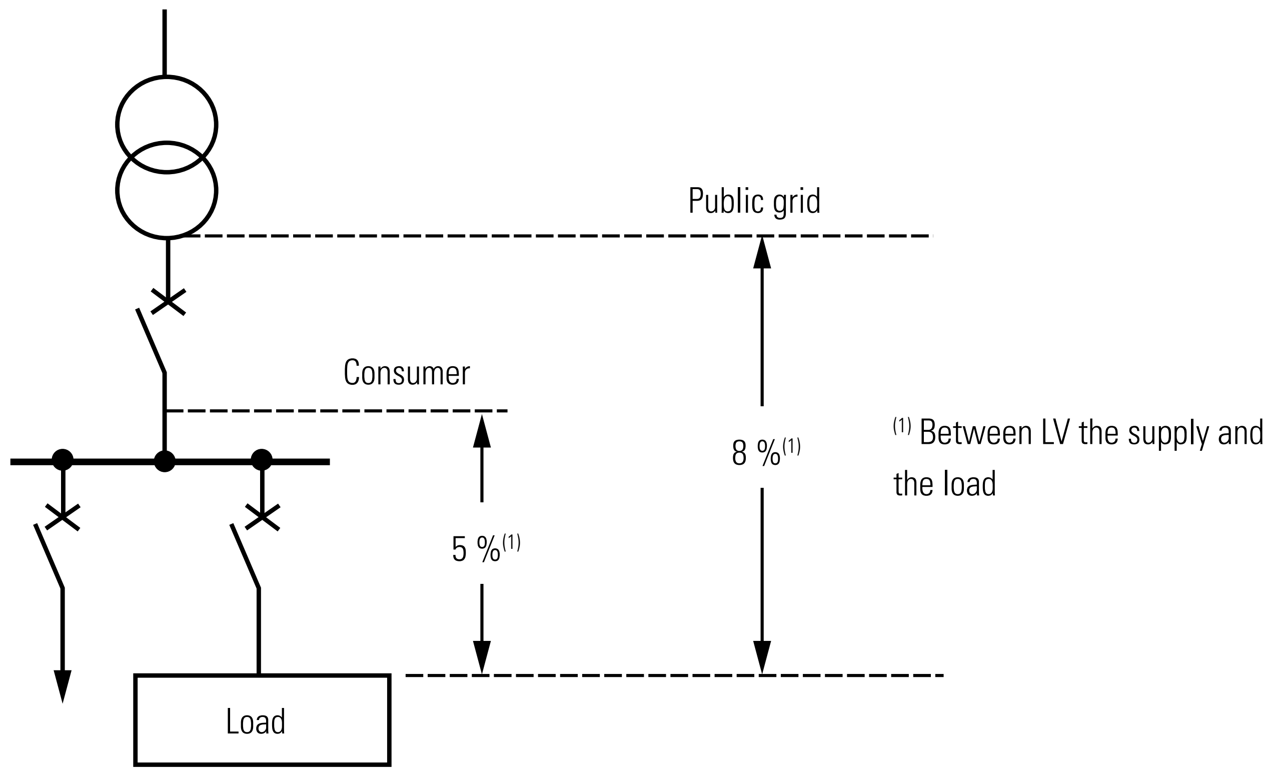


Figure 3. Voltage drops in consumer systems

The stronger the load, the higher the voltage drop. A greater voltage drop can be acceptable, for example in a motor when starting, and for other equipment with a high inrush current.

Type of installation	[%]	Other uses [%]
A - Low voltage installations supplied directly from a public low voltage distribution system	3	5
B - Low voltage installation supplied from private LV supply	6	8

Maximum value of voltage drop in consumer systems (according to IEC 60364-5-52 Table C.52.2)

As far as possible, it is recommended that voltage drop within the final circuits do not exceed those indicated in installation type A.

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 6: Overload protection

IEC 60364-4-43 ***Protection for safety - Protection against overcurrent,***

IEC 60364-5-53 ***Selection and erection of electrical equipment – Devices for protection for safety, isolation, switching, control and monitoring***

If a protected conductor is overloaded, its core must not exceed the maximum permitted temperature for overload, depending on insulation type. For the most widely used thermoplastic PVC insulation, this is 70°C at rated current at which temperature the device will not disconnect, 120°C at overload, at which temperature it should disconnect in a reasonable time and 160°C at short circuit current, when it must trip immediately. Thermosetting XLPE or EPR insulation can be used up to the maximum permitted temperatures of 90°C, 150°C and 250°C respectively.

To ensure appropriate overload protection, you can compare the tripping characteristic of a protective device with the overload characteristic of the protected conductor. For a definition of how tripping characteristics correspond to overload characteristics for the most used conductors, see Figure 4.

Note: In the event that conductor dimensions are changed, the protective device must be reviewed. Should another protective device then be chosen, for example due to selectivity optimisation, suitable cable must be sourced accordingly. The final solution is usually the result of several optimisation cycles.

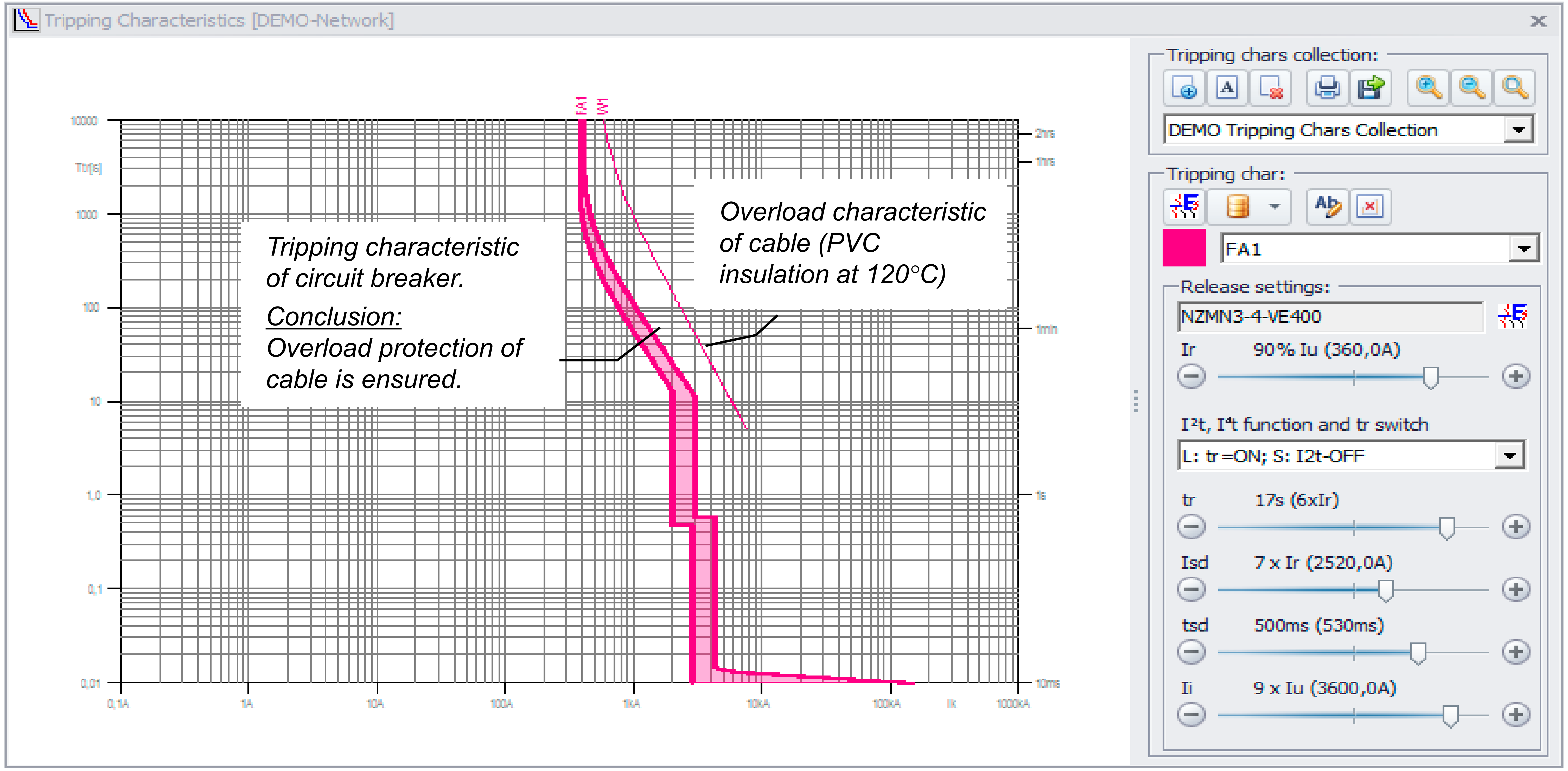


Figure 4. Comparison of characteristics using Eaton xSpider software

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 7: Short circuit current protection and co-ordination of protective devices

IEC 60364-4-43 ***Protection for safety – Protection against overcurrent***

IEC 60364-5-53 ***Devices for protection for safety, isolation, switching, control and monitoring***

IEC 60909-0 ***Short-circuit currents in three-phase AC systems – Calculation of currents***

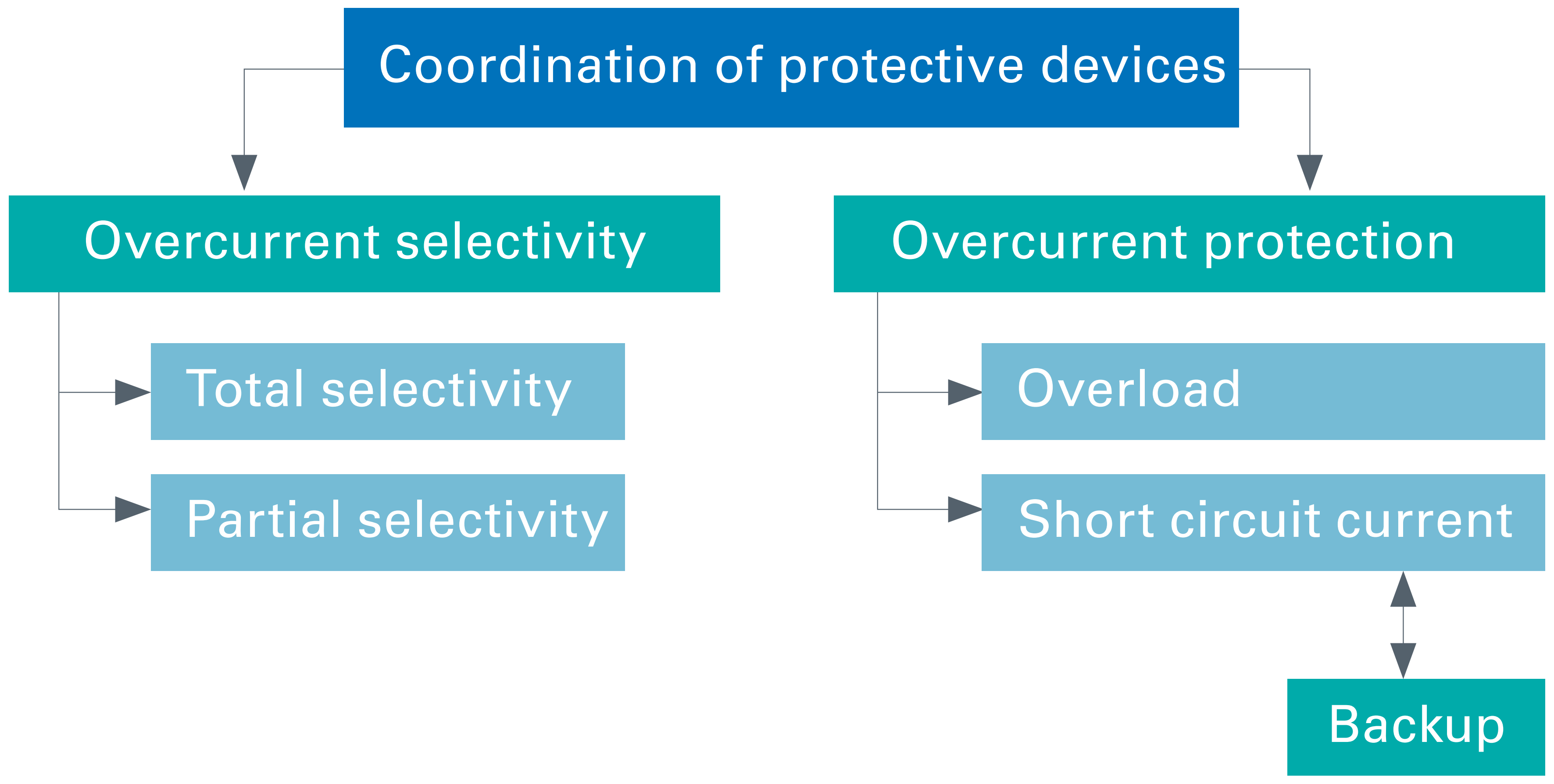
Calculating short circuit current value is a standard task for each project. Suitable software is usually used into which basic information about all components must be input. Alternatively, there are ready-to-use tables or nomograms which simplify the process and provide first results very quickly. Accuracy using these methods is sufficient. Should there be a requirement for greater accuracy, or a problem is identified, then more accurate calculations should be performed.

The coordination of protective devices is important to ensure appropriate protection in terms of overcurrent and selectivity (see Figure 1, Step 9).

Note: Globally accepted standard for calculations of short circuit currents is IEC 60909-0 Short circuit currents in three-phase AC systems – Calculation of currents

Short circuit protection of lines

Short circuit current considerations mean that the core of the protected conductor must not exceed maximum permitted temperature limits. The calculation is performed according to the standard IEC 60364-4-43 (see also Figure 1). See the Eaton Consulting Application Guide for further details.



Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 8: Protection against electric shock

IEC 60364-4-41 ***Protection for safety – Protection against electric shock***

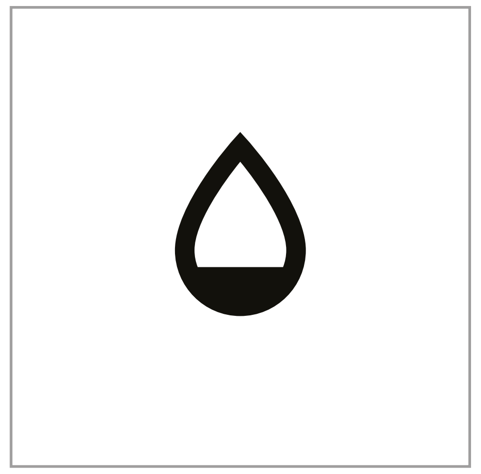
The fundamental rule of protection against electric shock says that hazardous live parts must not be accessible and accessible conductive parts must not be hazardous live. This applies to both normal conditions and single fault conditions.

In the event of a fault or dangerous exposed part, the touch voltage must be low enough (e.g., by using a separate extra low-voltage system).

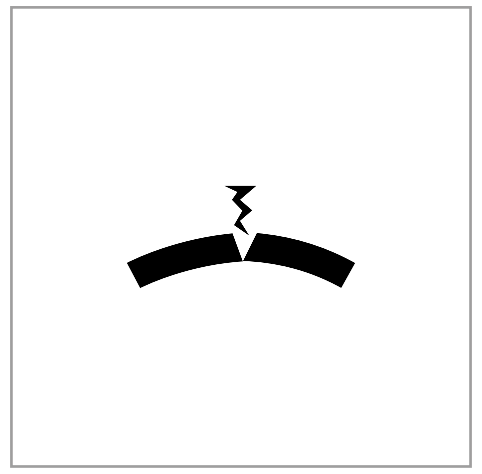
The most frequently used protective measure for electrical safety is automatic disconnection of fault within a sufficiently short time to make it safe.

Fault currents

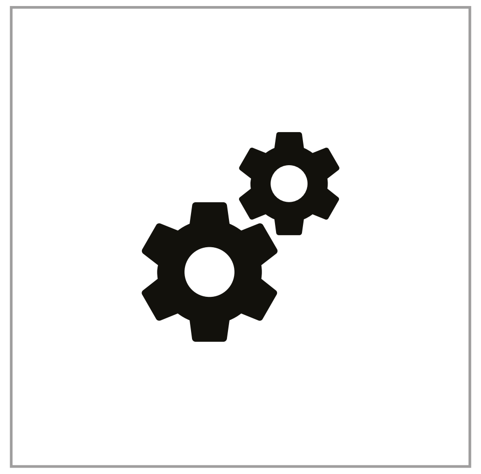
Typical causes include changes in insulation and insulation resistance due to:



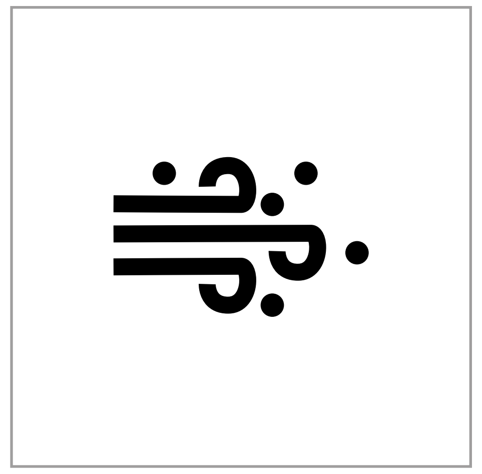
Humidity



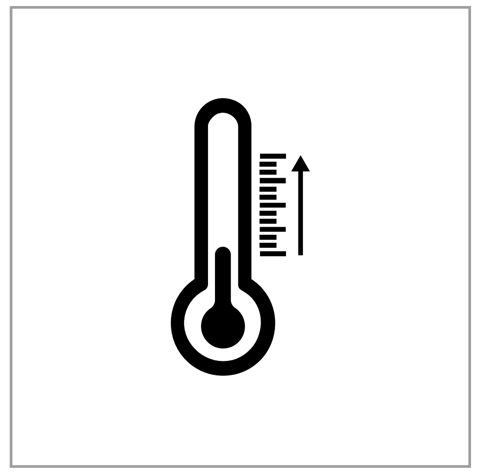
Ageing



Mechanical stress



Dust and dirt



Change of temperature of conductors

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Type of electrical networks

IEC 60364-1 *Fundamental principles, assessment of general characteristics, definitions*

Electrical networks can be earthed using one of several different systems available such as TT, TN or IT. The system used determines the fault protection required.

Two letters are used to classify networks – sometimes with the addition of C and/or S:

1st letter: the method of earthing the power source (source side) earthed (T) or insulated (I)

2nd letter: the mode of earthing of the metallic chassis (load side) earthed (T) or neutral (N)

3rd letter: combined (C) or separate (S) protective earthing conductor (PE) and neutral (N)

R_B resistance of the earth electrode and PE conductor on the source side

R_A resistance of the earth electrode and PE conductor for the exposed conductive parts

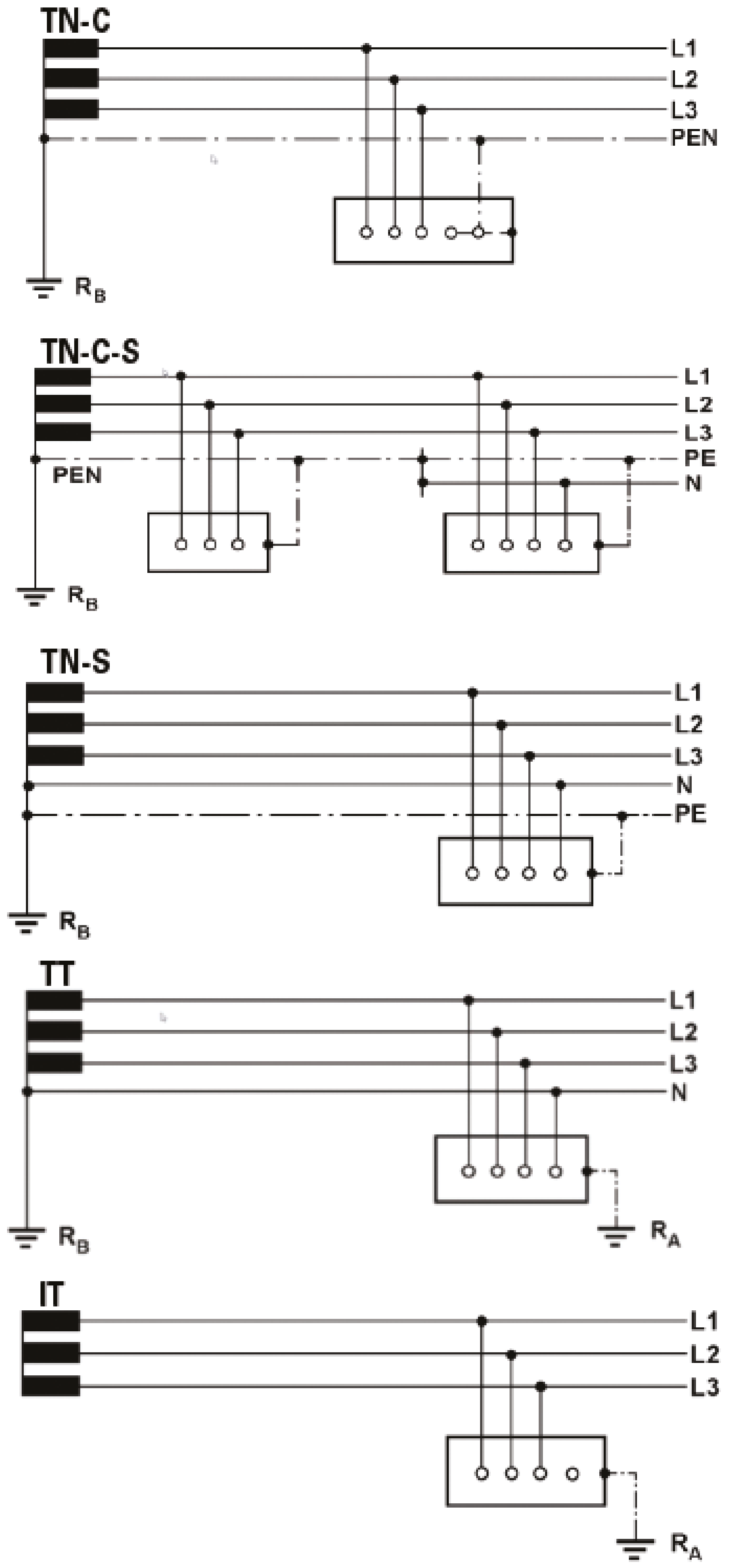
For a TN system, the touch voltage on the exposed conductive parts during a fault between phase and earth is max. 90 V. A further reduction of the touch voltage is achieved by additional earthing of protective conductor PEN and PE.

