UNIVERSITÀ DEGLI STUDI DI TRIESTE

dipartimento di ingegneria e architettura

Electrical systems design – part II

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Fundamentals of Modern Power Systems

IP ratings

IP rating

Electric and electronic equipment deteriorate or malfunction when water or dust enters the device. The IEC has developed the ingress protection (IP) ratings, which grade the resistance of an enclosure against the intrusion of dust or liquids. The ratings are widely used throughout industry.

In recent years, many consumers have taken an interest in smartphone features that include resilience against liquid and dust. However, it can be difficult to assess the meaning of terms such as waterproof or water-resistant when used for marketing purposes.

IEC 60529 has been developed to rate and grade the resistance of enclosures of electric and electronic devices against the intrusion of dust and liquids. It also rates how easy it is for individuals to access the potentially hazardous parts within the enclosure.

The standard, uses the IP code to rate the degrees of protection offered by the enclosure of electrical equipment with a rated voltage of a maximum of 72,5 kV. The standard also defines the tests to be performed to verify that the enclosure meets these requirements.

IP rating

The IP code is composed of two numerals:

- The first numeral refers to the protection against solid objects and is rated on a scale from 0 (no protection) to 6 (no ingress of dust).
- The second numeral rates the enclosure's protection against liquids and uses a scale from 0 (no protection) to 9 (high-pressure hot water from different angles).

IP rating

1st numeral - solid foreign objects

0	No protection
1	Protected against solid foreign objects of 50 mm Ø and greater
2	Protected against solid foreign objects of 12,5 mm Ø and greater
3	Protected against solid foreign objects of 2,5 mm Ø and greater
4	Protected against solid foreign objects of 1,0 mm Ø and greater
5	Dust-protected
6	Dust-tight

Example:

IP 65 → 6: Dust-tight; 5: Protected against water jets

2nd numeral - water

0	No protection	-
1	Protected against vertically falling water drops	Vertically falling drops shall have no harmful effects
2	Protected against vertically falling water drops when enclosure tilted up to 15°	Vertically falling drops shall have no harmful effects when the enclosure is tilted at any angle up to15° on either side of the vertical
3	Protected against spraying water	Water sprayed at an angle up to 60° on either side of the vertical shall have no harmful effects
4	Protected against splashing water	Water splashed against the enclosure from any direction shall have no harmful effects
5	Protected against water jets	Water projected in jets against the enclosure from any directions shall have no harmful effects
6	Protected against powerful water jets	Water projected in powerful jets against the enclosure from any direction shall have no harmful effects
7	Protected against the effects of temporary immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time
8	Protected against the effects of continuous immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under conditions which shall be agreed between manufacturer and user but which are more severe than for numeral 7
9	Protected against high pressure and temperature water jets	Water projected at high pressure and high temperature against the enclosure from any direction shall not have harmful effects

MV-LV substations

Definitions and classification

Substations transform voltage from a level to a different one, distribute power from one or more input lines to one or more output line, and several other important functions. A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two different transmission voltages. They are a common component of the infrastructure.

MV/LV transformation and distribution substations are of particular importance. They are the complex of conductors, equipment and machines designed to transform the voltage supplied by the MV distribution lines to the power values of the LV lines, also implementing sorting between the outgoing lines.

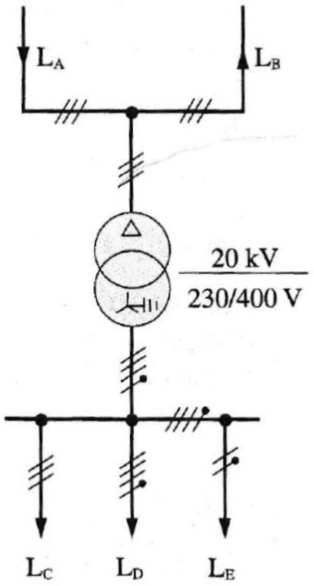
Substations are divided into:

- *Public*, owned by the electricity distribution company; they are used to supply private LV users with nominal voltages of 230 V single-phase and 400 V three-phase;
- *Private*, owned by the user; they are used to supply private systems with high installed power (approximately > 200 kW), with electricity supply in MV.

In private substations, the user must provide specific rooms for the installation of the measuring group and the equipment under the supplier's responsibility.