For a **TT system**, the touch voltage during a fault is close to phase-earth voltage (about 200 V). This means a TT system under fault conditions is more dangerous compared to a TN system (max. 90 V)

For an **IT system**, there is no low-impedance circuitry. This means an insulation fault, when an exposed conductive part is touched, is unlikely to cause dangerous current through the human body. However, a first insulation fault turns an IT system into TN system conditions (or TT, dependent on method of load earthing). A second insulation fault may cause a dangerous situation and automatic disconnection within a specified time is then required (see IEC 60364-4-41).

Conditions for the safe use of an electrical installation

- All accessible conductive parts of the equipment designed as Insulation Class I protection must be protected by a protective earth (PE) conductor.
- Each installation must be evaluated for touch voltage to ensure that accessible parts are safe. No dangerous voltage should be present or, if it is, it must be disconnected within a short, specified time.
- Fuses, circuit breakers and residual current devices (RCDs) are used to protect against faults.
- RCDs protect against the risk of electrical shock and fire caused by leakage currents ($I_{\Delta n}$ 300 mA $I_{\Delta n} \leq$ 300 mA)
- RCDs with a sensitivity up to 30 mA ($I_{\Delta n} \leq$ 30 mA) are used for the additional protection of people in all situations, where electrical installation has been operated by an unskilled person. This is also required in locations subject to external influences which increase the risk of electric shock, such as bathrooms and building sites etc. – see Part 7 of IEC 60364 for more on this.



Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Three-stage safety concept in low-voltage installations

IEC 60364-4-41 specifies the basic requirements for protection against electric shock:

1 Basic protection = protection against contact under normal conditions

This includes the use of high-quality insulating materials in accordance with valid standards (IEC, DIN VDE, British Standards - BS, etc.).

2 Fault protection = protection against indirect contact

This widely used protective measure automatically disconnects the power supply when a protective conductor is used. Enhanced protection is provided by double or reinforced insulation which provides both basic and fault protection.

3 Additional protection is a backup, for which a sensitive RCD with $I_{\Delta n}$ ≤ 30 mA is used or, if applicable, supplementary equipotential bonding.

Class of equipment	Equipment marking or instructions	Symbol	Conditions for connection of the equipment to the installation
Class I	Marking of the protective bonding terminal with graphical symbol 60417-5019:2006-08, or letters PE, or colour combination green-yellow		Connect this terminal to the protective-equipotential-bonding system of the installation
Class II	Marking with the graphical symbol IEC 60417-5172:2003-02 (double square)		No reliance on installation protective measures
Class III	Marking with the graphical symbol IEC 60417-5180:2003-02 (roman numeral III in a diamond)		Connect only to SELV or PELV systems

Application of equipment in a low-voltage installation

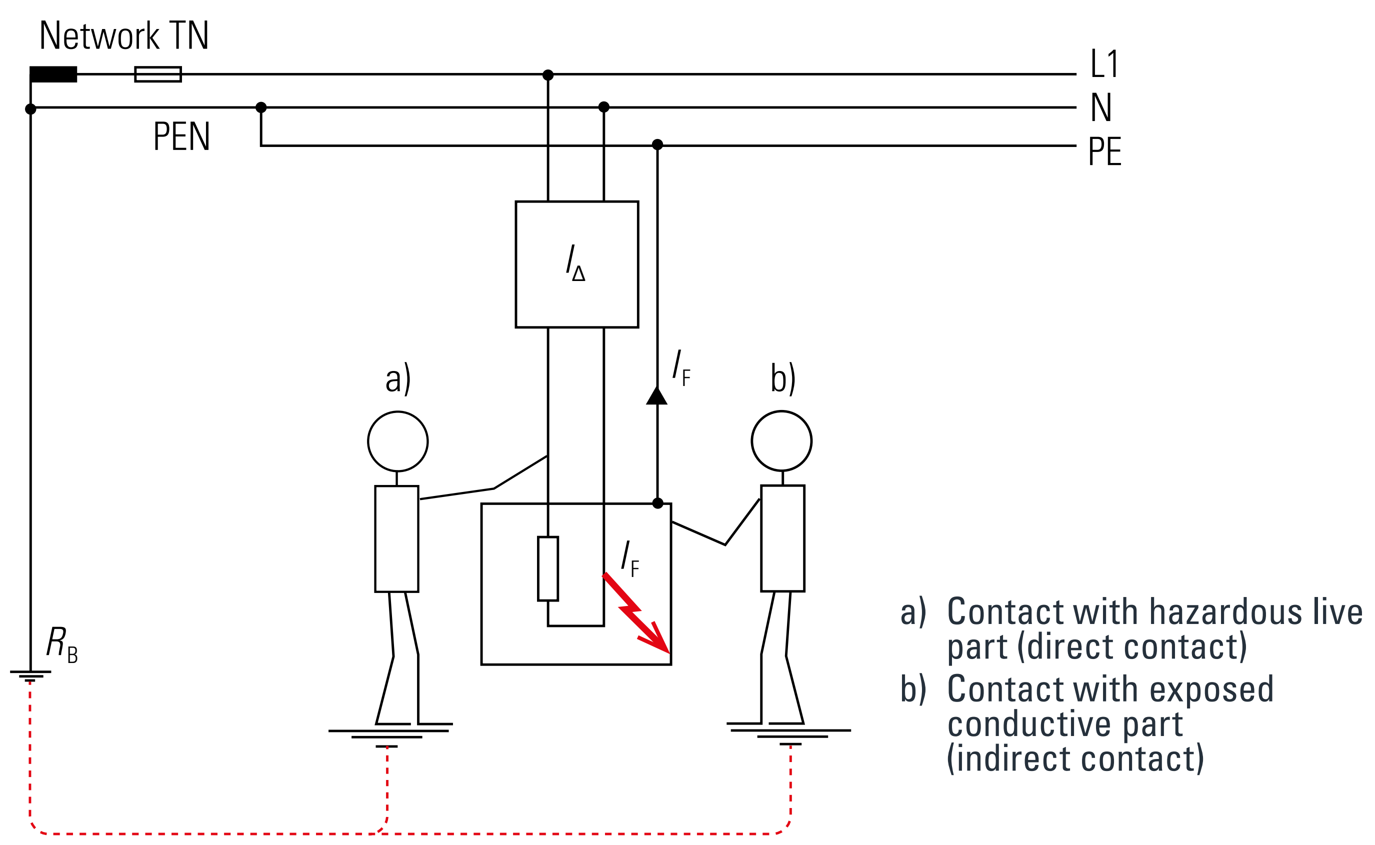


Figure 5. Contact with hazardous live part and exposed conductive part under fault condition

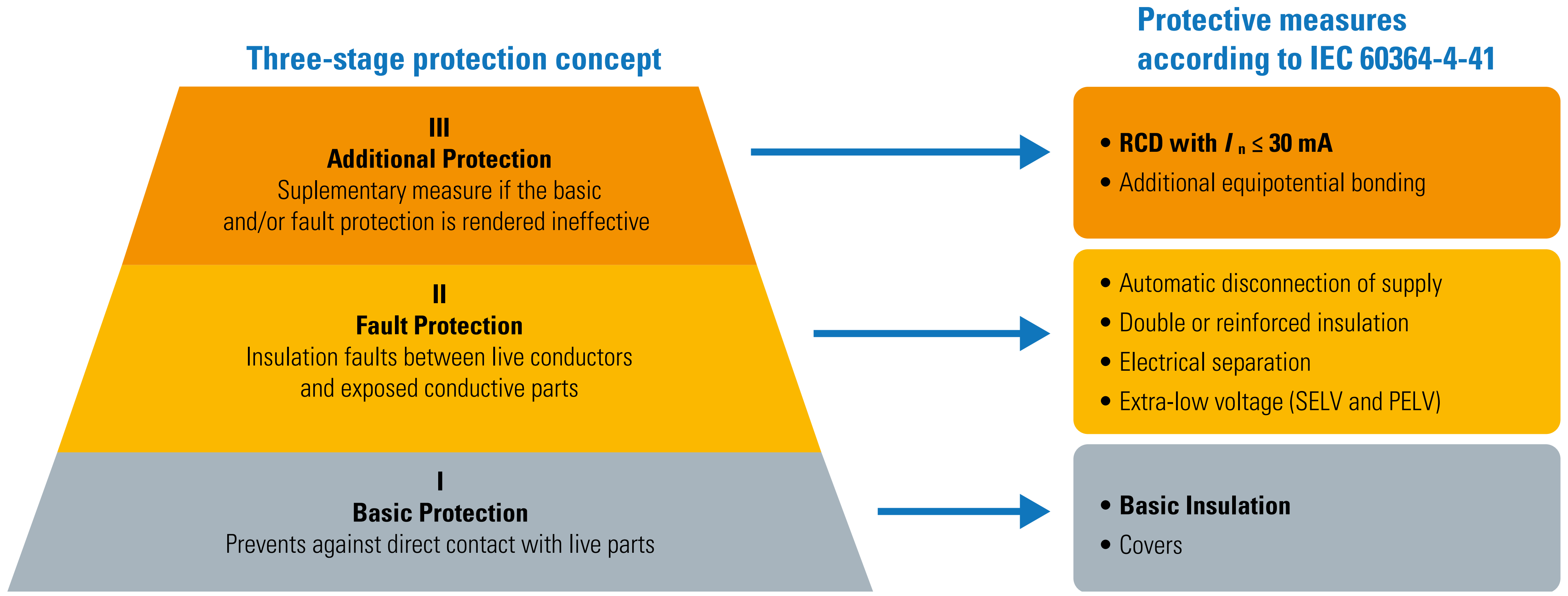


Figure 6. Personal protection concept

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Automatic disconnection of supply

The most frequently used method of fault protection – (previously as protection against indirect contact with exposed conductive parts) – is through the automatic disconnection of supply.

Clause 411.3 to 411.6 stipulates that this should be achieved through:

- **Basic protection** using basic insulation of live parts or by barriers or enclosures
- **Fault protection** provided by protective equipotential bonding and automatic disconnection

In the event of a fault between any of the line conductors and a protective conductor or exposed conductive part, the protective device will automatically interrupt the supply, the line conductor of the circuit or equipment within the required disconnection time.

The maximum disconnection times stated in Figure 7 shall be applied to final circuits with a rated current not exceeding:

- 63 A with one or more socket-outlets
- 32 A supplying only fixed, connected, current-using equipment.

The table reflects a situation where the touch voltage on a conductive part exceeds a safe value of 50 V (or 25 V, according to local conditions e.g., medical locations).

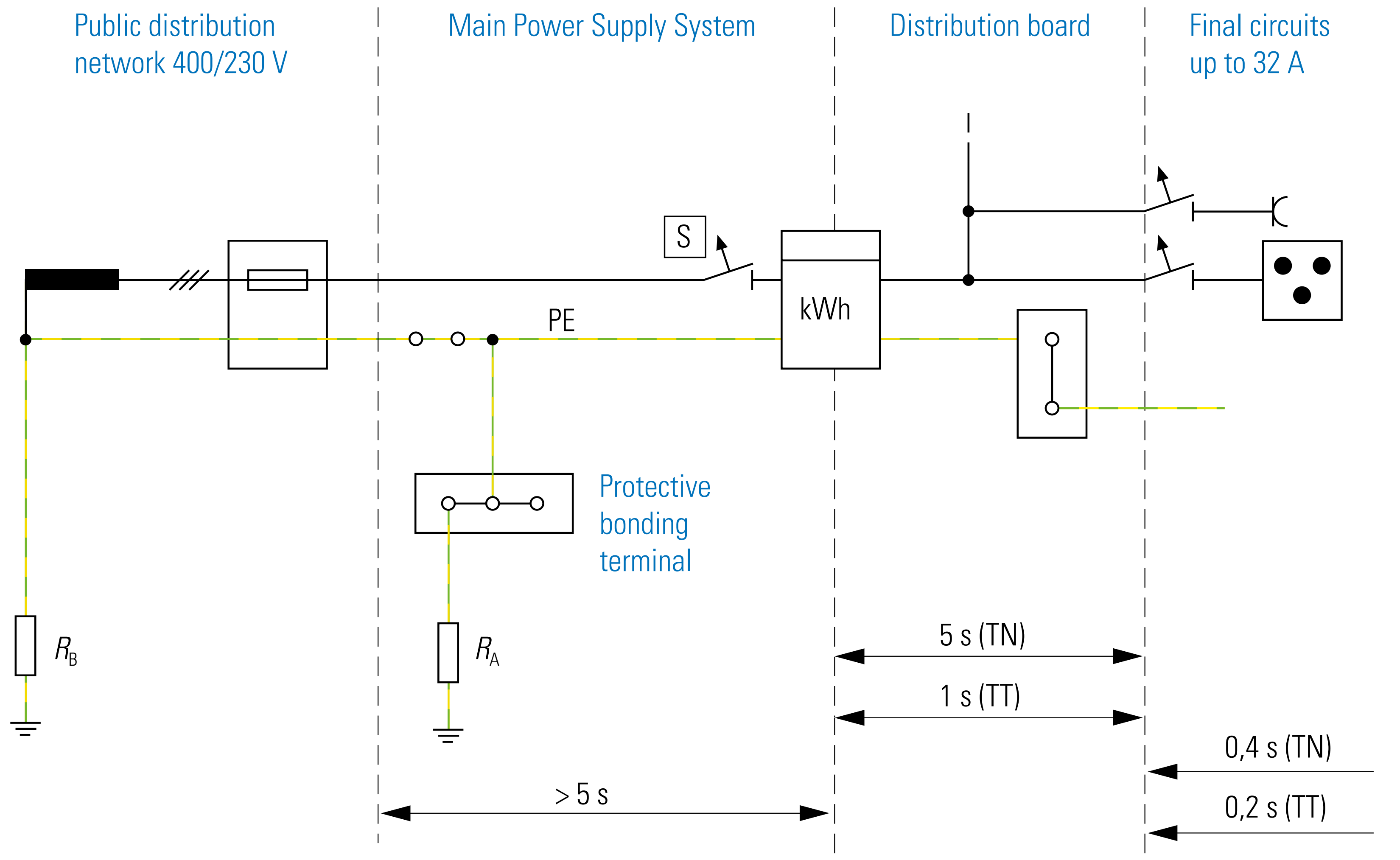


Figure 7. Maximum disconnection times in TN and TT systems with nominal AC voltage of 400/230 V (demonstration on TN system)

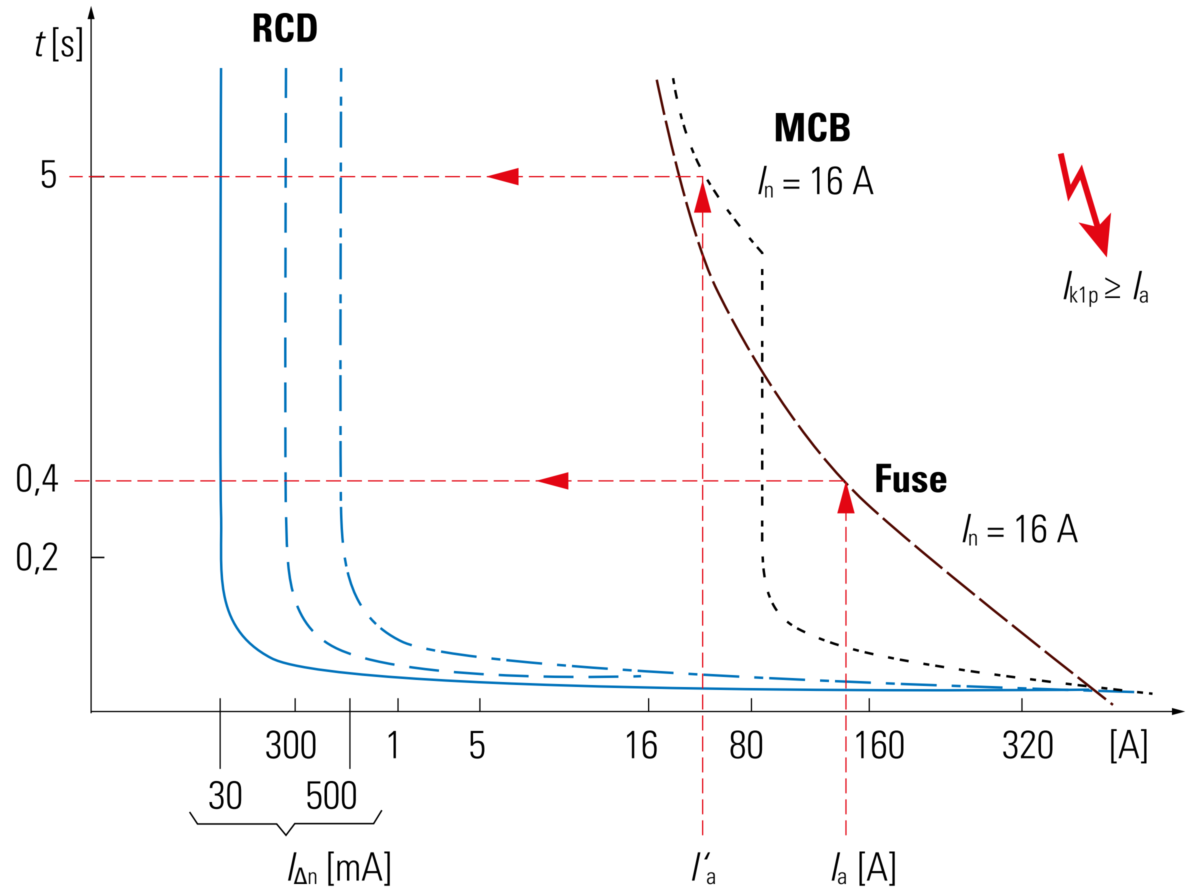


Figure 8. Comparison of needed tripping currents at specified time (0,4 and 5 s) of fuse, MCB and RCD in final circuit

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Maximum allowed fault loop impedance needed for safe disconnection:

$$Z_s = \frac{U_o}{I_a}$$

Z_s impedance of the fault loop [Ω]

U_o nominal line to earth voltage [V]

I_a the current causing operation of the protective device within the time required for TN system [A]

It is frequently asked how long the cable and cross section should be to fulfil the conditions for automatic disconnection in case of fault. Our guide 'Maximum cable lengths for Eaton's protective devices' is a useful reference. Our Consulting Application Guide, Part 5, and xSpider software also include this information.

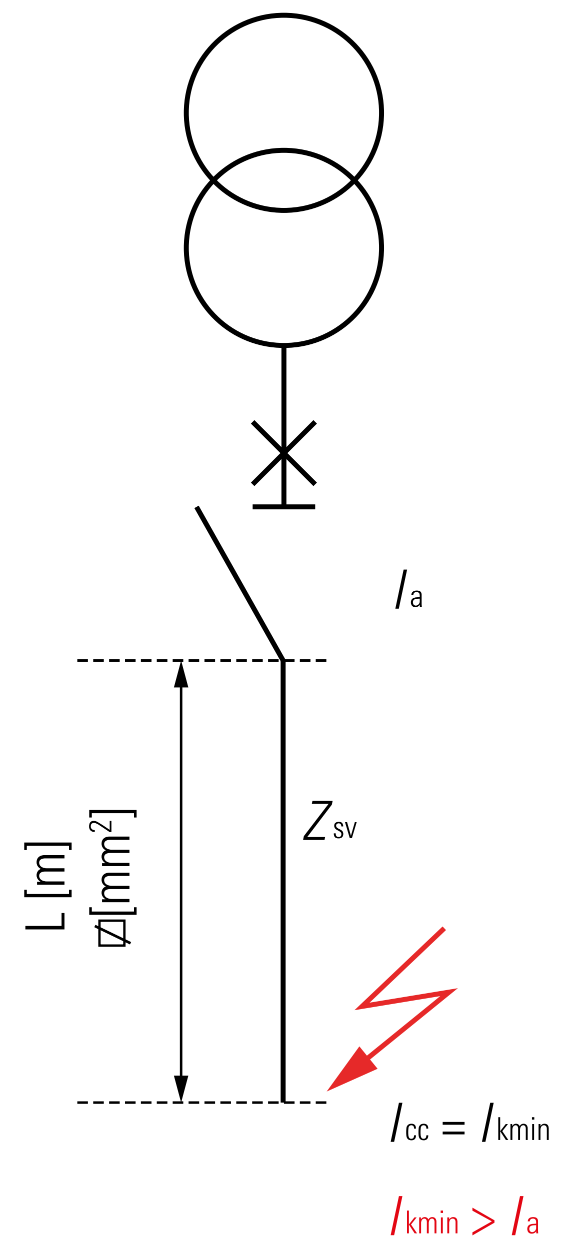
Additional protection

Additional protection using sensitive residual current devices with $I_{\Delta n} \leq 30$ mA is one of the most important safety improvements in comparison to standard levels of protection deployed 20 or 30 years ago. The main benefit of a sensitive RCD is its short disconnection time (up to 40 ms for residual currents above value $5.I_{\Delta n}$), which is safe for people in the event of direct contact with dangerous voltage.

Basic safety requirements for socket outlets and the supply of mobile equipment for use outdoors are as follows (according to IEC 60364-4-41, cl. 411.3.3):

Additional protection from a residual current protective device (RCD) with $I_{\Delta n} \leq 30$ mA shall be provided for:

- AC socket-outlets with a rated current not exceeding 32 A that are likely to be used by ordinary (unskilled) persons and are intended for general use.
- AC mobile equipment for use outdoors with a rated current not exceeding 32 A



Z_{sv} Fault loop impedance [Ω]

I_{cc} Prospective short-circuit current [A]

I_{kmin} Minimum short-circuit current [A]

I_a Tripping time of protective device [s]

L Cable length [m]

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 9: Fire risk

IEC 60364-4-42 ***Protection for safety - Protection against thermal effects***

IEC 60364-4-43 ***Protection for safety - Protection against overcurrent***

Should conductors not be properly protected according to IEC 60364-4-43, there is a risk of fire caused by high temperature. Installations at higher risk of fire must be equipped with cables that have higher resistance insulation.

Other fire hazards are in areas with combustible materials where leakage current via damaged cable insulation can cause fire. In this case the electrical installation must be protected by RCD with $I_{\Delta n} \leq 300$ mA. This is a good solution proven over many years. However, it only works in cases where leakage current flows to earth.

The most advanced solution for final circuits up to 40 A, mainly in family houses, is the arc fault detection device (AFDD). This device can detect all kinds of arc faults.

Arc fault currents

Typically at nominal current or just below, and therefore difficult to detect. Small arcs can grow over time as insulation is increasingly damaged. Identified by high frequency noise and breakdown of the fault current close to the zero-crossing of the driving voltage.

Arc fault types

Figure 9 shows different types of arc faults:

- Serial arc between disconnected conductors
- Parallel arc between phase and neutral (N)
- Parallel arc between phase and earthing (PE)

A parallel arc created between conductors can be protected by overcurrent protective devices. But a miniature circuit breaker (MCB) is only able to react to relatively high currents while an RCD can react only in the case of earth leakage currents. While a serial arc is the most frequent fault in installations, neither an MCB nor RCD can detect it. An arc fault detection device (AFDD) is the best option.

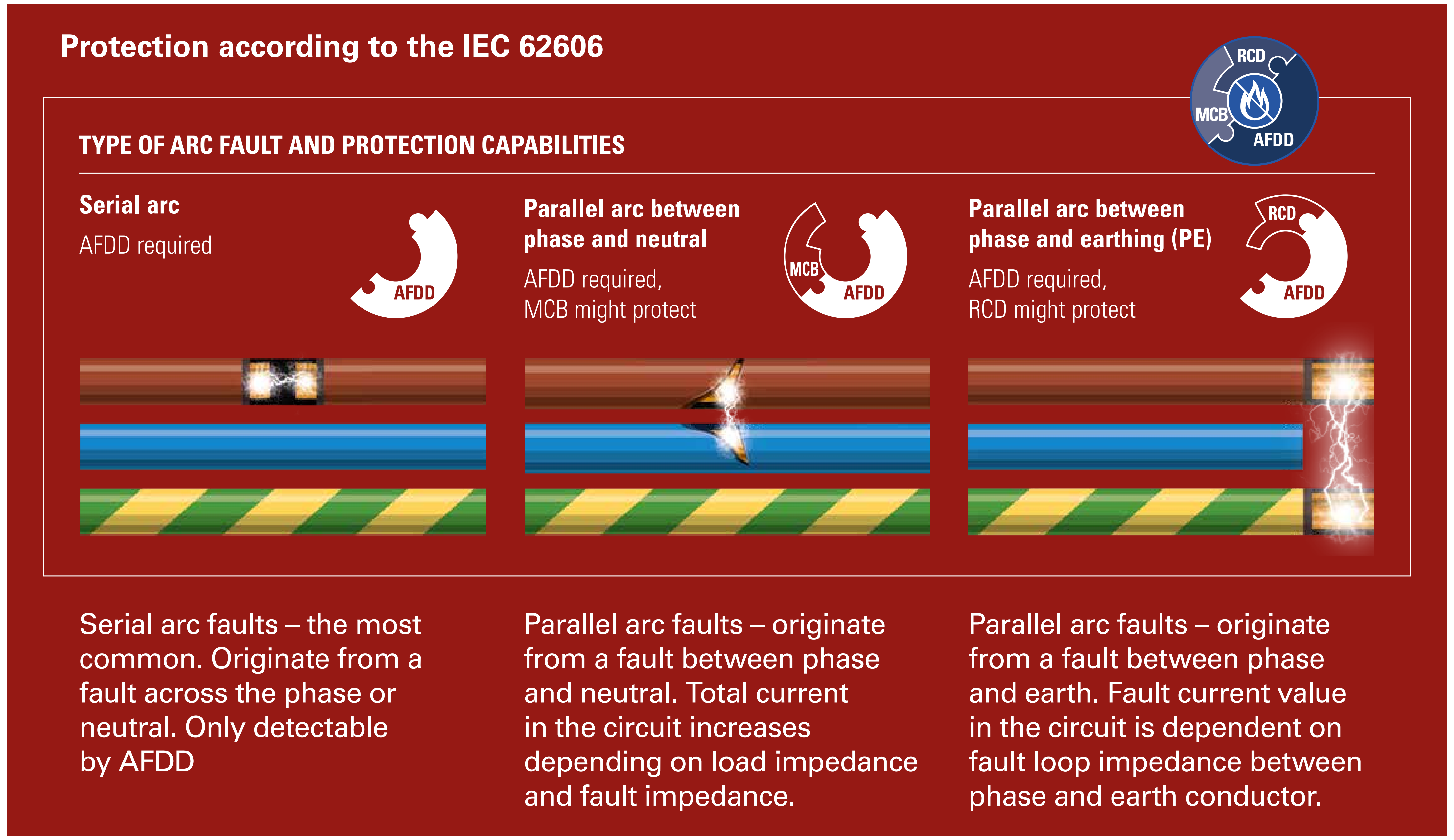
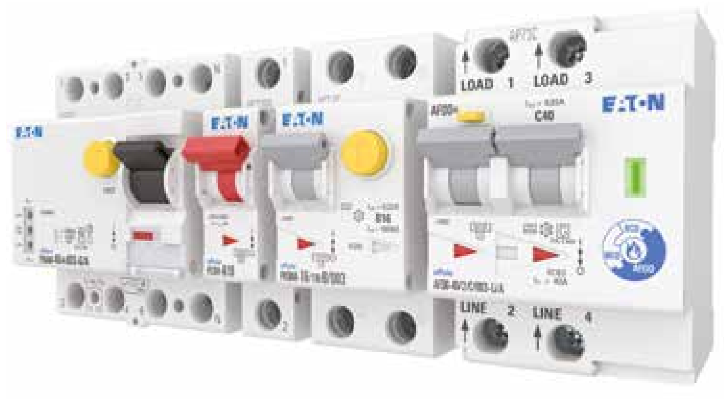


Figure 9. Arc fault types



IEC 60364-4-42 recommends AFDD's in final circuits mainly for premises with:

- Sleeping accommodation such as hotels and facilities that care for the elderly and sick
- Combustible materials and fire propagating structures such as high-rise buildings
- Fire risk due to the nature of processed or stored materials such as at garages, wooden material shops, storage facilities with combustible materials
- Combustible structural materials such as at wooden buildings)
- Possible danger posed to irreplaceable goods

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 10: Overvoltage protection

IEC 60364-4-443 *Protection against transient overvoltages of atmospheric origin or due to switching*

IEC 62305 *Protection against lightning (more parts)*

Over the course of their operation, electrical equipment and appliances have to operate at the rated voltage for which they were designed. Any voltage that exceeds the maximum allowed voltage value of a device or circuit is named overvoltage. Any dangerous overvoltage, which can cause damage of electrical and electronic components which are used in the installation, must be reduced to a safe level. This results in ever-increasing demands on overvoltage protection that is mandatory in all installations where there is a risk of overvoltage identified. The distance from source nevertheless plays an essential role in the effective mitigation of danger, with every extra meter of cable increasing circuit impedance.

External lightning rods, however, are in no way sufficient to protect the many sensitive electrical installations and equipment now used in buildings. Instead, three-stage surge protection devices are needed.
These should include:

- **Lightning arresters:** usually installed in the main distribution board connection and can conduct high lightning currents to the ground
- **Surge arresters:** usually installed in the sub distribution board and designed to reduce the surge voltage to a level that is harmless to the electrical installation (max. 2.5 kV peak)
- **Fine surge protectors:** either in the terminal box or in the socket, to protect the terminal equipment connected to it.

Protection against overvoltage, either from lightning or switching caused by disconnection of inductive loads, always represents a certain investment. This is, however, worth it when compared to the price of repairing or replacing damaged equipment that contains electronics.

Risk assessment according to IEC 62305-2

A risk analysis for the overall assessment should be performed before the surge protection concept is drawn up.

The following points should be taken into account:

- Location
  Where is the building located?
- Lightning intensity
  How much lightning is to be expected?
- Full protection
  Installing external lightning protection measures and internal surge protection measures is always recommended.
- National regulations
  The national wiring regulations for the electrical installations and corresponding surge protection measures must be taken into account at the planning stage.

Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

Step 11: Protection against interruption of supply

IEC 60364-5-56 *Safety services*

Electrical installations with high demand for uninterruptible supply such as hospitals, data centres, telecommunication equipment etc. must use one or more backup sources, which are able to supply critical parts of installation within the necessary timeframe (e.g., see IEC 60364-5-56). Best results are when all three backup sources are implemented:

Transformers are connected in seconds to the network by an automatic changeover system when the primary transformer loses its voltage.

Generators are generally diesel-powered, and their operating time is mainly dependent on fuel availability. The disconnection time up to moment when the motor starts is a maximum of only a few minutes.

The most modern solution involves electronic **uninterruptible power supply (UPS)** units which can work for a defined time, depending on the capacity of the batteries. With a UPS, there is no interruption to supply.

To fulfil the conditions for protection against interruption of supply, combinations of either the first two or all three above methods are used. For example, medical locations such like hospitals, usually use two or more transformers, in the best case supplied from independent medium voltage lines. Then one or more generators for the emergency supply of critical parts of installations are ready for quick start if the main supply voltage is not available.

Finally, powerful online UPSs are installed for the critical parts of installations. They are designed for a relatively short time of operation (from 10 minutes up to hours), to cover the gap from generator start up to recovery of voltage from the transformer. Such a high redundancy system is very reliable and ensures a high level of installation safety in all expected situations.

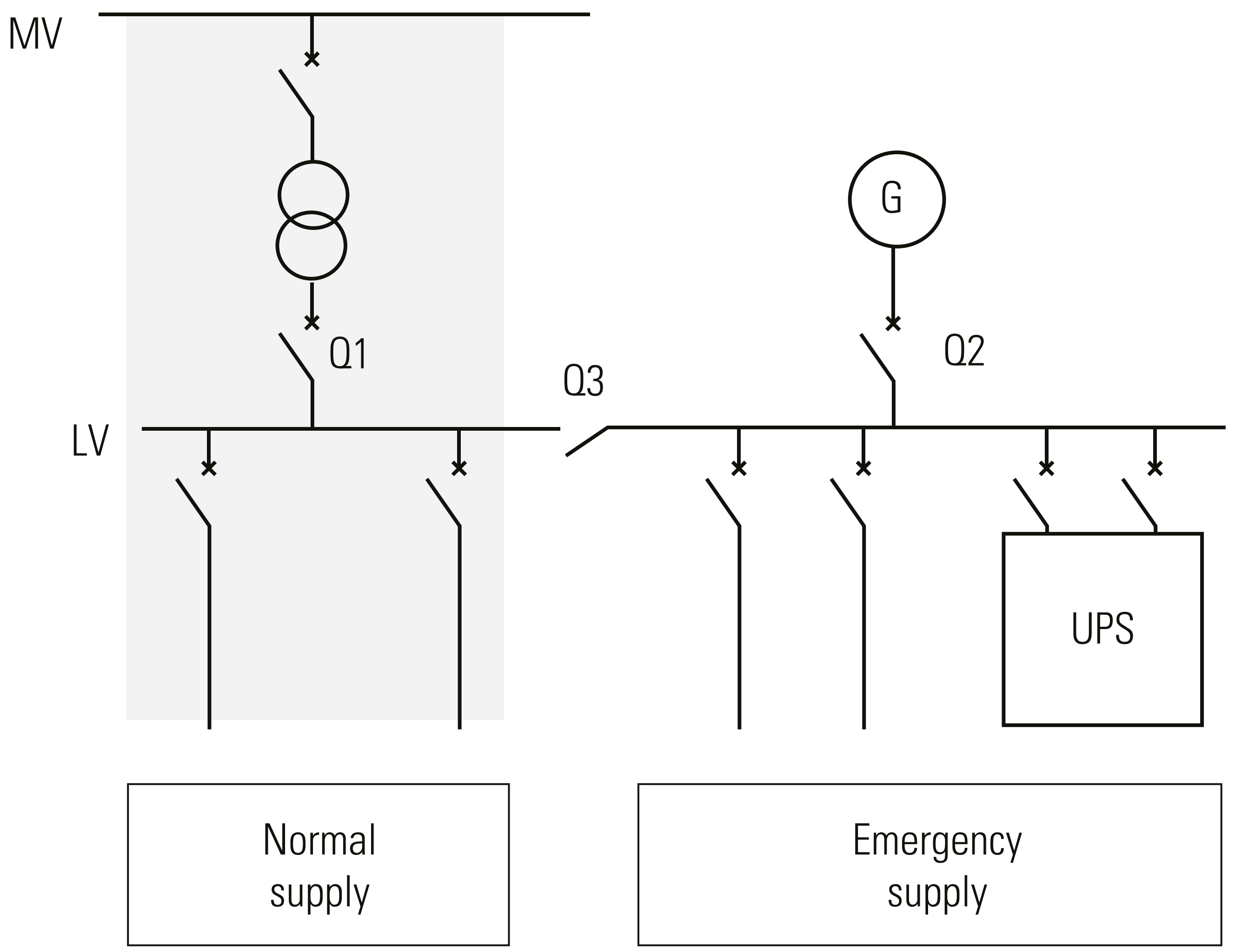
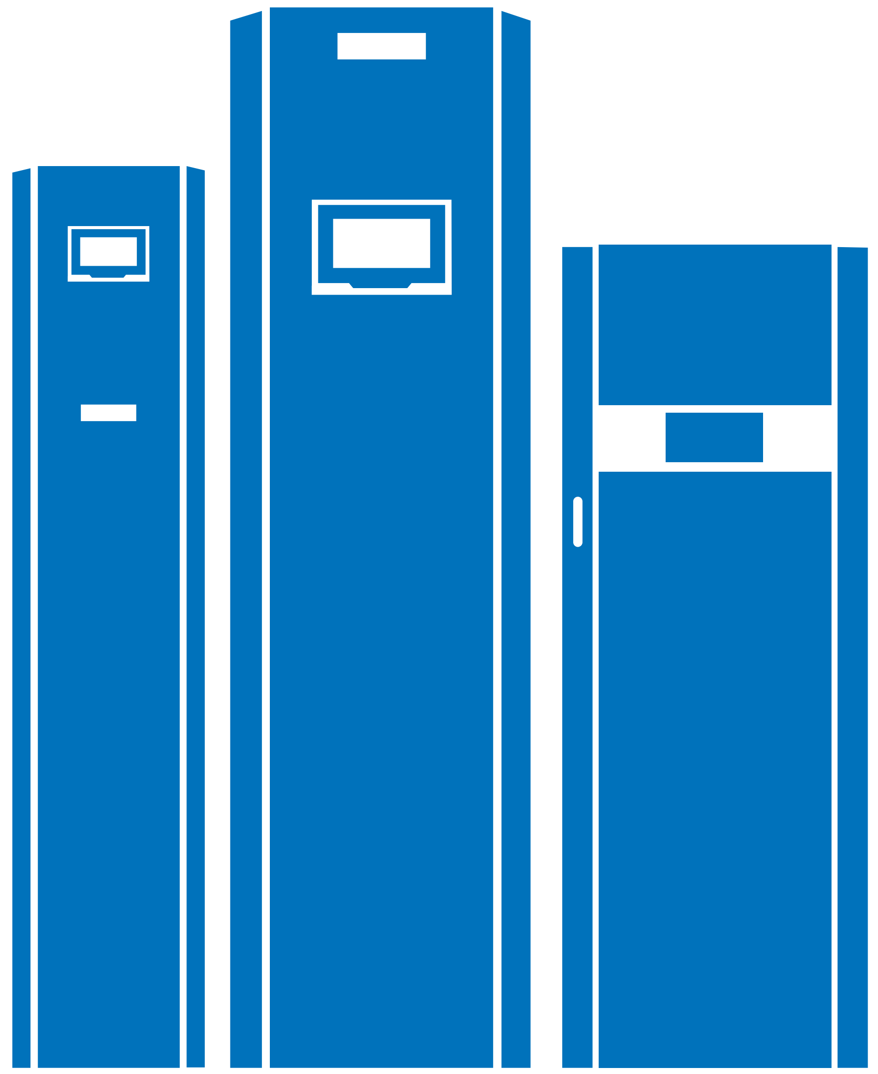


Figure 10. Typical connection of power supplies in a highly critical installation



Designing low-voltage electrical installations to IEC 60364

2.1.5 Design steps in close up

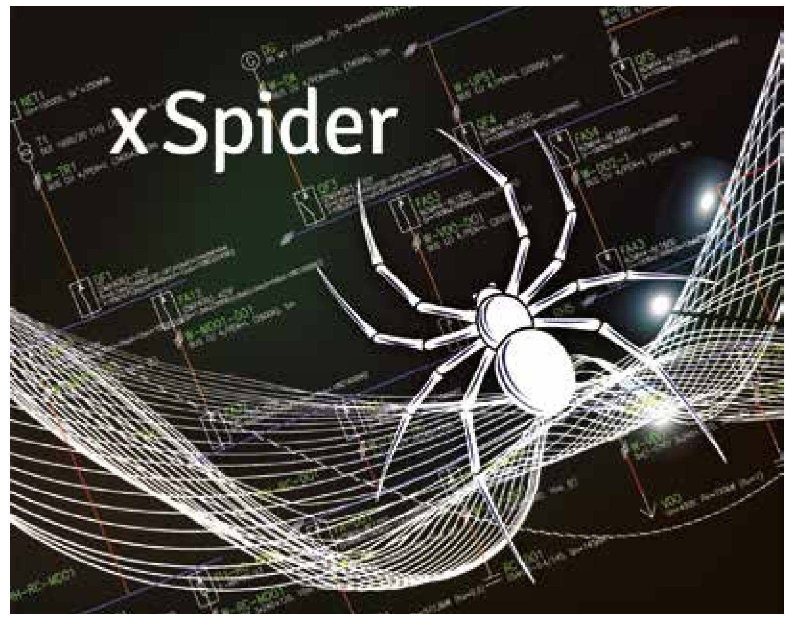
Step 12: Selectivity

Selectivity is the coordination of overcurrent protection devices so that a fault in the installation is cleared by the protection device located immediately upstream of the fault. The purpose of selectivity is to minimise the impact of a failure on the network.

Selective coordination is required for systems related to important circuits (e.g., life safety, technology, etc.). It applies for the full range of overcurrent protection devices on the system (total selectivity) or as a partial selectivity up to a defined selectivity limit current. A selectivity study provides information about features of used combinations. Information about prospective short circuit current at the specified node is also needed.

Verification of selectivity can be done by desk study e.g., comparison of tripping characteristics and parameters of settings (e.g., times, currents) or by tests.

Eaton xSpider software can also be used.



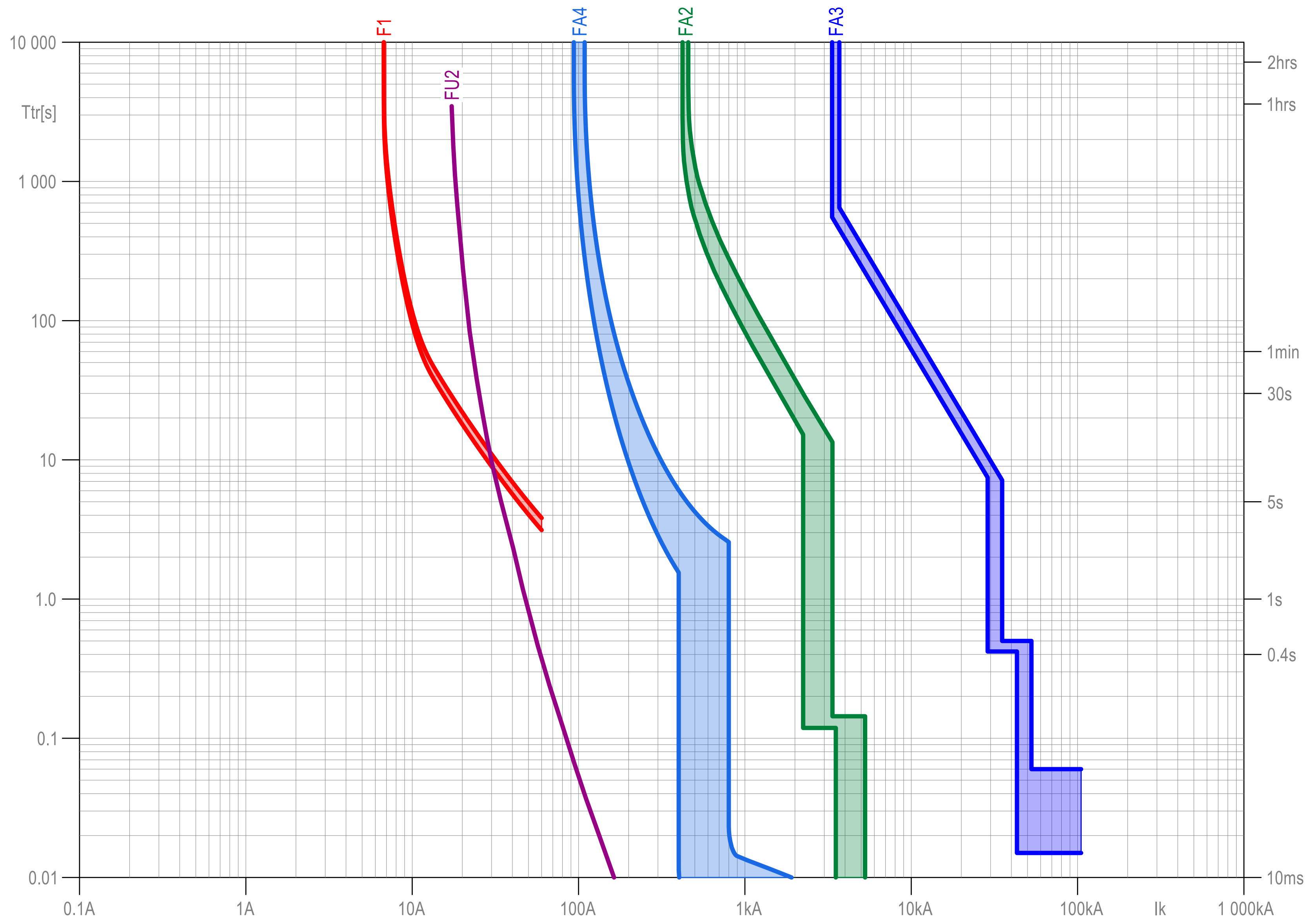


Figure 11. Comparison of tripping characteristics

Documentation and report

Once the results of all the electrical installation design steps are evaluated and satisfactory, project documentation and a report can be produced.