Definitions and classification

Simplified diagram of distribution and transformation substation



Floor plan of a user substation

A Distributor room at the user's premises

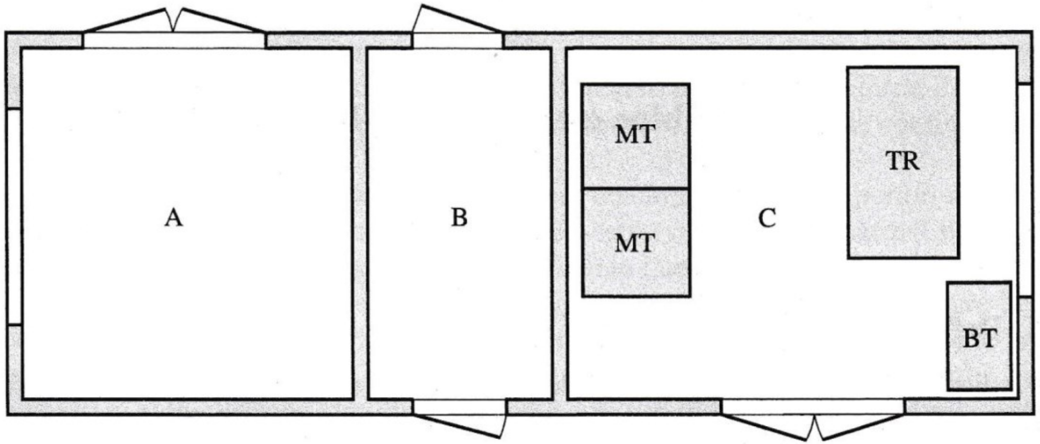
B Measurement room

C User room

TR Transformer

MT MV equipment

BT LV switchboard



Connection of MV/LV substations to the distribution network

In the MV room of the distributor there are at least two compartments, each equipped with a switch-disconnector with interlocked earth knives (for grounding the line in case of work on it):

- compartment dedicated to receiving power from the network via the MV line;
- compartment dedicated to delivering energy to the user (equipped with measurement transformers for powering the measurement group, located in the measurement room).

For connection to ring MV lines, the addition of a third compartment is necessary, in order to create the in-out connection of the MV line (shown in detail below).

The measurement group includes:

- Active energy meter (Wh), with indication of the power flow direction;
- Maximum power drawn indicator (P_{max});
- Reactive energy meter (varh).

Connection of MV/LV substations to the distribution network

General scheme for the connection of passive medium voltage users

D Distributor room at the user's premises

M Measurement room

U User room

SL Compartment (cell) per line

SC Delivery compartment (cell)

C Point of Common Coupling

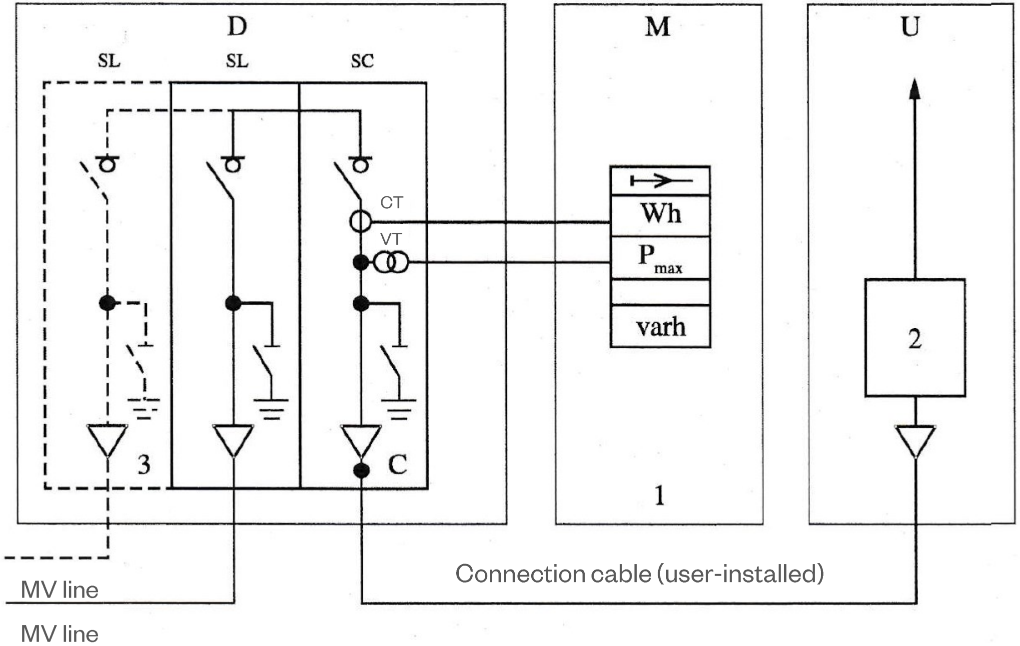
1 Measurement group

2 General protection device of the user

3 Compartment for in-out connection

CT Phase current transformer

VT Voltage transformer



Connection of MV/LV substations to the distribution network

Diagram of the MV side of a user substation with single riser (single transformer) – room U of t previous figure