Ensuring standards continue to be met

Meeting IEC 60364 standards is not only important at system design and installation but during the system's entire lifetime. Regular testing and verification are therefore needed to continue to protect people from electrical hazards, deliver system uptime and continuity, and protect capital investment.

Meeting IEC 61439 standards for low-voltage switchboards

Overall responsibilities:

- **Rating of the distribution board** – responsibility is defined by the designer in cooperation with the end user
- **Compliance with the design verification** – responsibility rests with the original manufacturer (preferred) or assembly manufacturer
- **Marking and documentation of the assembly** – responsibility rests with the assembly manufacturer
- **Performance of the design verification and documentation, CE-confirmation** – this is the responsibility original manufacturer and assembly manufacturer

Panel builders (assembly manufacturers) can meet these responsibilities by following strict rules. Preferably, they use the original manufacturer's documents for this.

Assembled switchboards must fulfil conditions of routine verification, an integral part of the documentation needed for the issue of the CE declaration of conformity declaring that an assembled product is safe for use.

Eaton Arc Flash risk analysis

Arc fault protection for switchboards is important for the safety of operational personnel and property in the event of an internal arc inside of switchboards. Eaton therefore offers an Arc Flash risk analysis service. Helping to avoid the need for expensive future changes post-installation, this determines the need at planning stage for safety measures such as internal separation (Form 1a – 4b), circuit breakers with Zone Selectivity Interlocking (ZSI), or the Arc Reduction Maintenance System™ functions (ARMS) or an ARCON system. It is good to know, that the IEC 60364-4-42 standard, for which a new edition is currently being prepared, will mandate arc flash risk analysis for all installations above 800 A with prospective short circuit current above 25 kA.

Low-voltage switchboards (distribution boards) are essential elements of every electrical installation because they combine protective, switching and control devices. They are subject to IEC 61439 *Low-voltage switchgear and control gear assemblies*, a very important product standard which describes how a low-voltage switchboard or distribution board should be built to be both safe and functional.

The standard details specific responsibilities for the original manufacturer, assembly manufacturer (panel builder) and end user. It also describes operating conditions, technical properties and verification options. Finally, it defines which documents belong to a low-voltage distribution board.

Risks in buildings created by new technologies

New installations, for example those integrating renewable power sources, EV charging stations and energy storage, often have more stringent requirements both for the electrical installation and the components they contain.

IEC 60364 details basic safety elements (such as Part 4-41, 4-42, etc) with a definition of safety conditions for installations. Additionally, separate parts (Part 7-7xx) are available which are dedicated for installations in special locations (such as bathrooms, building sites, medical locations, etc.). Special sections apply to PV power supply systems (Part 7-712) and EV charging infrastructure (Part 7-722).

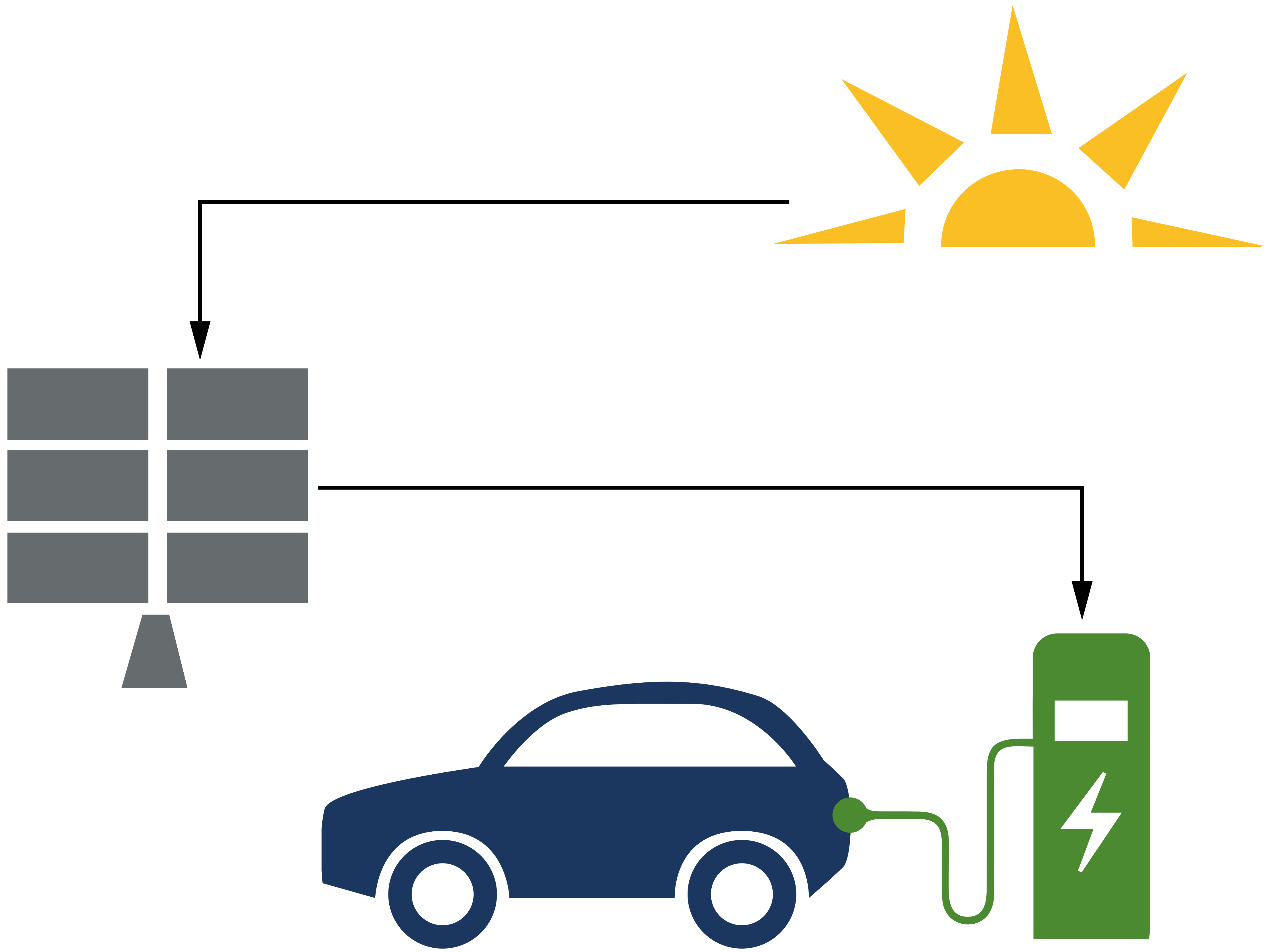
Specific requirements for EV charger and PV infrastructure

Protection against electric shock

EV charger power electronics and PV inverters can produce DC fault and leakage currents during operation. RCDs applied in circuits with PV or EV chargers therefore require at least RCD type A (when DC fault current protection higher than 6 mA is provided) or type B (applicable for all types of fault currents).

Protection against overvoltage

Electronic circuits are very sensitive to overvoltage. For this reason, Surge Protection Devices (SPD) type 1 and type 2 are used. The basic requirements for overvoltage protection are stated in IEC 60364-1 General requirement for electrical installations. As a general recommendation, SPD is mandatory in all installations where there is risk. Details are based on risk analysis (see Step 10: Overvoltage protection).



Protecting people, property, equipment and data

'Safety is not just meeting standards, it's exceeding them.'

In this section learn about:

- The wide range of protective devices available and the standards to which they relate
- Factors to consider when designing LV switchboards
- How to manage the growth in renewables

3.1

Selecting protective devices

From RCDs through to RCBOs, CBRs and more – understand the importance of making the right choice of device to meet compliance requirements and provide for safety.

3.2

Designing LV switchboards

Explore protection considerations relevant for both design consultants and panel builders embracing both technical and organisational approaches.

3.3

Integrating renewable energy sources and loads

New protection strategies are needed for the new technology now driving the renewables revolution.

Selecting protective devices

Fuses, switch-fuse combinations, circuit breakers, overload relays and motor starters provide protection against the risks of overload and short circuit.

Fuses serve two main purposes. They protect lines, components and equipment against overcurrents and disconnect subsystems from the main system once a fault has occurred.

Simple, economical and ensuring very high breaking capacity at small dimensions, fuses contain a metal wire or strip that melts when the current becomes too high, thereby interrupting the electrical circuit. Depending on the application, there are various types of tripping characteristics available, e.g., gG – mostly used for protecting cables, aM – for motors and gR – for semiconductors. The main product standard for fuses is IEC 60269.

Switch and fuse combination units integrate both circuit protection provided by fuse links and circuit switching provided by the switch in one unit. A very important parameter for their use is their utilisation category e.g., AC20, AC21, etc.).

Circuit breakers can protect against all kind of overcurrents (overload and short circuit currents).

Types include:

- Miniature circuit breaker (MCB) up to 125 A – specifically for protecting conductors
- Moulded case circuit breaker (MCCB) up to 1600 A – for protecting conductors or loads
- Air circuit breaker (ACB) up to 6300 A – for protecting conductors or loads

See chapters 3.1.1-3 for more on these three circuit breaker types.

Overload relays offer sensitive overload protection for motors, with settings according to the motors' rated current.

Motor starters offer a dedicated motor protection solution that includes overload and short circuit current protection.

Eaton Bussmann series

These fuses play a major role in industrial or commercial facilities by providing reliable, maximum protection for power systems.

Selecting protective devices

3.1.1 Miniature Circuit Breakers (MCBs)

Miniature Circuit Breakers (MCBs) are electromechanical protective devices used in almost every electrical installation to protect against overload and short circuit currents in the line and electrical equipment up to the value of its tripping capability. Overload currents can cause hazardous dissipation of high energy along the wire, leading to its heating and destruction, and potential impact on its immediate environment. MCBs combine a relatively slow, current-dependent, overcurrent protection trip unit with bi-metal and very fast, current-independent short circuit protection.

Two product standards are relevant for MCBs:

- IEC 60898-1 for MCBs up to 125 A (operated by 'ordinary persons', as referenced in standards)
- IEC 60947-2 for circuit breakers up to 6300 A (operated by skilled people, mainly for industrial applications)

Figure 12. Miniature circuit breaker (MCB)

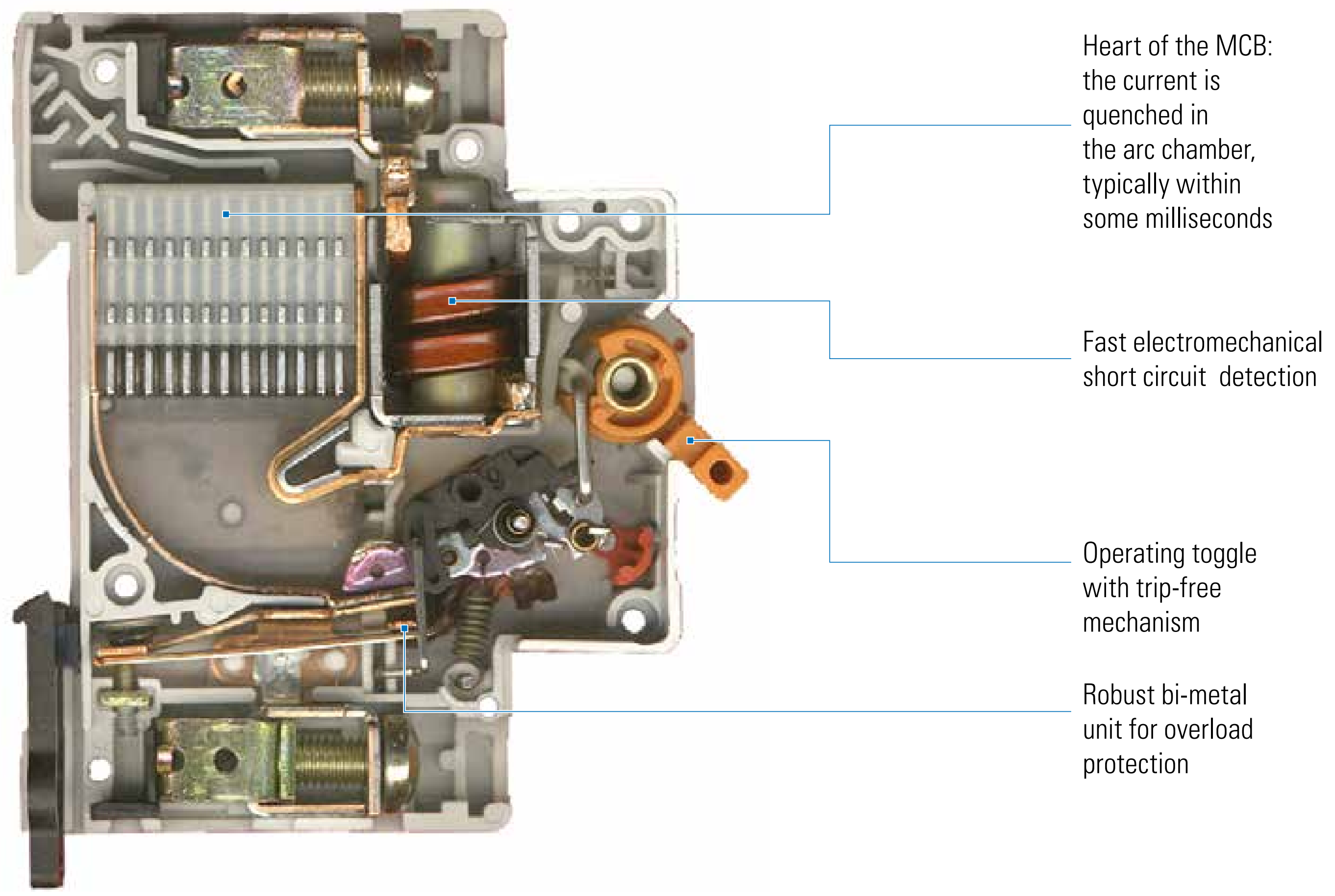


Figure 13. MCB structural components

3.1.2 Moulded case circuit breakers (MCCB) and air circuit breakers (ACB)

Moulded case circuit breakers (MCCB) and air circuit breakers (ACB) are power circuit breakers. Their basic functions include:

- Protection against overcurrents
- Isolation from source
- Operation of switchgears.

MCCBs are designed up to 1600 A and their features are dependent on their construction.

Types up to 630 A are designed as current limiting breakers with very short tripping times during short circuit current. This helps with high breaking capacity and possible backup protection of smaller-sized circuit breakers. MCCBs with rated currents from 630 A up to 1600 A are designed as non-current limiting breakers. These are needed for main incomers and for good selectivity coordination to downstream breakers.

ACBs have rated currents up to 6300 A and share many characteristics with non-current limiting MCCBs.

The product standard for both MCCBs and ACBs is IEC 60947-2 Circuit breakers.

Selecting protective devices

3.1.3 Residual current devices (RCD)

Abbreviations

RCD – residual current device (generic name)

RCCB – residual current device without overcurrent protection (IEC/EN 61008)

RCBO – residual current device with integrated overcurrent protection i.e., a combination of RCCB + MCB (IEC/EN 61009)

CBR – Circuit breaker with integral IEC/EN 60947-2

MRCD – Modular residual current device (IEC/EN 60947-2)

Types of RCDs

These differ according to sensitivity to various forms of residual currents:

- **Type AC** (alternating residual current) – useful only for loads for general use (resistive or inductive loads only). Not allowed in most countries.
- **Type A, F, B, Bfq, B+** (alternating, pulsating Direct Current (DC) or smooth DC) – needed in circuits with semiconductors, which can create DC component.

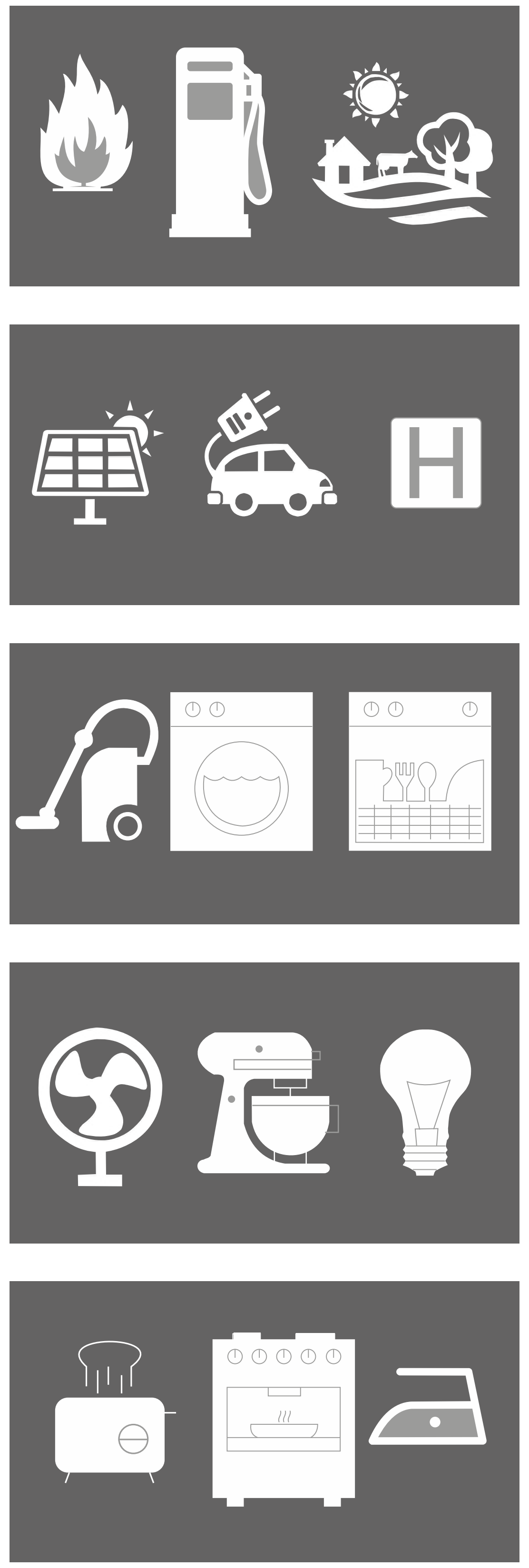
These differ according to time-current tripping characteristics:

- Non-delayed
- G, Li: high resistance against nuisance tripping; 30 mA sensitivity is suitable as additional protection (min 10 ms non-actuating time)
- S: Selective (min 40 ms non-actuating time)

RCDs with a defined, non-actuating time delay provide high resistivity against nuisance trips. This is very important in all circuits with high inrush currents (e.g., charging current peaks, overvoltage protective devices, etc.).

Type	Level	Description
B+ (kHz)	COMPREHENSIVE	Provides an additional protection as higher frequency fault currents can be detected. This contributes to protection against thermal hazards such as electrically ignited fires.
B	ALLROUND	All current sensitive RCD that detects smooth DC currents that can occur in installations containing PV systems, UPS Units, EV charging stations and appliances with 3 phase frequency converts.
F	ADVANCED	Is a pulse-sensitive RCD that also detects pulsating currents with DC components up to 10 mA and mixed frequencies up to 1 kHz. This provides advanced protection for electronic loads. Recommended for all loads with 1 phase frequency converters.
A	STANDARD	Improved level of safety as this type can also detect pulsating AC fault currents which are typical in most of today's applications.
AC	MINIMUM	RCD which detects sinusoidal fault currents only. This RCD type fulfi lls the minimum requirements. For today's applications a higher level of safety is recommended. **Is not allowed anymore in various local wiring regulations.**

Typical loads



Selecting protective devices

3.1.3 Residual current devices (RCD)

RCDs are applied in all modern low-voltage installations, their role dependent on usage:

1. Additional protection by RCD (with sensitivity $I_{\Delta n} \leq 30$ mA)

=> Protection against electric shock caused by direct contact with a live part

2. Fault protection by automatic disconnection in case of failure (sensitivity depends on conditions in the place of installation)

=> Protection against electric shock (indirect contact)

3. Protection against fire caused by leaking currents by RCD with sensitivity $I_{\Delta n} \leq 300$ mA

=> Protection against the risk of fire

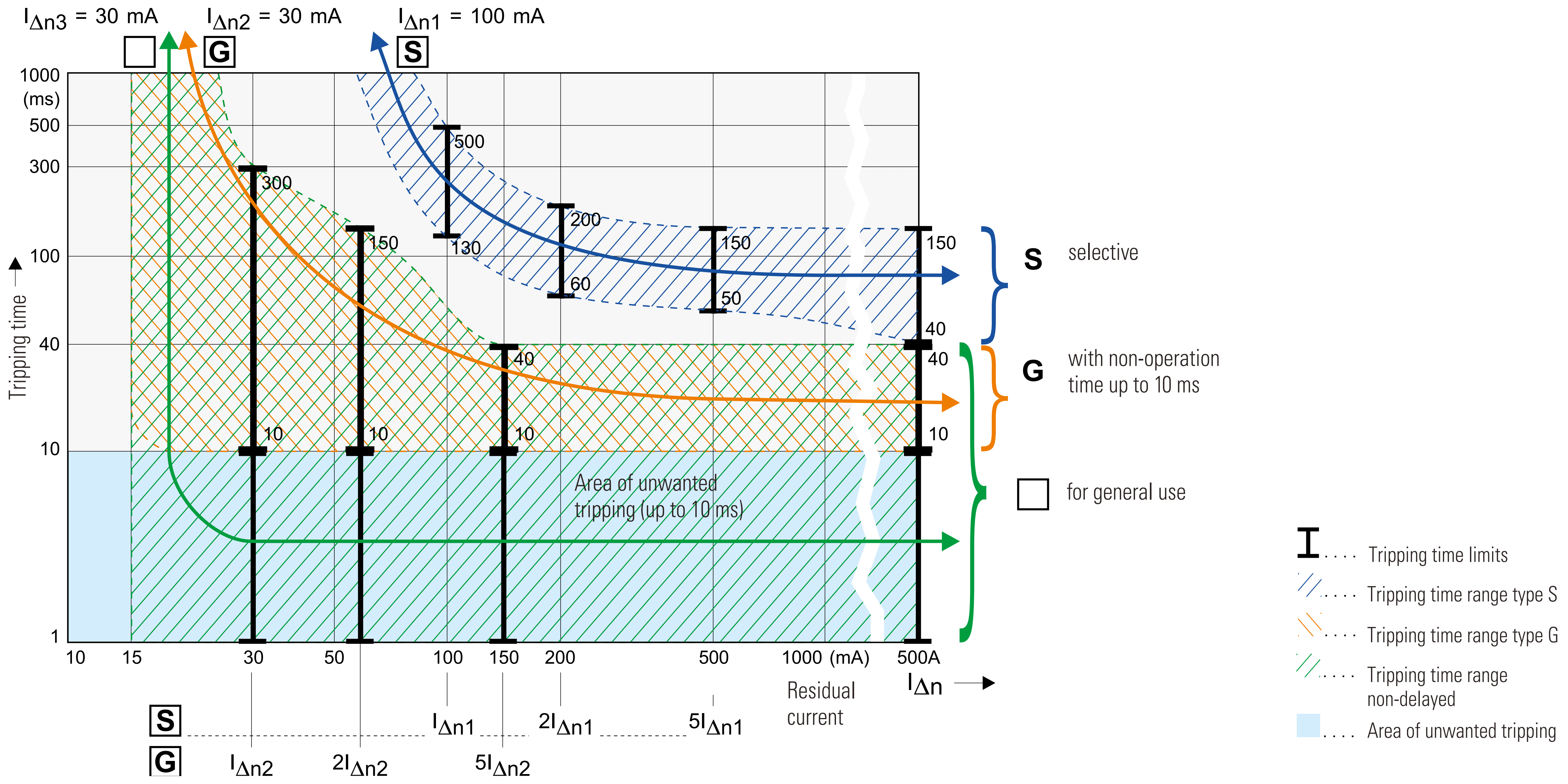


Figure 14.Tripping characteristics, tripping time range and selectivity RCDs

The most widely used product standards for RCDs are:

- IEC 61008 (RCCBs), IEC 61009 (RCBOs) – type AC and A
- IEC 62423 - type F and type B (valid for RCCBs and RCBOs)

Selecting protective devices

3.1.3 Residual current devices (RCD)

Coordinating RCDs correctly

Some new technology, including PV inverters and EV chargers, can generate smooth DC fault currents. These are caused by the use of semiconductor components in their power electronics which can cause DC residual current under normal or fault conditions.