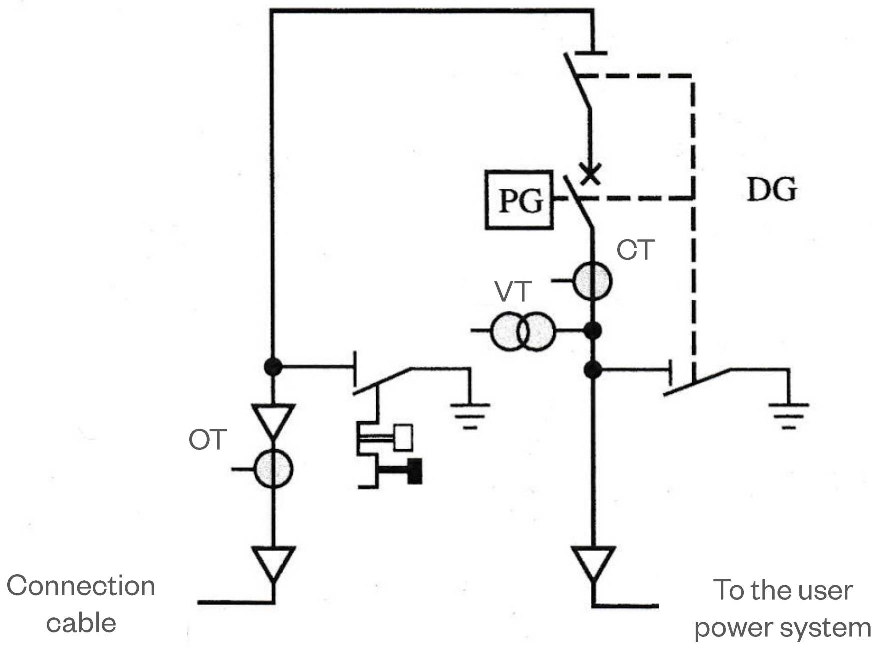
CT Phase current transformer

OT Homopolar current transformer

VT Voltage transformer

PG General protections

DG General protection device



Connection of MV/LV substations to the distribution network

At the entrance to the user room there is a lockable earthing switch with a key for grounding and short-circuiting the connection cable. This is necessary for carrying out electrical work upstream of the user's sectioning device. The disconnection and safety of the connection cable must be requested from the distributor, and for safety the grounding switch on the user side must be operable only with a key given by the user to the distributor. This key is released and given to the user only after the earthing switch on the distributor side has been closed, so as to avoid earthing the user side with the connection cable still live.

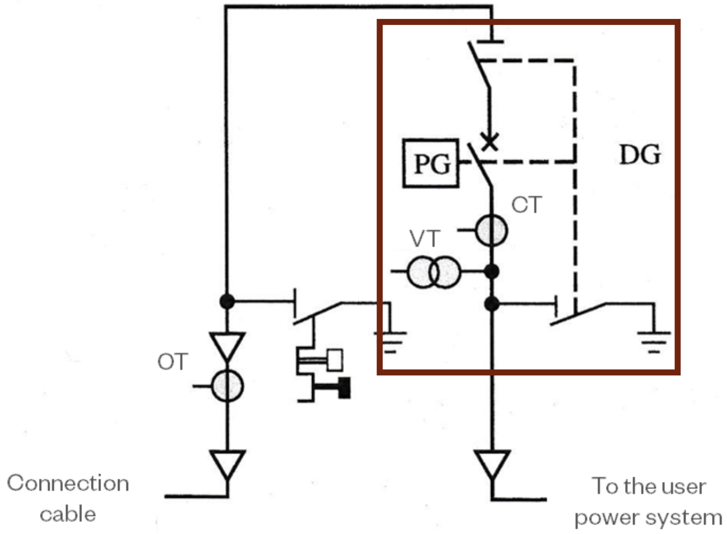
The earthing switch on the user side can be omitted if earthing and safety is carried out with mobile means, while always respecting the sequence of the operation. This solution is feasible only when the head of the cable is easily accessible.

Connection of MV/LV substations to the distribution network

The *general protection device* (DG) of the substation is installed in the user room, having the task of separating the user system from the power grid and allowing selective coordination between the distributor's and user's protections.