A conventional Type AC RCD is only suitable for circuits with potential alternating (AC) residual current. Type A can detect alternating as well as pulsating DC residual currents, where a small value of DC residual current can also be present (up to 6 mA). However, if the DC residual current exceeds 6 mA, magnetic material of the core balanced transformer is fully saturated by DC magnetic flux and the RCD will not be able to react to any form of residual current, a situation where we say the RCD is 'blind'. This clearly makes the electrical installation very dangerous, because protection with a sensitive RCD is unavailable. In such situations the Type B must be installed, which is designed for all kinds of residual currents.

A type A RCD should not be used upstream in combination with a type B, as it will be negated.

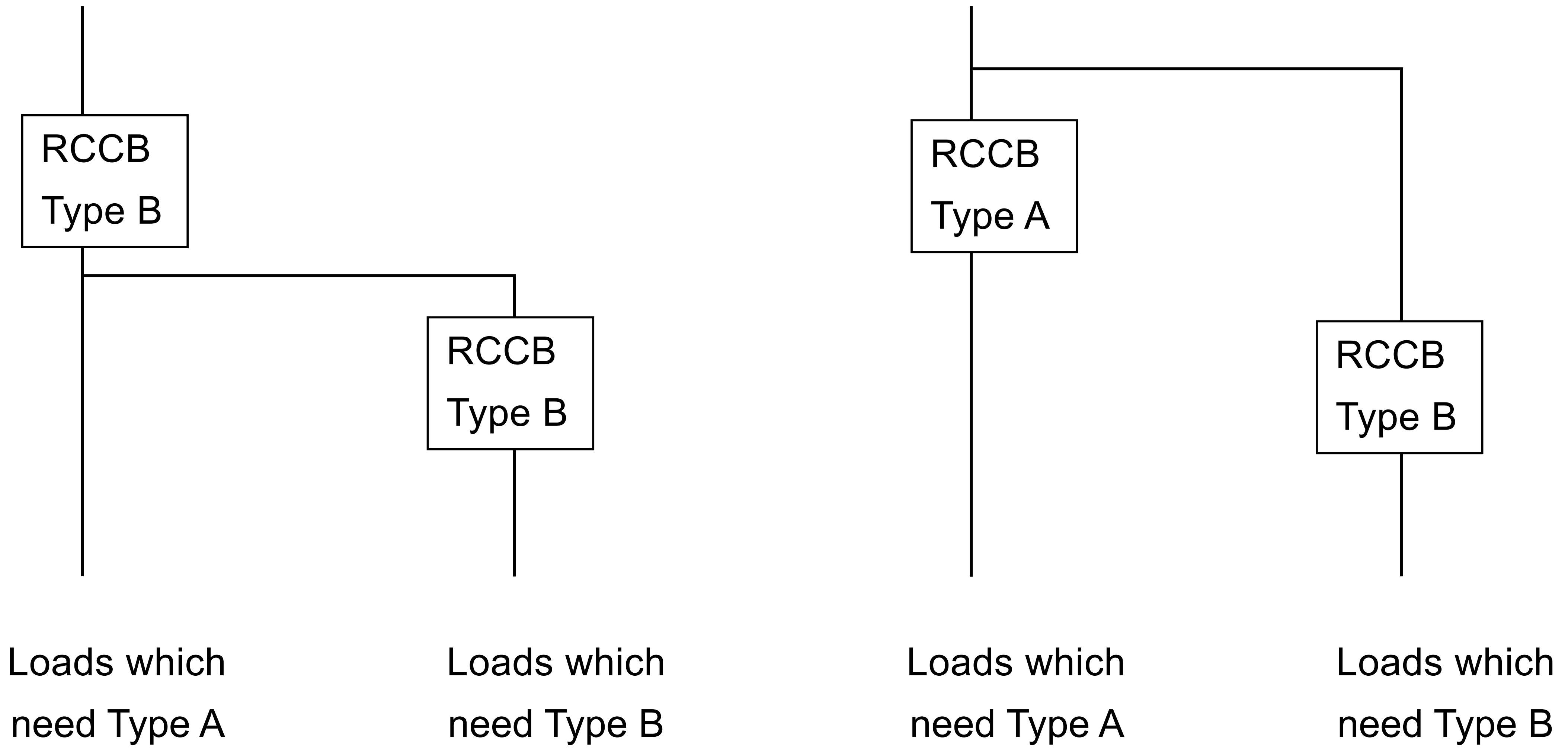


Figure 15.Coordination of RCD types

Selecting protective devices

3.1.4 Arc Fault Detection Device (AFDD)

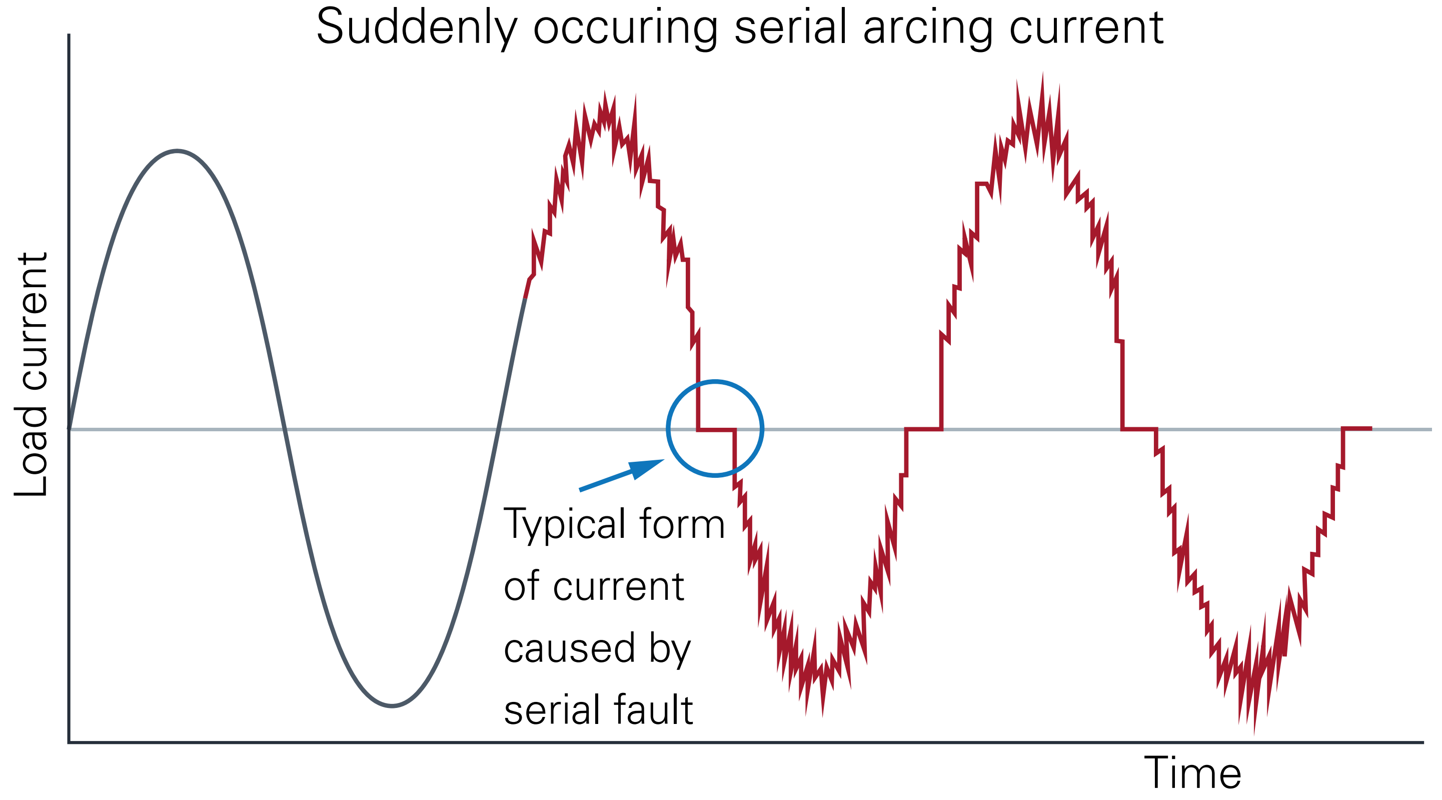
An arc fault detection device (AFDD) offers advanced protection. Used in end circuits in combination with circuit breakers and residual current devices, it comprehensively reduces the risk of electrical fire in electrical installations. AFDDs can detect arc faults both between all conductors and between conductors and ground. The most common causes include:

- Damaged cable insulation, for example from nails, screws or fastening clamps
- Cables that are pinched between doors and windows
- Breaks in cables from bent plugs and cables, for example from furniture that has been carelessly moved
- Loose contacts and connections in switches or sockets.

Cables can also be damaged by environmental influences such as heat, humidity, aggressive gases and UV radiation in the outdoor environment, or rodents gnawing through the insulation.

How does an AFDD work?

The AFDD unit continuously measures high-frequency current and voltage noise in terms of intensity, duration and wave spacing. Integrated filters with appropriate software evaluate these signals and, in the event of deviations from the expected waveforms, ensure that the connected circuit is turned off during operation. AFDD not only monitors electrical lines but also all connected electrical equipment to offer high-quality additional protection. AFDD devices are used in new, as well as older installations, where the risk of dangerous arcing faults increases over time alongside further risks.

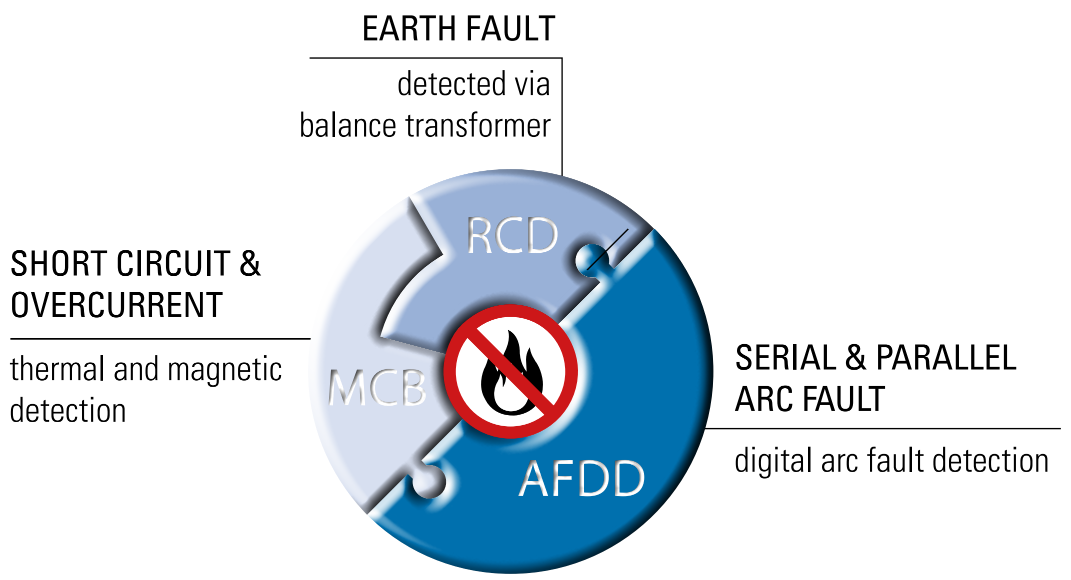


Arc stops during voltage zero-crossing

Arc generates high frequency signal from 100 khz to 70 MHz

Eaton's offering: AFDD+

An all-in-one device with integrated overload and short circuit protection, including earth fault and arc fault protection



Selecting protective devices

3.1.5 Surge Detection Devices (SPDs)

Surge Protection Devices (SPDs) safeguard properties and data against overvoltage caused by atmospheric disturbances and overvoltage peaks resulting from switching operations.

The product standard for SPDs is *Low-voltage surge protective devices* IEC 61643 .

SPD for protection against overvoltage protection by lightning:

IEC 62305-1 Protection against lightning – Part 1: General principles

Lightning protection zones are defined in IEC 62305-1 in three main categories comprising four lightning protection classes. Known as lightning protection levels, each sets out maximum and minimum parameters for the lightning current.

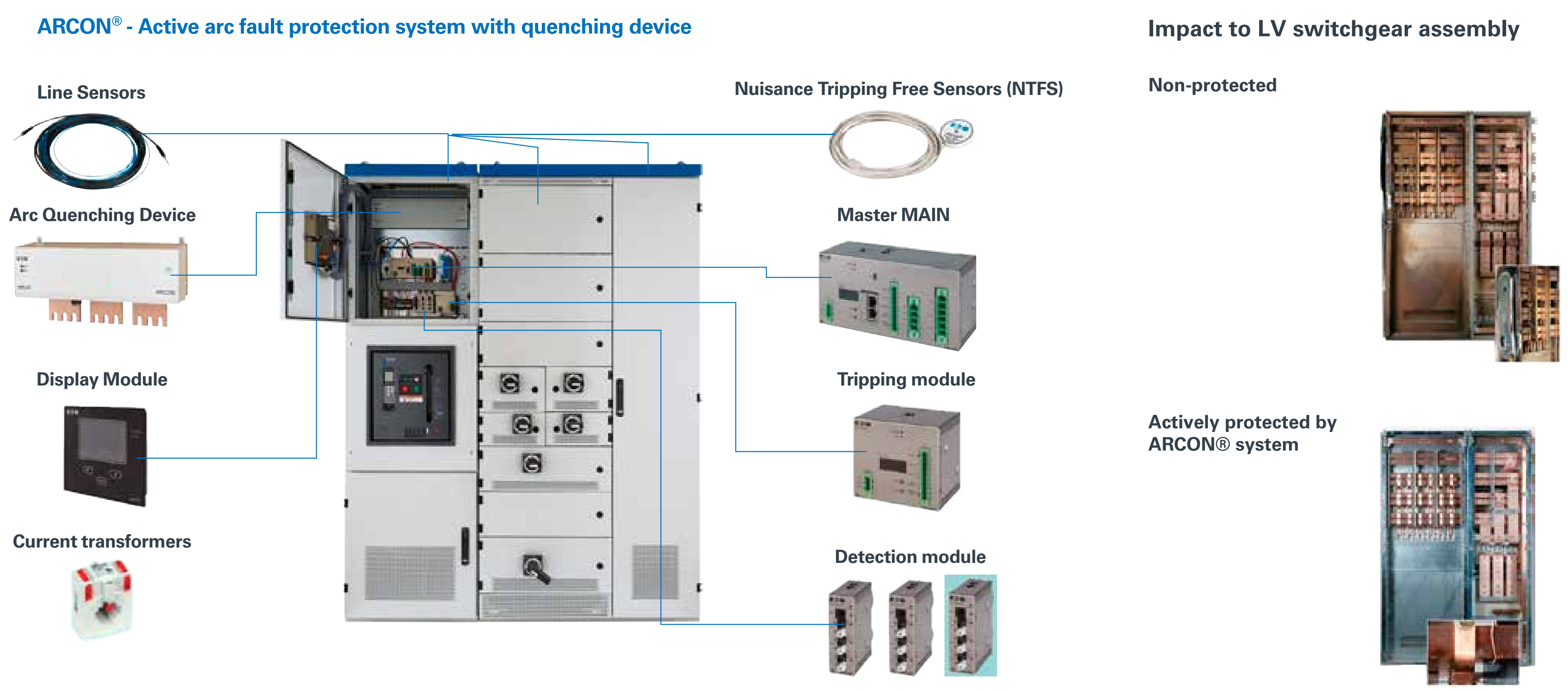
Lightning Protection Level LPL	Surge current (10/350) µs [kA]
I	100/k
II	75/k
III, IV	50/k

k = number of conductors through which a surge current may flow.

SPDs must at least be installed as close as achievable to the origin of the electrical installation. Class II-tested SPDs must be installed to ensure protection against the effects of lightning and switching overvoltages.

Class I-tested SPDs must be installed if the structure is equipped with an external lightning protection system or if other such arrangements for protection against the effects of direct lightning have been made. Structures not protected by an external lightning protection system, and for which the occurrence of direct lightning strikes to the overhead lines between the last pole and the installation's point of entry is a possibility, may be protected by class I tested SPDs at or near the origin of the electrical installation.

Three-stage surge protection concept where surge protection is installed at various locations



Selecting protective devices

3.1.5 Surge Detection Devices (SPDs)

Lightning protection levels in low-voltage electrical installations (I-IV)

Protection level 1: Lightning current protection device

Usual installation location: Main distribution board

SPD class: IEC Class I tested
EN Type 1
VDE Class T1

Voltage protection level: < 4 kV

Protection level 2: Surge protection device

Usual installation location: sub-distribution board

SPD class: IEC Class II tested
EN Type 2
VDE Class T2

Voltage protection level: < 2.5 kV

Protection level 3: Device protection

Usual installation location: directly upstream of the device

SPD class: IEC Class III tested
EN Type 3
VDE Class T3

Voltage protection level: < 1.5 kV

Correct use and coordination SPDs is well described in IEC 60364-5-53 *Low-voltage electrical installations - Part 5-53: Selection and erection of electrical equipment - Devices for protection for safety, isolation, switching, control and monitoring*

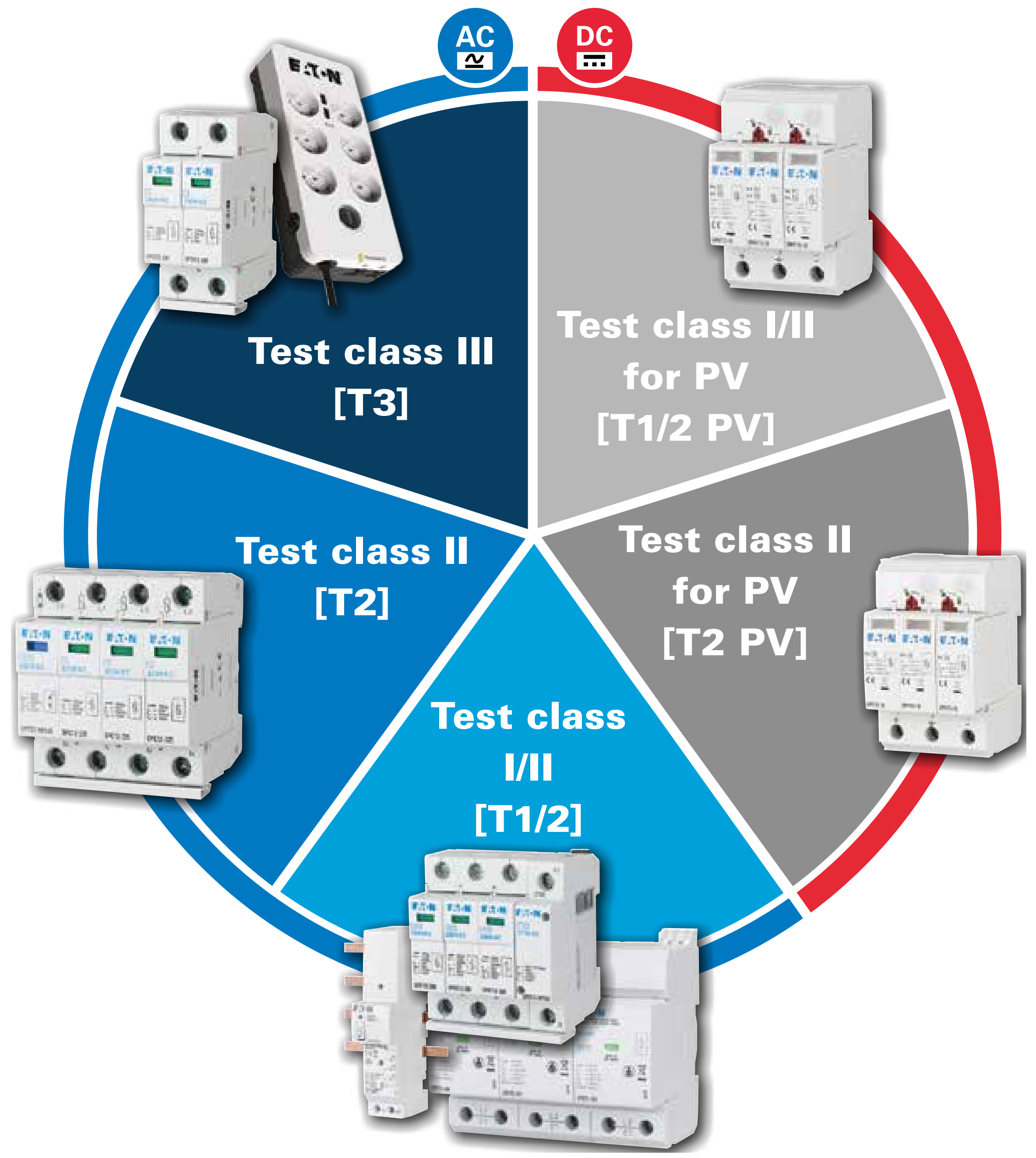
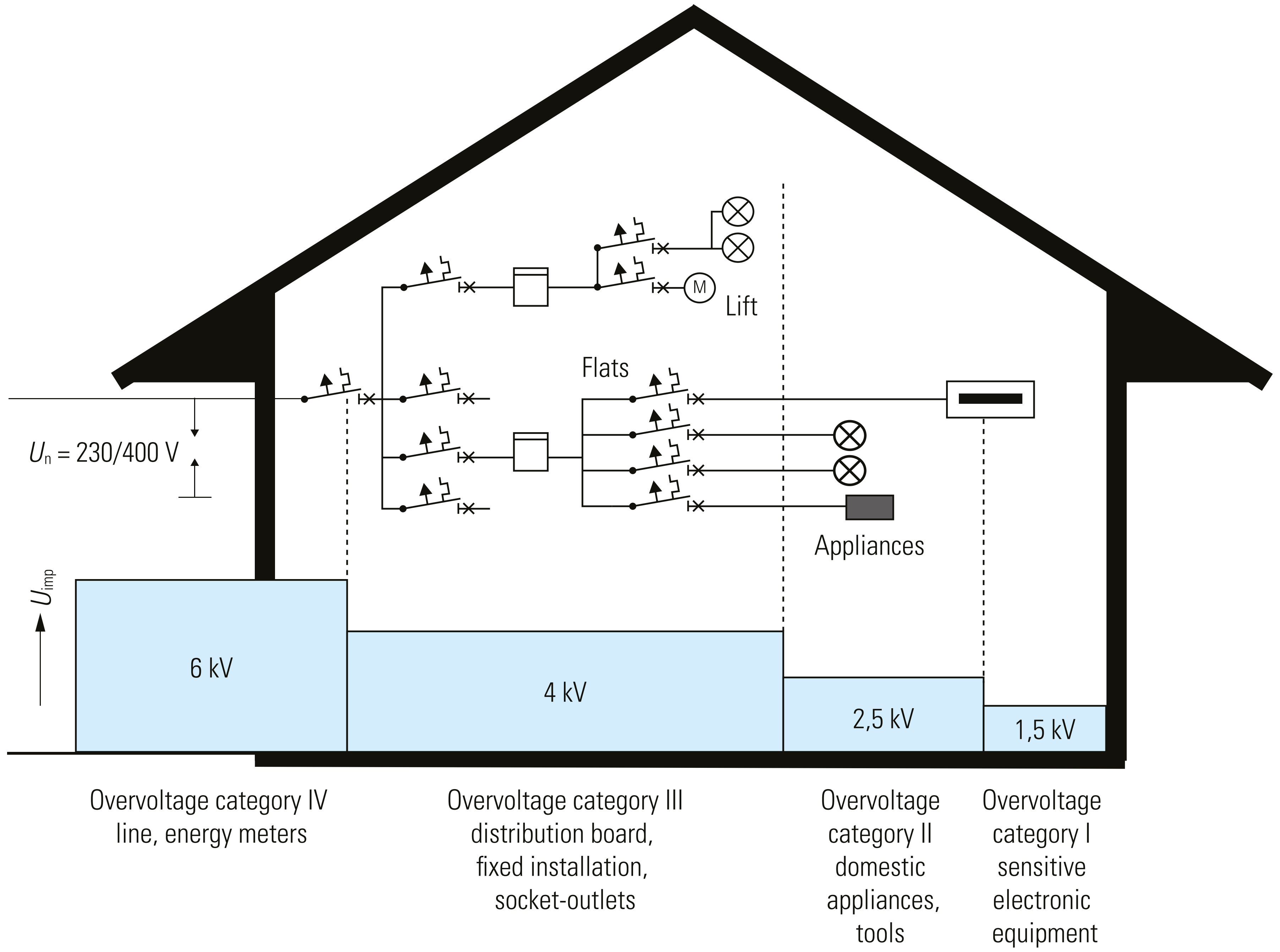


Figure 16. Eaton's offering includes also special types for PV applications (DC-side)



Designing LV switchboards

While the detailed design stage for a distribution board occurs almost at the end of a building's design process or when construction starts, it nevertheless plays an important role.

Depending on project stage, it's only usually necessary to specify main mechanical and electrical parameters such as rated voltage, rated current, prospective short circuit current level in the place of installation, degree of protection (external influence) and main switchboard dimensions.

The designer does not normally have to be concerned with all LV switchboard details as it's for the panel builder to comply with the mandatory IEC 61439 standard. This incorporates optimising the assembly according to the needs of the end user and ensuring a safe assembly design.

Mandatory steps for the switchboard manufacturer according to IEC 61439

1. Create application documentation
2. Select components and enclosure
3. Collect technical data sheets and CE declarations of components and enclosure
4. Project the "Switchgear and Controlgear Assembly"
5. Perform design verification
6. Assemble and wire the distribution board
7. Document the bill of material
8. Proof of EU directives
9. Carry out marking of the switchgear assemblies
10. Issue the EC declaration of conformity and CE marking of the distributuion board
11. Archive documents (steps 1-10) for min.10 years

Designing LV switchboards

3.2.1 Internal arc in electrical switchboards

An electric arc in a circuit inside a switchboard can develop to become an arc short circuit current also known as an arc flash. A significant arc flash can cause considerable damage, fire and injury. Every switchboard has a different arc flash risk which should be evaluated at the design stage. Given that the risk of creating an internal arc in the switchboard is significantly greater than the risk in other parts of an installation, this is where the main design focus must be on possible protective measures. Implementing safety measures afterwards is both costly and inefficient.

Compliance with the IEC 61439 standard can still leave companies at risk of an arc flash, as the standard does not specifically address the possibility, only briefly mentioning it in a note in the last edition (2021). This is why Eaton offers additional safety functions that go beyond the standard requirements with efficient protective measures such as thermal diagnostics (Diagnose system), Arc Reduction Maintenance System™ or Arcon®.

Arc flash risks are caused by:

- Loose or weak connections, defect contacts
- Tools and materials left behind
- Undetected material defects
- Small animals in the switchgear
- The switching equipment is not suitable for the application
- Unsuitable operating conditions
- Incorrect operation
- Insufficient maintenance

High testing arc currents. Pressure can be 20 tons/m^2. Reduction of tripping time reduces energy average clearing times:

- 30 ms - ACBs up to 4000 A, instaneous trip
- 15 ms - ACB up to 1600 A, instaneous trip
- 5 ms - high current limiting MCCB
- 2 ms - active system Arcon

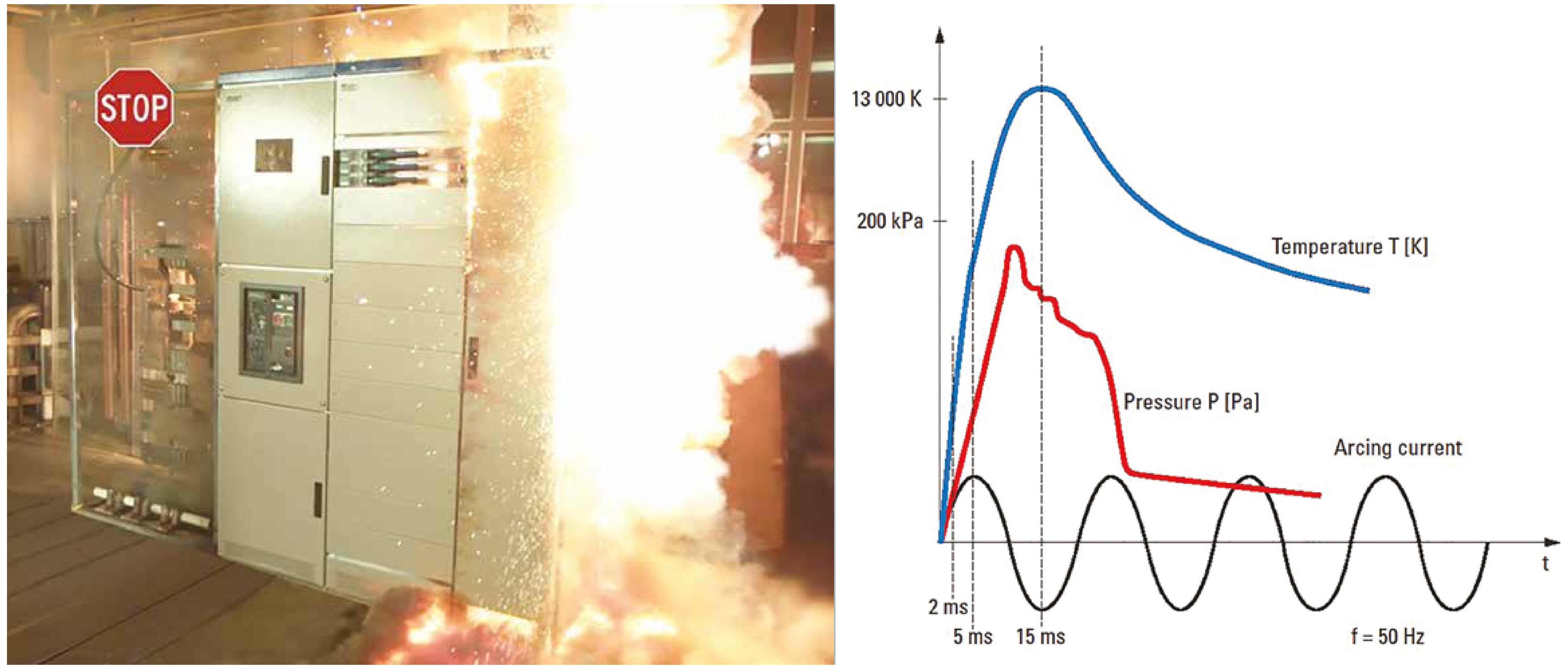


Figure 17. Development of temperature and pressure in a switchboard during internal arc

Eaton's tailor-made Arc Flash Hazard Analysis

Based on IEC (International Electrotechnical Commission) and IEEE (Institute of Electrical and Electronics Engineers) standards, this service:

- Identifies potential hazards within the electrical network under normal operating conditions or maintenance.
- Quantifies the arc flash risk (a calculation of incident energy value).
- Provides recommendations to prevent an arc flash (e.g., internal separation, thermal diagnostics, arc-free design, qualification of staff etc.)
- Proposes a selection of options to mitigate the arc flash risk (e.g., circuit breaker settings, Arc Reduction Maintenance System™, ARCON®).
- Offers improved working methods to minimise employee risk.
- Proposes practical training for personnel who operate and maintain electrical equipment.

Eaton can carry out a complementary safety evaluation of an Eaton switchboard equipped with available protective measures using xSpider's ArcRISK module.

Designing LV switchboards

3.2.2 Arc prevention through technology and organisational measures

To increase safety for operating and maintenance staff working nearby, arc prevention can be managed through technical (see below) and organisational measures such as safety rules, staff qualifications, warnings and labels etc. Should the worst happen and an arc be created, protective measures dedicated for its mitigation come into play.

Measures to avoid arcing

- Power switchgear assembly according to IEC 61439
- Internal separation of the switchgear (Form 1 – 4)
- Installation technique for the protective devices (fixed, removable, withdrawable)
- DIAGNOSE – Permanent temperature monitoring
- Earthquake-proof switchgear

Measures to reduce arcing consequences

- Passive fault arc protection (according to IEC/TR 61641)
- Protective devices selection and settings
- ZSI – Zone selectivity interlocking
- Arc Reduction Maintenance System™ – maintenance setting for circuit breakers (MCCB, ACB)
- Arcon® – Active fault arc protection system with quenching unit
- PPE – personal protective equipment, certified for dedicated category of protection against arc

The ArcRISK module in Eaton's xSpider software is an effective way of evaluating the efficiency of individual protective measures used in low-voltage switchboards. This software can be used for coordinating complex short circuit selective and protective devices including AC arc flash incident energy analysis.

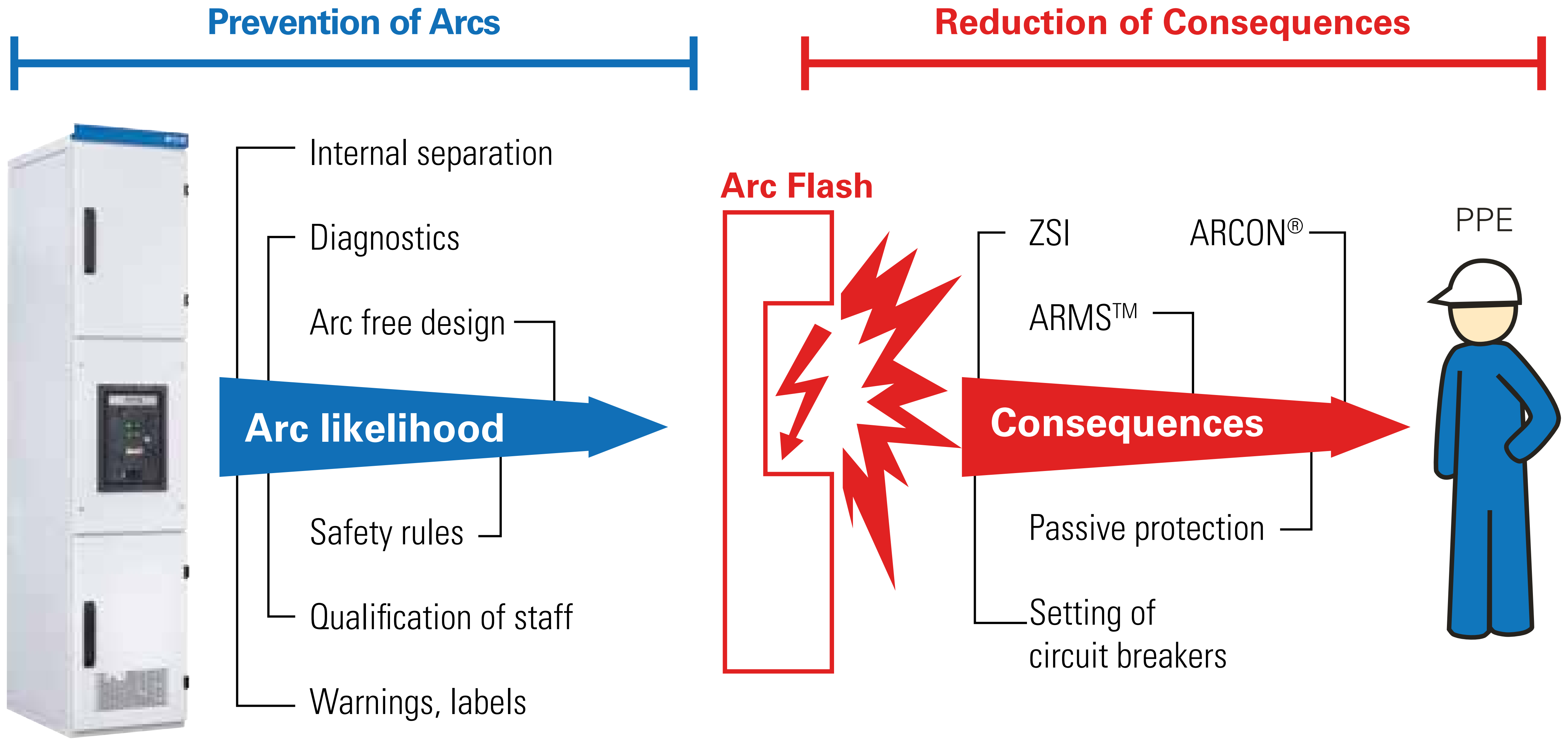


Figure 18. Safety management model for low-voltage electrical switchboards

Designing LV switchboards

3.2.2 Arc prevention through technology and organisational measures

Arc protection measures by Eaton

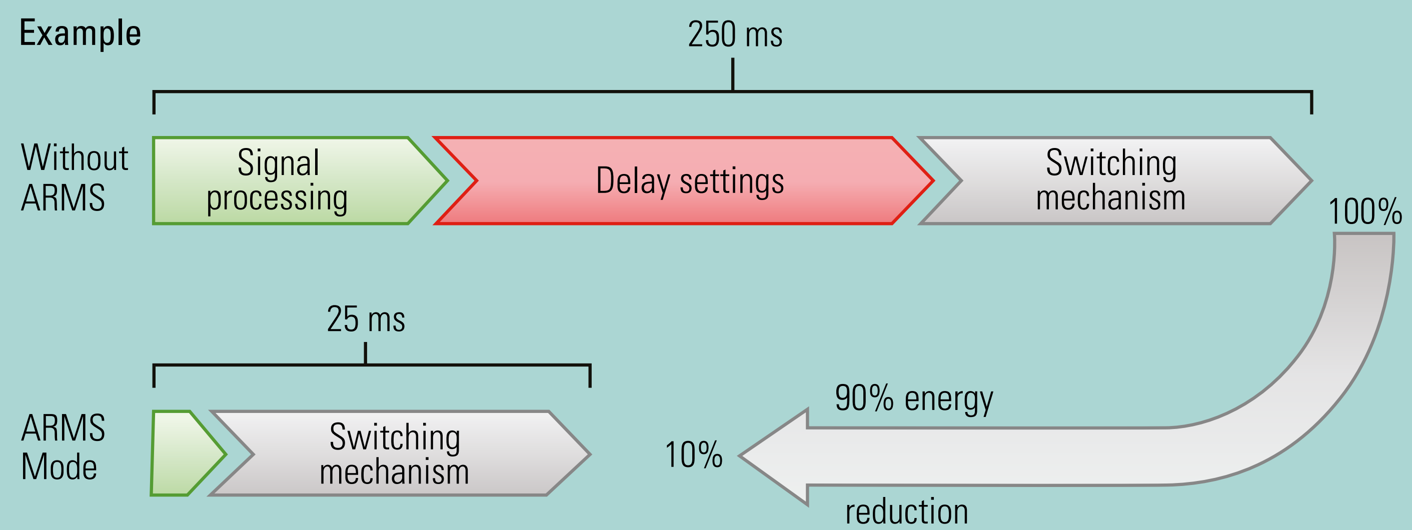
While the following measures are not required directly by the standards or regulations, they are available as a standard Eaton offer that significantly increases the safety of switchboards and the electrical installation as a whole.

Temperature DIAGNOSE

This system can be installed in the distribution board to constantly monitor and diagnose the thermal condition at key points to optimise planned maintenance and pre-empt dangerous developments.

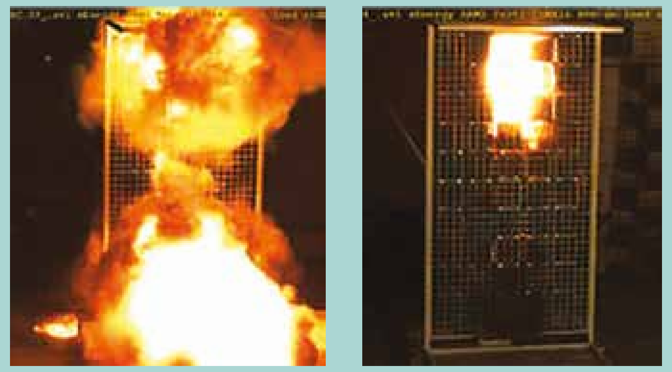
The Arc Reduction Maintenance System™

The Arc Reduction Maintenance System™ is a solution on Eaton circuit breakers (ACBs and MCCBs) that enables even shorter disconnection times. Compared with other standard electronic trip units, the ARMS can reduce the circuit breaker's total tripping time by some 30%. This improvement reduces the thermal energy in the event of an arc, a situation usually very dangerous for the operator (calculated as an incident energy). The Arc Reduction Maintenance System™ can be automatically activated by door contact on the low-voltage distribution board when someone is carrying out service work or at the time of its installation.



A blue ring surrounding the maintenance mode switch is illuminated when ARMS is enabled.

Figure 19. Effect of activated ARMS function, example with IZMX40 (ACBs)



Without ARMS ARMS activated

The thermal effect of ARMS to person is captured with cotton indicators as described in chapter about passive protection.