The figure shows the standard solution, consisting of a line disconnector with interlocked earth knives and a breaker triggered by a proper set of protection relays.

A cheaper solution is also permitted, consisting of a switch-disconnector with associated fuses, applicable only to passive users with a single transformer with a maximum power of 400 kVA and nominal fuse current of up to 25 A (additional conditions may apply, depending on the standards of the specific state).

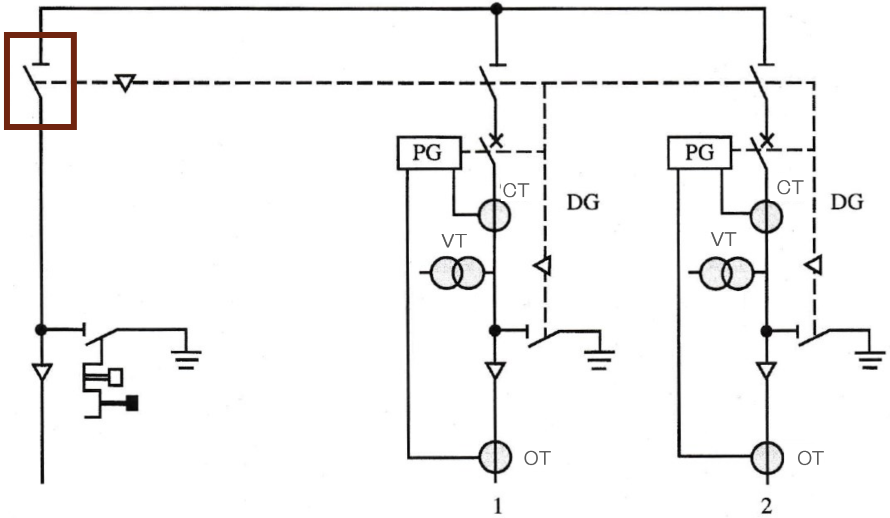


Connection of MV/LV substations to the distribution network

The DG breaker intervenes, in the event of a fault in the user system, triggered by the protection relays which, together, constitute the general protection (PG) of the cabin. The acronym SPG instead indicates the general protection system, including all the PGs, CTs and TVs for powering the relays and the related protection and release circuits.

In the case of cabins with multiple transformers, in the past it was customary to install a general breaker upstream of all the MV power supply uprights of the transformers. Nowadays it is allowed to replaced this general breaker with a disconnector interlocked with the DGs of the individual risers (see figure), in the case of only two uprights and in compliance with some additional indications.

CT Phase current transformer
VT Voltage transformer
OT Homopolar current transformer
PG General protection
DG General prot. device
1-2 User MV risers



Typical electrical substations diagrams

Some typical diagrams of private MV/LV substations are shown. The MV measurement group is not shown in the diagrams, as it is the responsibility of the electricity supplier.

MV side diagrams

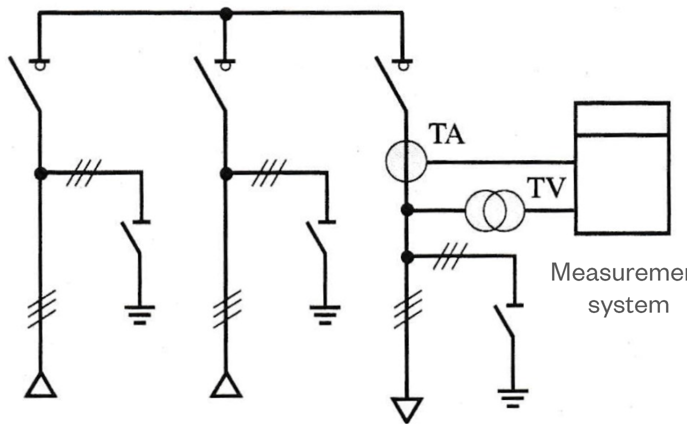
The MV side configuration of a private cabin depends on several factors, such as the type of power supply, the type of protection and switching equipment, and the number of transformers used.

Depending on the type of power supply, substations are divided into:

- substations powered by a *terminal line* (which does not continue beyond the cabin itself);
- substations powered by a *ring line*, in which an in-out device consisting of two load disconnectors must be installed, to allow the substation to be powered by one or both lines and to maintain the continuity of the ring even when the substation is disconnected.