Figure 20. Thermal effect of internal arc flash in switchboard during ACB switch off (Eaton IZMX16), without and with activated ARMS function

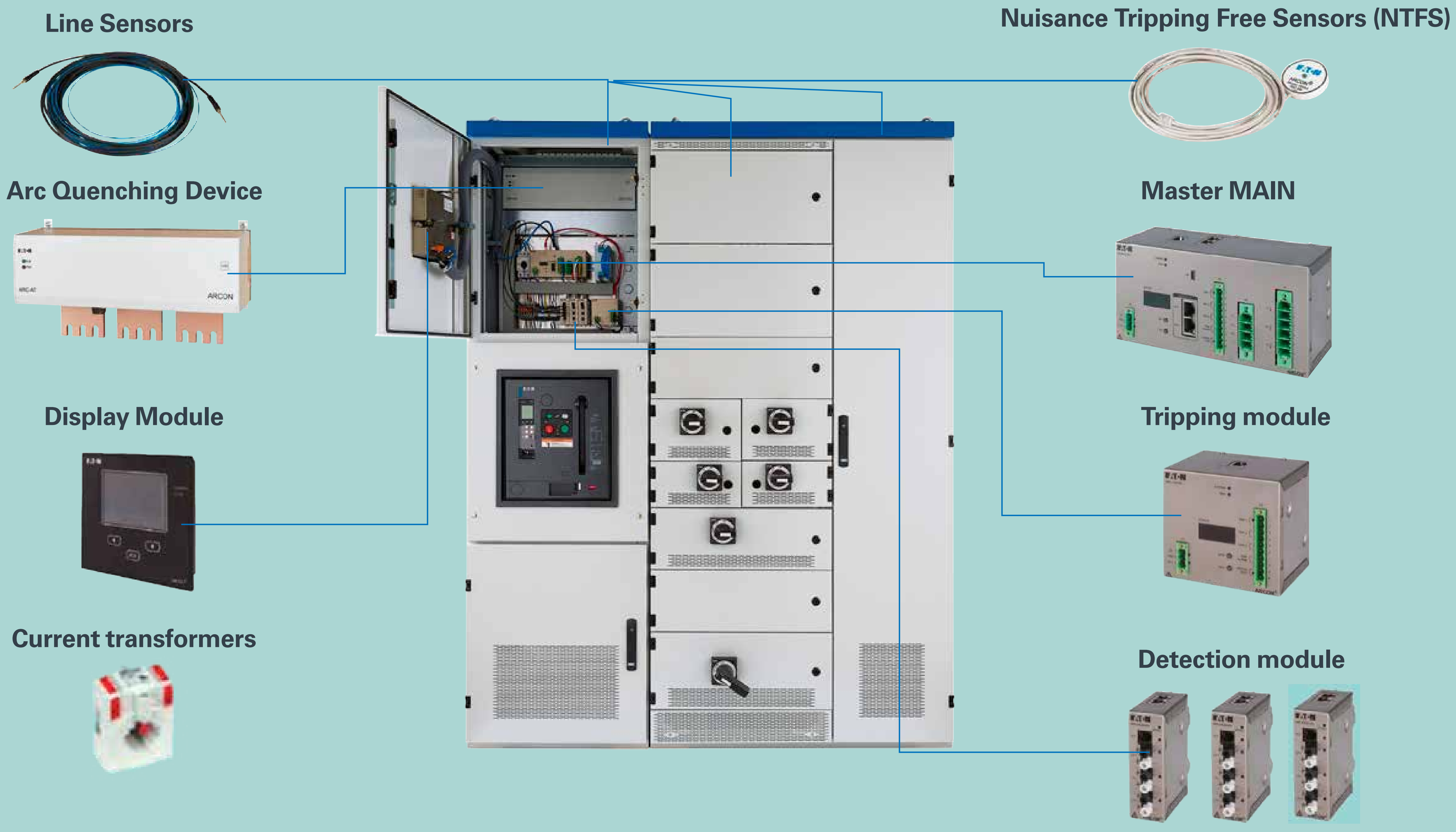
Designing LV switchboards

3.2.2 Arc prevention through technology and organisational measures

ARCON®

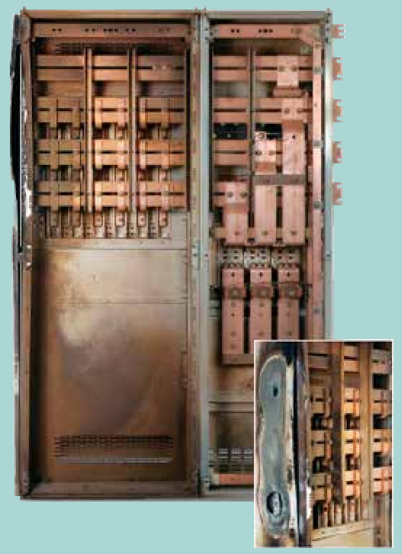
This active arc system is based on light and overcurrent detection, It eliminates an internal arc by using a quenching unit, artificially creating a short circuit inside it to reduce voltage on busbars to almost zero. Arcon's total reaction time is up to 2 ms - so quick that it prevents any internal arc in the distribution board from developing into a dangerous arc flash. This minimises both the danger to people in the vicinity and potential damage to the distribution board so that it can be back in use in only a short time.

ARCON® - Active arc fault protection system with quenching device

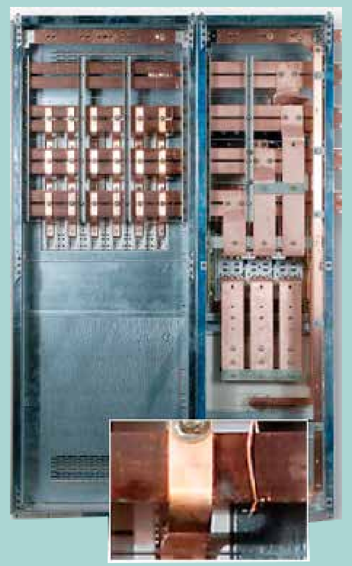


Impact to LV switchgear assembly

Non-protected



Actively protected by ARCON® system



Integrating renewable energy sources and loads

New technologies such as renewable energy sources and power loads with semiconductors feature different characteristics and behaviour than traditional approaches. Temperature rise and DC fault currents are two important differences.

Temperature rise

Newly installed renewable energy sources and loads can result in a significant temperature rise in the distribution board. If internal temperatures are too high, they can have major consequences for the continuity and safety of the configuration. It's therefore important that the electrical installation and distribution board, including their components and wiring, are correctly dimensioned to prevent overheating.

An unacceptable temperature rise during operation should be avoided by verifying the distribution board design as per IEC61439-1. The assessment is required for all parts of a distribution board that are not tested, such as an empty enclosure filled with a project-specific mix of devices and wiring. It also applies should there be substantial modification to an existing installation such as additional PV and EV groups.

Eaton's free temperature tool enables you to calculate temperature rise scenarios. It contains data for more than 1200 Eaton devices and enclosures and is based on calculation methods detailed in IEC 61439-1:2021 and IEC 60890:2019.

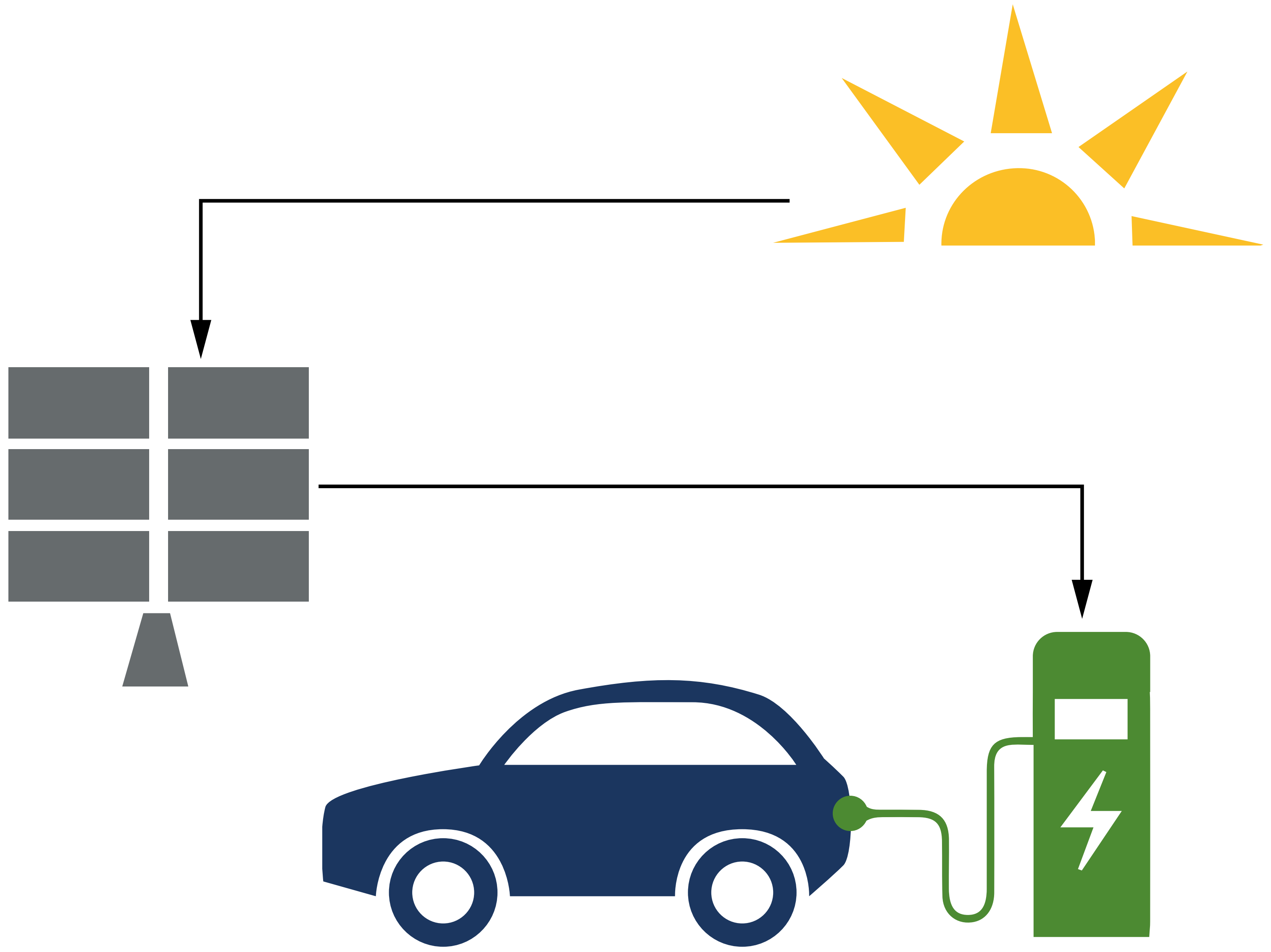
DC fault currents

All new technology including PV inverters and EV chargers contains power electronics which can generate a smooth DC fault current. This effect is caused by converting DC current to AC.

There are four RCD types: AC, A, F and B (as explained in 3.1.3). Conventional type AC RCDs are only able to detect AC residual currents, so are not permitted for protecting circuits with power electronics. Type A RCDs, which are more advanced, can detect both pulsating DC and a very low DC residual current, up to a maximum 6 mA. Type F is a more advanced version of type A, which is designed for circuits with frequency inverters. In the event of a load or inverter fault, if the DC residual current component is greater than 6 mA, a type B RCD must be used. If an RCD is utilised to protect three-phase loads using six-pulse rectification (rectifiers, inverters), a type B RCD must be used.

Type A or B? EV charger specifics

As an alternative to type B, type A in conjunction with DC residual monitoring relay (RDC-DD) can be used, as per IEC 60364-7-722 *Requirements for special installations or locations - Supplies for electric vehicles*. The RDC-DD detects all forms of residual current and, if the DC residual current exceeds 6 mA, this relay ensures load disconnection from the supply. As this functionality is integrated into AC EV chargers provided by Eaton, only type A RCDs are needed.

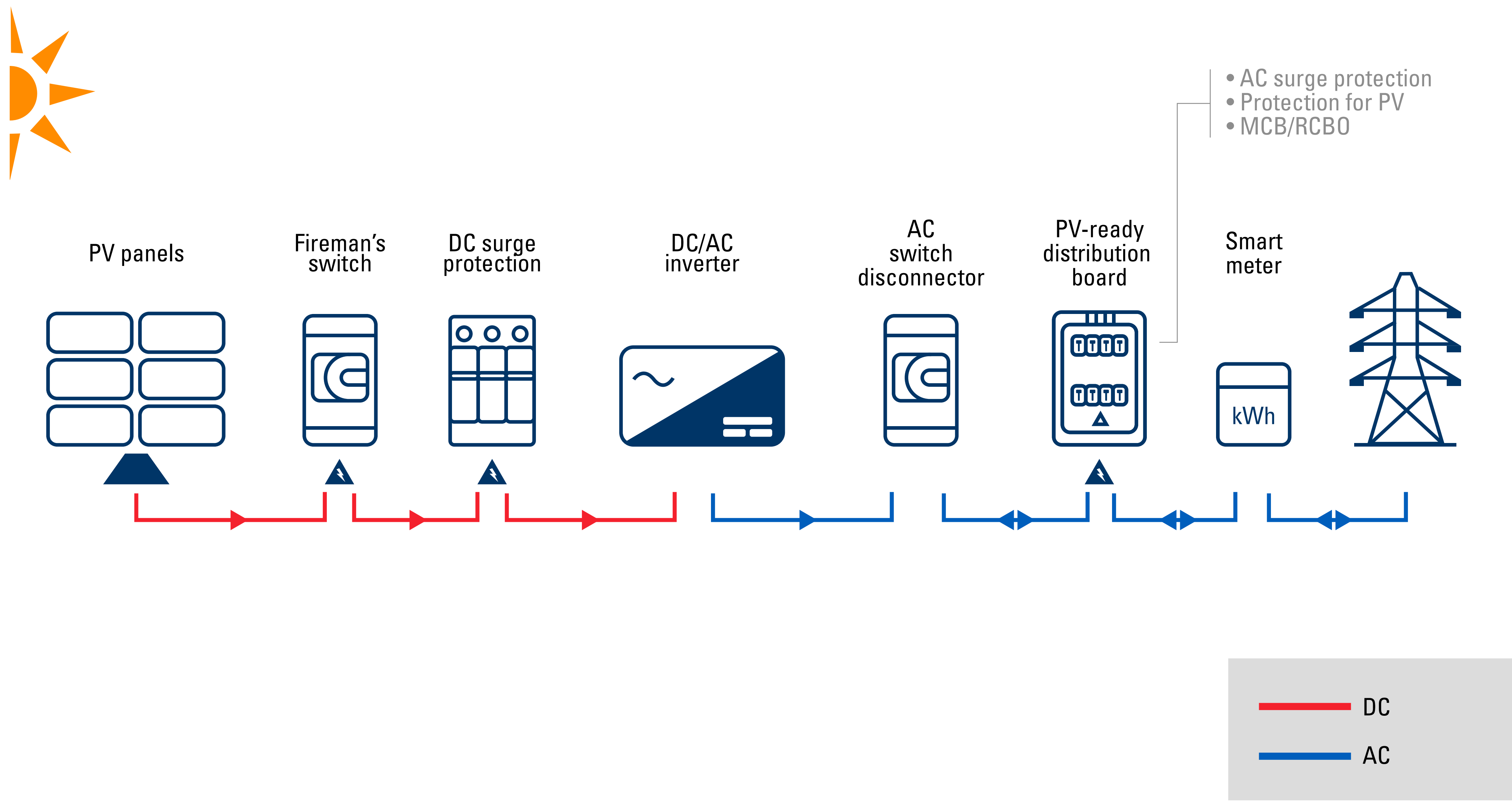


Integrating renewable energy sources and loads

3.3.1 Protection for photovoltaic (PV) applications

Dedicated surge protection devices (SPDs) exist to protect buildings with PV arrays against transient overvoltage events caused by indirect lightning strikes at the DC side of the inverter.

IEC 60364-7-712 *Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems* states that where protection against transient overvoltage is required by IEC 60364-4-44, such protection shall also be applied to the DC side of the PV installation. It also specifies other safety requirements for PV power supply systems, such as an accessible fireman's safety switch as detailed in the dedicated Part 7-712.



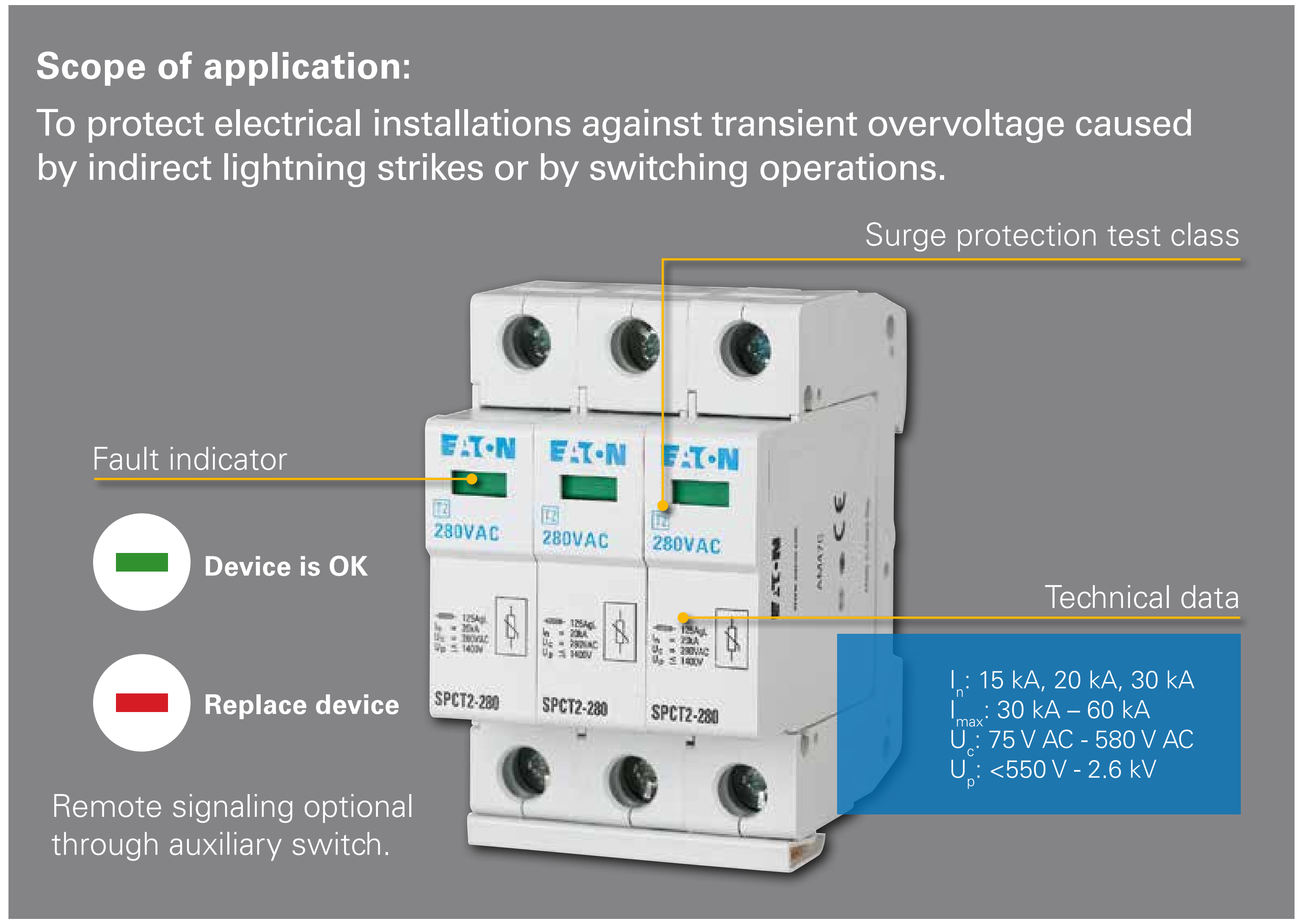


Figure 21. Surge protection device

Building types and applications

'The priorities and design choices required may vary from building type to building type, depending on its use'.

In this section learn about:

- Different building types with specified design priority examples
- Basic conditions for the correct selection of protective measures

Due to various purposes of building use, needed priorities and required design decisions may differ from building type to building type according to its exploitation. The following pages introduce various building types with specified design priority examples.

Residential apartment buildings

Building type: Residential apartment buildings

Basic conditions of IEC 60364 must be applied, including Part 7 *Requirements for special installations or locations*. Additionally, local regulations in individual countries must be followed, mainly with respect to fire conditions, access to measuring devices, etc.

- Electrical installation is operated by unskilled persons (ordinary persons).
- In case a distribution transformer is not close to building, there will not be an issue with high short circuit current value.
- Check of the actual fault loop impedance in the buildings helps, as it is described in the IEC 60364-6 *Verification*.
- Backup protection of main circuit breakers (MCBs) is usually ensured by fuses on grid side.
- Almost all circuit breakers used in domestic installations are MCB types, their serial combinations do not provide good selectivity. But generally, this fact does not create any serious risk.
- Residual current devices (RCD) are mandatory for almost all circuits with outlet sockets up to 32 A and for lightings (see IEC 60364-4-41 *Protection against electric shock*). There are only a few exceptions, for which the RCD can't be used, like circuits, where a nuisance trip of RCD can cause significant damage (refrigerators).
- Use of type A of RCD in the new installations is mandatory in most countries now (more details are described in the Amendments of IEC 60364-5-53 *Devices for protection for safety, isolation, switching, control and monitoring)*.
- Other types of RCDs e.g., type F or B may be installed for protection of circuits with specific loads e.g., circuits using frequency inverters or PV inverters, if RCD is used (see IEC 60364-7-712 *Solar photovoltaic (PV) power supply systems)*.
- It is highly recommended to install arc fault detection devices (AFDD) in locations for sleeping, for children, elderly or handicapped persons, as specified in the IEC 60364-4-42 *Protection against thermal effects*.

MCB	RCCB	RCBO	AFDD+
			Arc fault protection
		Earth fault current protection	Earth fault current protection
Short circuit and overcurrent protection	Earth fault current protection	Short circuit & overcurrent protection	Short circuit & overcurrent protection
Basic fire protection	Basic fire protection	Increased fire protection	Enhanced fire protection
	Shock prevention	Shock prevention	Shock prevention

PROTECTION ↑ / FUNCTIONALITY →

Office buildings

Building type: Office buildings

Electrical installation in office buildings is designed in the same way as for commercial buildings. Additionally, some specifics are necessary to consider:

- Office technology equipment like computers, scanners, printers, copy machines and others are using electronic switched sources ("electronic transformers") which generate certain value of leakage current to protective earth conductor, usually about 0,5 – 2 mA of each.
- High volumes of electrical equipment with relatively small leakage currents create high value of earth leakage current in the common protective earth conductors. However, this in turn can cause unwanted tripping of sensitive RCDs. It then becomes necessary to split 'problematic' circuits into two or more separate circuits that are independently protected by individual RCDs. Alternatively, a larger PE conductor is another option offering additional protection. But this kind of protective measure requires operation of electrical equipment by skilled persons.
- Electrical installation must be designed in a way to be operated by unskilled persons.

Additionally, above mentioned types of installations are using large numbers of fluorescent lamps and LED lightings with incorporated electronic drivers, which generate harmonic currents. In total, individual single phase supplied loads interfere together in three phase feeding cables, what causes an increased value of current in the neutral conductor. Then usually used cables with reduced cross section of PEN conductor are not applicable there, as described in the IEC 60364-5-52 *Wiring systems*.

Note: Eaton's free xSpider software is a helpful tool for evaluating harmonics for lights and other load to ensure correct design of feeding cables.