Typical electrical substations diagrams

User substation powered by a ring line



Measurement system

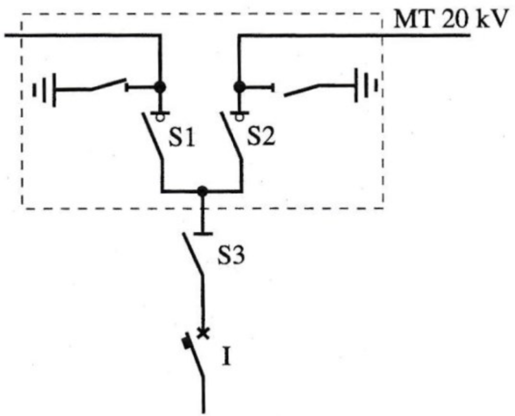
MV incoming lines

To user side

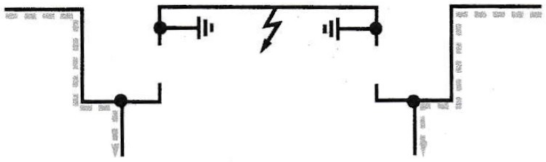
S1, S2: In-out load disconnectors

S3: Substation disconnector

I: substation main breaker



Configuration in case of failure on a line between two substations



Subs. A

Subs. B

Configuration in case of exclusion of a substation

Subs. A

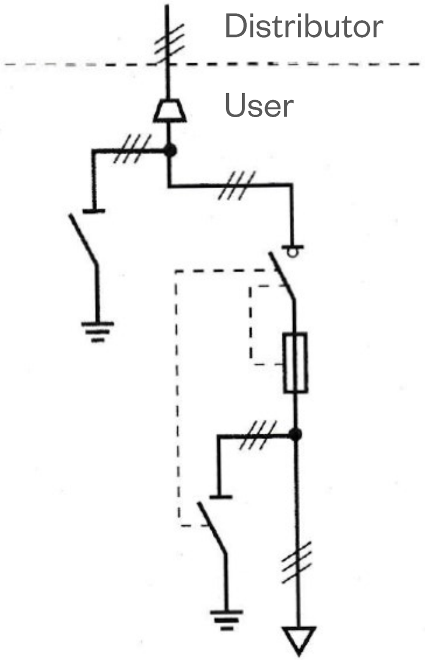
Subs. B

Typical electrical substations diagrams

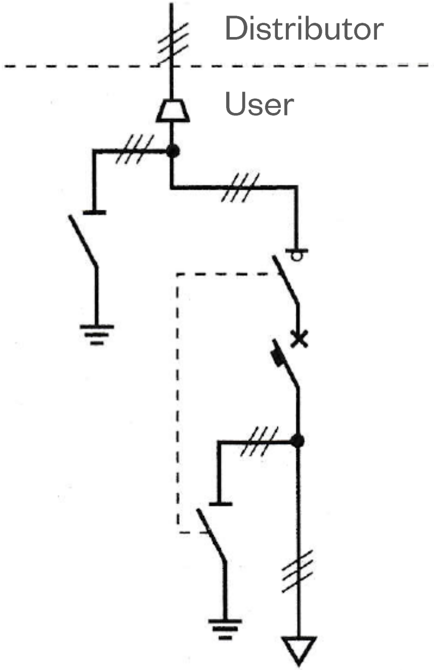
As regards the protection and switching equipment to be installed on the MV side:

a) Switch-disconnectors for switching and fuses for protection, in the case of low-power cabins; in this case the fuses must be interlocked with the disconnector to actuate the complete downstream disconnection downstream even in the case of a single single-phase fault;

b) Disconnector and breaker in the case of high-power cabins.



Solution a)



Solution b)

Typical electrical substations diagrams

The number of transformers installed in the substation determines the number of switching and protection equipment on the MV user side. It is common to use modular substations, made with standardized compartments (cells), to adapt the solution to the individual application.

1, 2: Power lines cells (in-out)

3: Measuring group cell

4: Cell of the main breaker-disconnector

5: Transformer control and protection cell (external transformer)

6: Cell for the output of the power supply line of another user MV side

7: Transformer control and protection cell (transformer inside the panel)

8: Cell for an integrated transformer

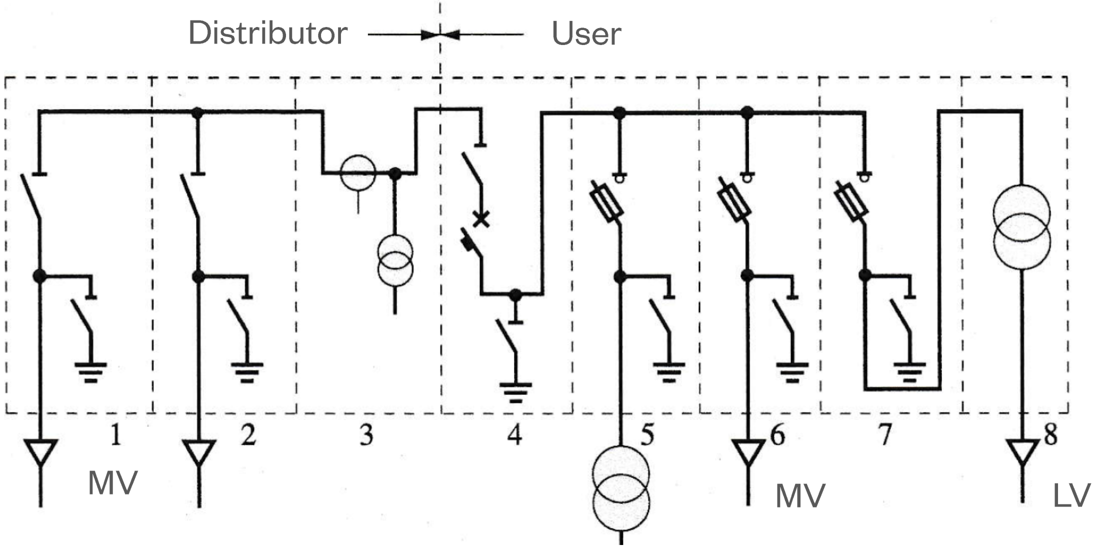


Diagram of a substation composed of modular metal compartments

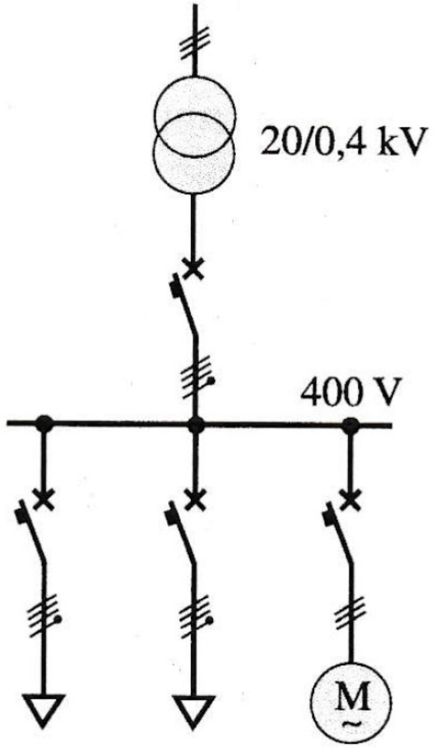
Typical electrical substations diagrams

LV side diagrams

The LV side configuration of a private transformer and switching substation depends on several factors, including the number of transformers, the number and arrangement of loads, the continuity of service requirements, and the short-circuit current values.

Single transformer and single starting line

Single transformer and multiple outgoing lines (*simple radial scheme*)



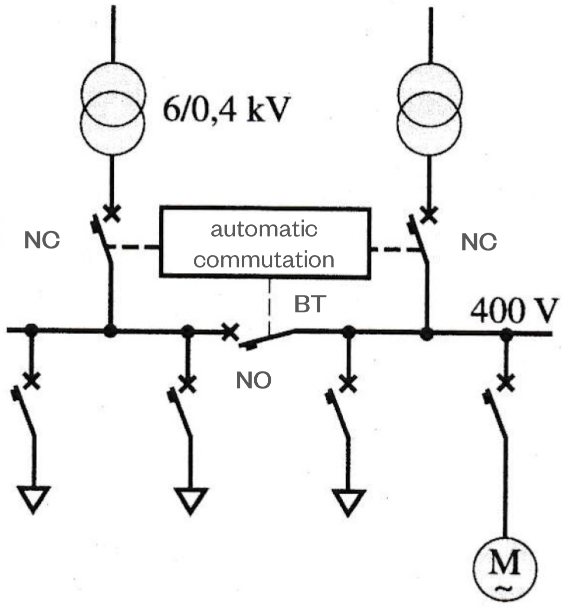
Typical electrical substations diagrams

In the case of multiple transformers, the most commonly used schemes are the following. They allow obtaining certain continuity of service performances.

Double radial scheme

Transformers always operate with the busbar tie (BT) open. In the absence of a transformer (fault or maintenance) the tie is closed ensuring power supply also to the loads on the other busbar.

By sizing each transformer for the maximum power of the system it is possible to operate at full load even with a disconnected transformer. Otherwise, it is necessary to evaluate the power of the users that have greater needs in terms of continuity of service, size the transformer on these, and disconnect the other users in case of need.