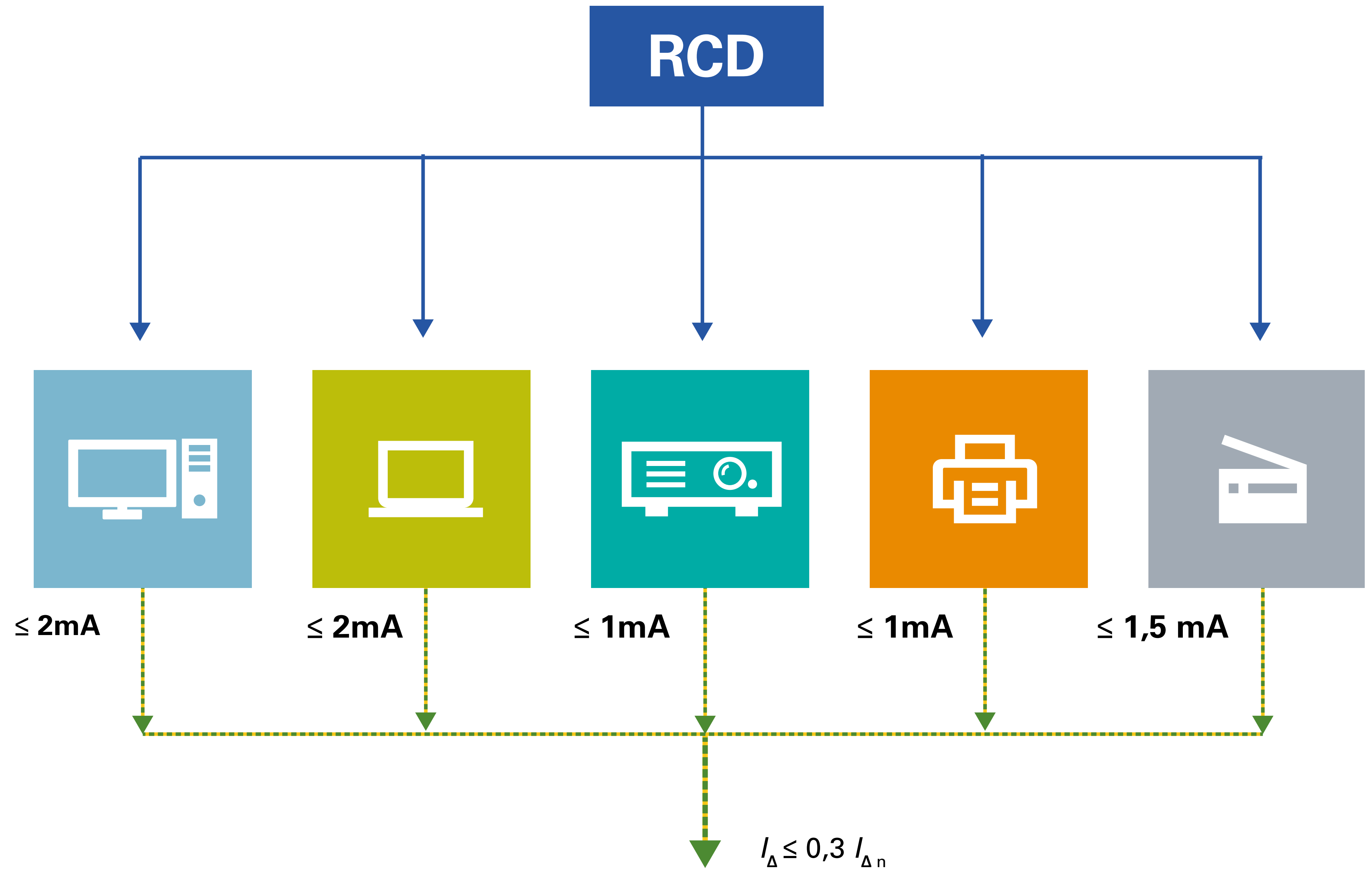
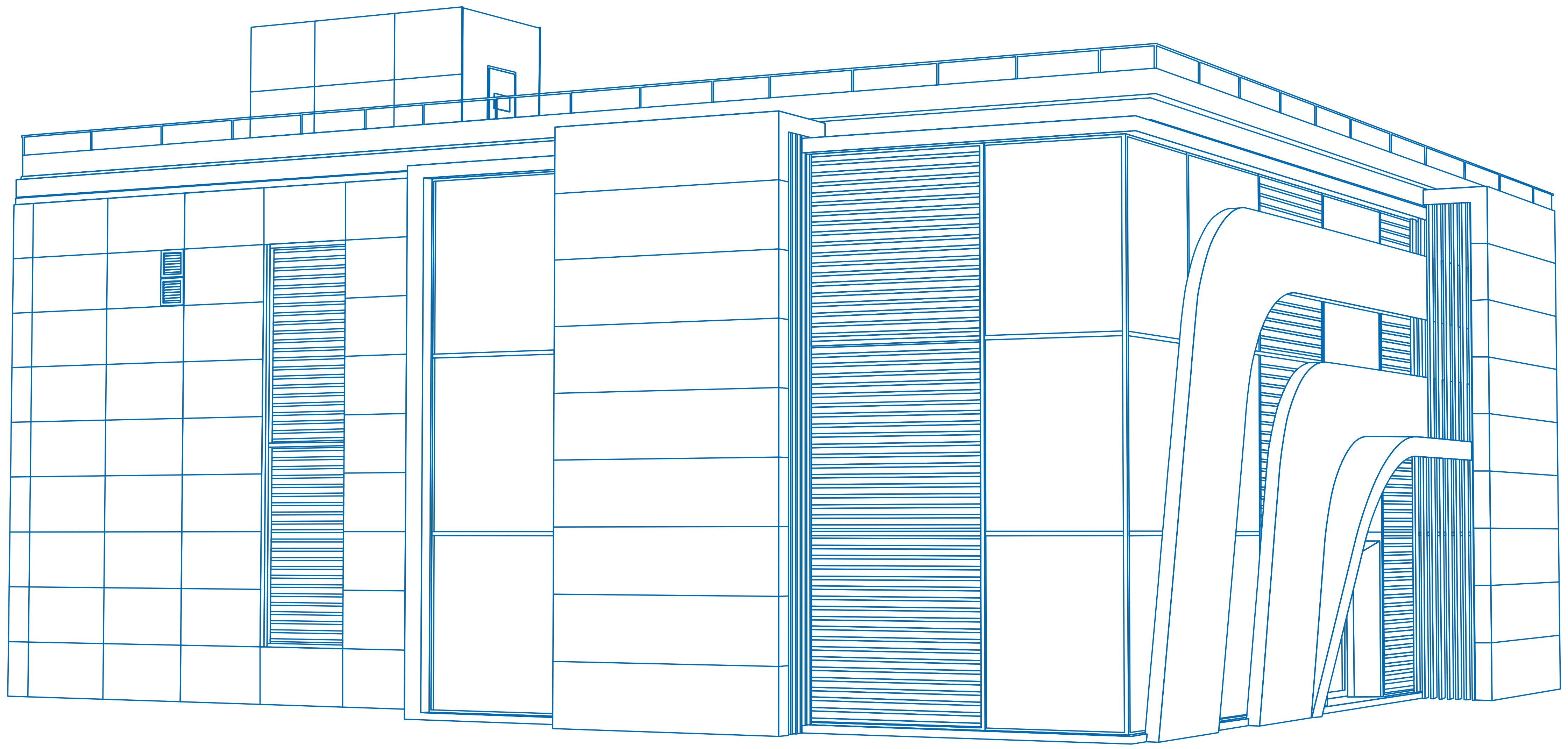


Figure 22. Risk of unwanted tripping of RCD due to high value of leakage current of various office equipment.

Other commercial buildings

Building type: Other commercial buildings (retail, hospitality, education, etc.)

- Smaller commercial buildings are usually supplied from public grid. Connection conditions are specified by local utilities.
- Larger commercial buildings with high power demand use own MV/LV transformer very often which is located inside the building. If this is the case, dry type transformers are usually required to reduce risk of fire inside of building. Short distances inside of buildings cause relatively high short circuit current values in case of fault.
- Correct selection of suitable devices with regard to breaking capacity, backup protection of protective devices and short circuit current coordination of devices and equipment together is a design priority.
- Good selectivity or protective devices ensures that only part affected by fault is disconnected and at the same time the other parts of installation continue with supply without interruption.
- Electrical installation must be designed in a way to be operated by unskilled persons.



Hospitals and medical locations

Building type: Hospitals / medical locations

Critical power infrastructure demands use main supply from the grid and additionally also backup supply sources, which are secured by generators and uninterruptible power supply sources (UPS) to ensure the uninterrupted supply of critical loads in dedicated parts of medical installations.
The IEC 60364-7-710 *Medical locations* describes details about specific requirements for medical locations, especially as follows:

- Any project preparation for medical location and further operation of electrical installation during its use requires very specific know-how.
- Local needs must be well communicated between designer and qualified medical and technical staff.
- Choosing the correct protective devices improves the reliability of the power supply to ensure safety of patients.
- Proper design of designed power and size of backup sources (generators, UPSs), according to real needs.
- Determining short circuit currents, mainly behind powerful transformers, and corresponding selection of suitable protective devices.
- Correct coordination of basic and backup sources in case of emergency, with respect to high enough redundancy.
- IT network with special insulation monitoring devices (IMD) are used for selected circuits, mainly for lamps in operating rooms.
- Proper selection of residual current device (RCD) types. Use of type A or type B is mandatory, AC type is not allowed in any medical locations. High resistance against unwanted trips must be guaranteed by use of suitable types, such as type G for additional protection and type S (selective).
- Surge protection is mandatory due to the high number of devices with sensitive electronics.
- Halogen-free and fire-resistant cables should be used in specified locations, taking into the account the correct design of their overcurrent protection. and medical staff.

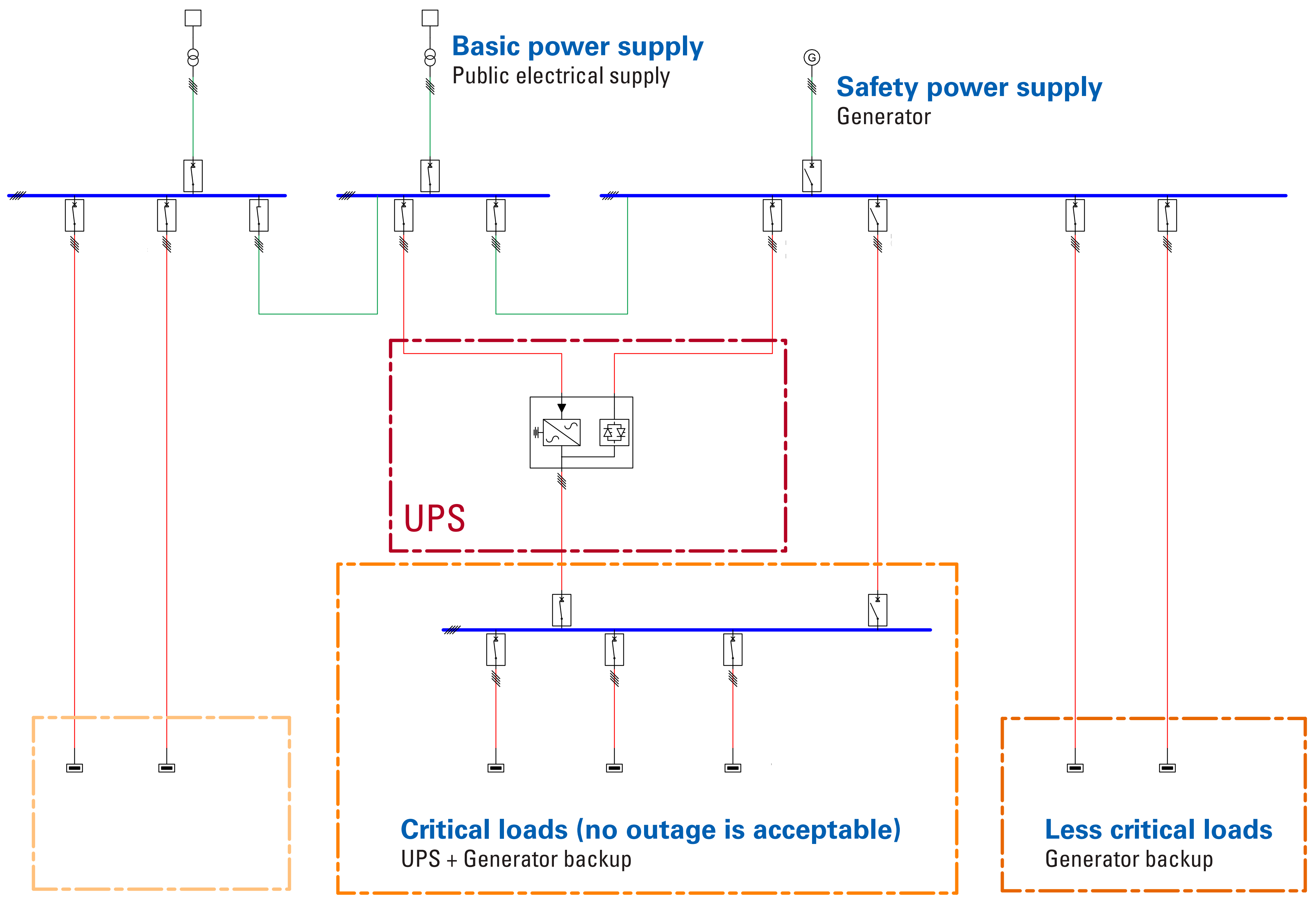
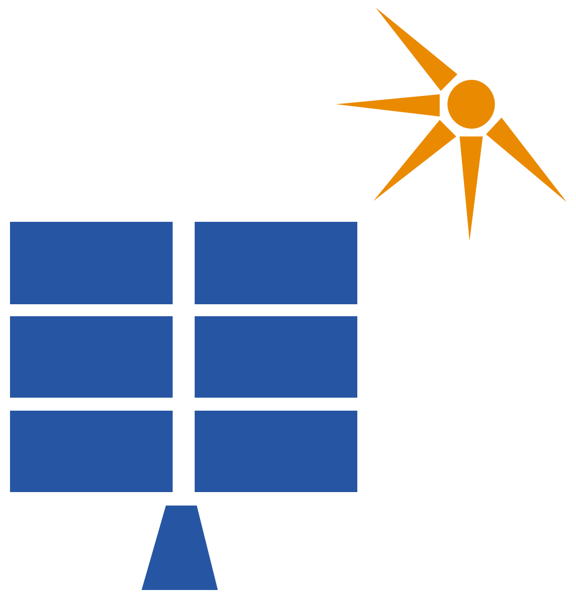


Figure 23. Typical split of main groups of electrical installation in hospital

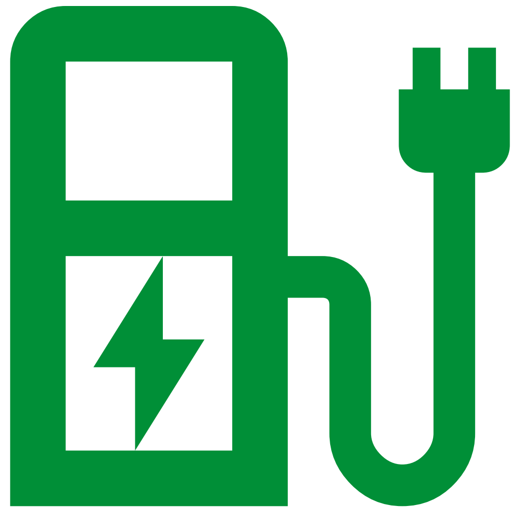
Buildings with PV installations and EV chargers



Application type: Buildings with PV installations

Those planning PV systems must follow IEC 60364-7-712 dedicated to electrical installation of PV systems.

- With respect to actual arrangement, the correct selection of protective devices is important for fire safety. If RCD is used, type B is required (the B+ type which is designed for optimal fire protection). Type B is not required if it is specified by the inverter manufacturer.
- Accessible fireman switches must be installed to ensure safe conditions in the event of fire.



Application type: Buildings with EV chargers

Newly installed EV charging infrastructures or extension to existing installation require a specific design and installation approach.

- The standard IEC 60364-7-712 must be respected.
- Appropriate overcurrent protection has to be applied for each added circuit.
- EV chargers must be protected using a suitable type of RCD. Depending on the EV charger manufacturer's specification, a type A or type B must be used.
- Type A can be used, if EV charger will not generate any DC residual current higher than 6 mA.
- Alternatively, a protected circuit can be fitted with an RCD-DD (Residual Current Detection Device) according to IEC 62955, which will disconnect the EV charger from the mains in the event of a fault.

Generally, if a short circuit current value is high in the installation, designer must manage a proper selection and coordination of protective and switching devices. But on the other hand, such situation creates very good conditions for quick disconnection from source in case of fault. Also, a voltage drop will not be any issue because of low resistance of lines.

Another situation is in the installations with long circuits, where the fault loop impedance is relatively high. Here, the conditions for protection against electric shock must be evaluated carefully and voltage drop limits for selected applications should be observed too.

Additional resources and knowledge checklist

'Eaton offers a range of additional resources to help you plan your building's electrical safety and compliance strategy. We're also always available to meet online or in person at your convenience and continue the conversation around helping you meet your requirements.'

In this section learn about:

- Further Eaton advice and information available
- Checking your understanding of buildings electrical safety fundamentals

5.1

Buildings electrical safety knowledge checklist

Review what you've learned from this guide.

5.2

Access further resources

Read up on more in-depth information around buildings electrical safety or get in touch to find out more.

Additional resources and knowledge checklist

5.1 Buildings electrical safety knowledge checklist

Identify any gaps in your building's electrical safety knowledge with our handy checklist. Then close them by reviewing the relevant guide section or talking to an Eaton expert.

S1: Buildings electrical safety essentials

Do you know why buildings electrical safety matters? Are you familiar with hot current topics influencing electrical safety strategy? And do you know the basics of the regulatory framework protecting people and assets?

S2: Understanding system approaches

Have you understood IEC 60364 in greater detail and the 12-step approach to ensuring low-voltage installation compliance? Are you clear about low-voltage switchboard conformity to IEC 61439? And the safety implications for installations featuring new technology?

S3: Protecting people, property, equipment and data

Are you aware of the wide range of protective devices available and how they relate to the standards? Do you know the factors to consider when designing LV switchboards? And how to address safety specifics arising from the growth in renewables?

S4: Regulations appendix

Are you up to speed on the most relevant sections of IEC 60364 for LV installation designers? And the verification protocols for electrical installations both when they are new and during their lifetime?

Additional resources and knowledge checklist

5.2 Access further resources

Eaton offers a range of additional resources to help you plan your buildings electrical safety and compliance strategy. We're also always available to meet online or in person at your convenience and continue the conversation around helping you meet your requirements.

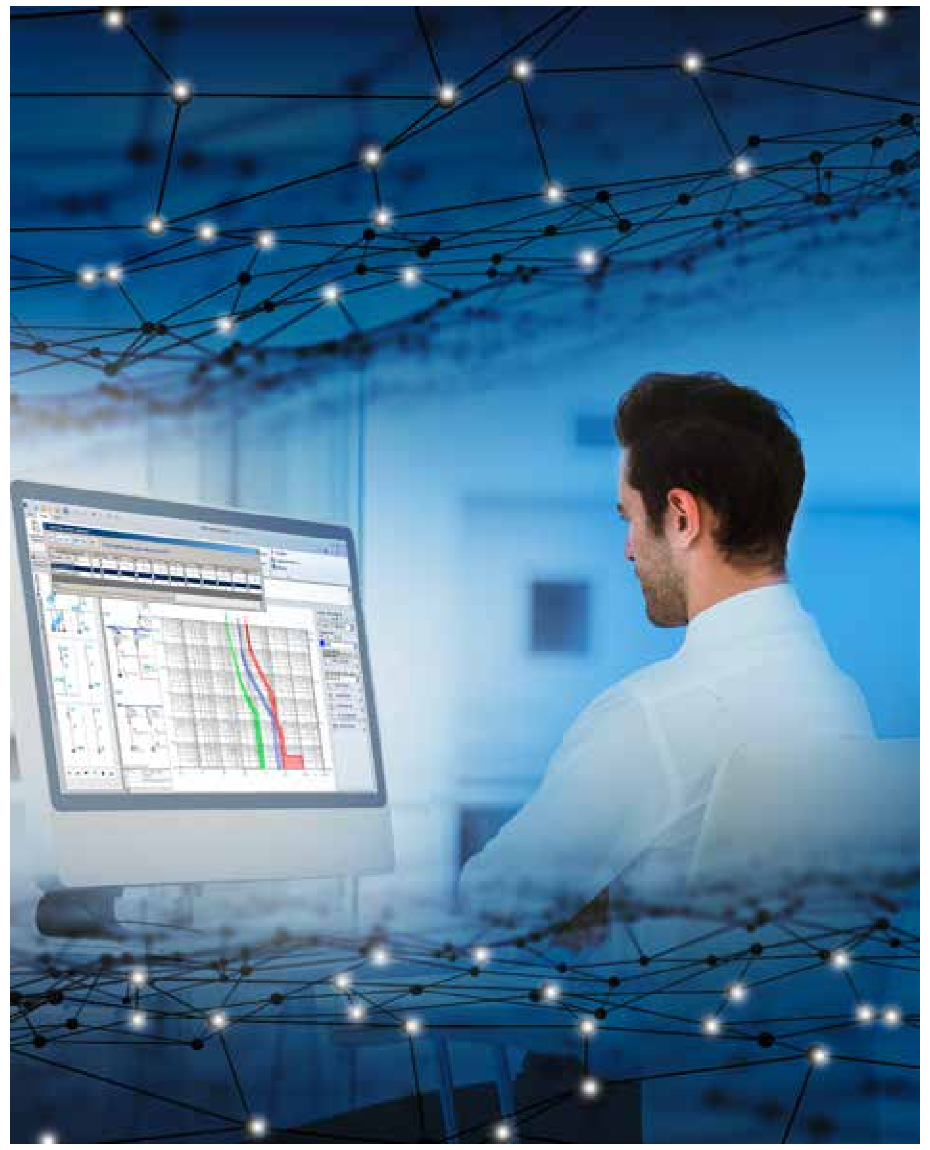
Consulting Applications Guide according to IEC standards, Low-voltage Volume

The comprehensive, highly detailed Consulting Application Guide, Low-voltage Volume, is designed to help electrical consultants, electricians and power system design engineers with the layout and specification of equipment.

Drawn up by experienced experts and containing many products, services and application-specific information, the guide covers standards for electrical installations (IEC 60364 series) and other product standards.

Simplifying low-voltage networks installation with Eaton xSpider

Designing an installation to ensure adherence to current standards and acceptable levels of arc flash risk is made significantly easier by using Eaton's xSpider software. This performs calculations at all design stages and optimises design for all common installation types ranging from those in homes to very complex, multi-source industrial settings.



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