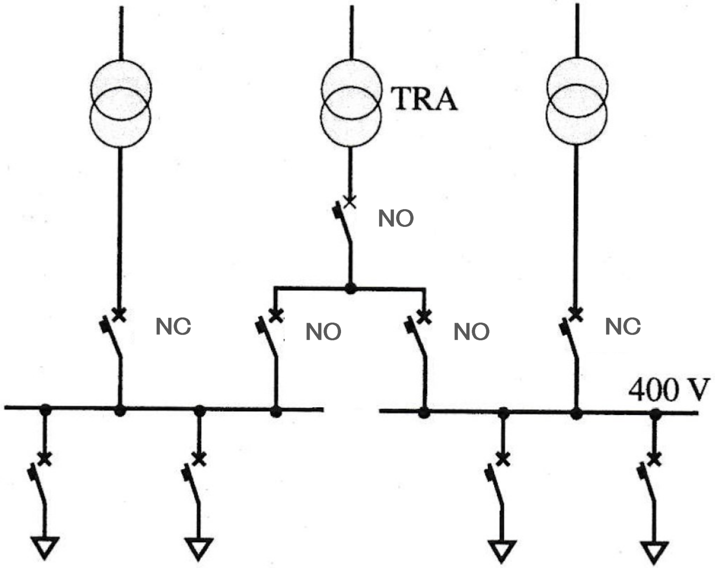
Typical electrical substations diagrams

2+1 scheme

This is a particular case of application of the *n+1 redundancy scheme*. An auxiliary transformer (TRA) is installed but is not normally used.

It is therefore possible to implement different combinations depending on the needs, including power supply from the TRA alone if it has sufficient power.

The number of possible combinations (between power of the loads, of the transformers, and of configurations for the cabin) is higher than the previous case, therefore the sizing of the cabin becomes more complicated and mainly follows criteria of continuity of service to the essential loads of the user system.



Typical electrical substations diagrams

Generally, disconnectors are not used on the LV side, as the same function is performed by breakers. The devices are usually air-insulated and are installed in various types of metal switchboards. Depending on the case, the following are used:

- Automatic breakers with thermo-magnetic or electronic maximum current relays;
- Switches with fuses.

Measurement apparatuses

The measurement of active and reactive energy for billing purposes is done on the MV side, so the instrumentation installed on the LV side is limited in most cases to voltmeters and ammeters (more rarely power meters).

Being in LV, voltametric instruments use direct insertion. On the contrary, ammeter coils usually require indirect insertion using current transformers, given the high current value on the LV side.

A particularly high precision value is not required for these instruments, since they do not perform any function other than that of visual indication.

Electrical distribution systems in the industrial sector

MV distribution systems

In the case of private electrical systems, MV distribution concerns the power supply of the transformation substations present in the system by means of MV lines .

The problem of designing a MV distribution arises when the distribution is carried out with the *approach based on load centers*, that is, when multiple MV/LV substations are installed, each supplying a certain number of loads with their own LV networks.

When, on the other hand, the MV/LV transformation is concentrated in a single substation, we speak of *centralized distribution approach*, and the only MV line is the one that supplies the substation.

The choice between the two types of distribution depends mainly on the value of the installed power, the extension of the area where the loads are located, the needs for continuity of service, and the cost of the system.

MV distribution systems

A load centers' distribution, although more expensive, allows:

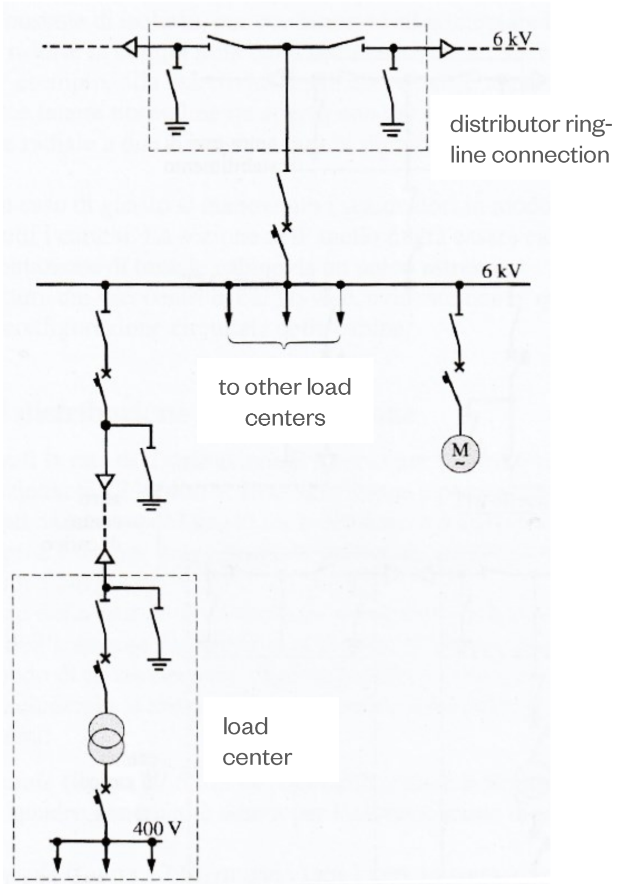
- to reduce the extension of the LV distribution network, by positioning the cabins in a barycentric position with respect to the load zones;
- to separately supply the different systems into which the overall power system can be broken down, adapting the characteristics of the supply for each load zone;
- to obtain greater flexibility and continuity of service;
- to be able to expand the system more easily, by installing other substations.

MV distribution systems

Load centers distribution with radial MV network

This is the simplest scheme. The various load centers (area substations) and any MV users are radially powered, each with its own line, by the MV busbars at the point of delivery of the plant.

The drawback is the poor continuity of service, given that a fault in the MV busbars or in the upstream system compromises the power supply of the entire complex. Furthermore, each load center is powered by a single line, which in the event of a fault puts the entire area served by the single substation out of service.



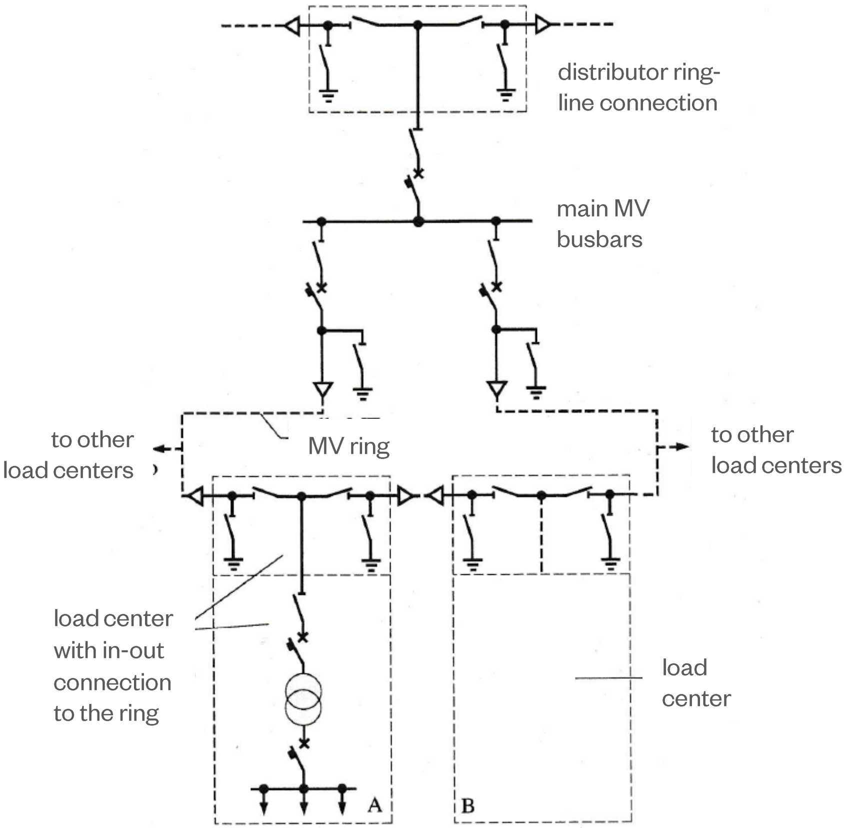
MV distribution systems

Load centers distribution with ring MV network

This scheme improves the continuity of service of the system compared to the previous one. All the load centers and any MV users are connected to a ring line by an in-out system, starting from the main MV busbars. In this way it is possible to guarantee the power supply to all the load centers even in the presence of a fault on a section of the ring.

Often, to reduce the complexity of the protections, it is common to keep one of the ring disconnectors always open, thus creating a radial structure with two lines. In the event of a fault, the disconnectors are operated to exclude the faulty portion and re-power all the load centers.

The ring must be sized for the worst load condition, with power supply from a single side of it.



LV distribution systems

For private systems, the LV distribution network is used to supply single-phase and three-phase users, operating at 230/400 V. It develops from the electric power meter for systems powered by the public LV network, and from the LV substation switchboard for systems equipped with their own.

The most commonly used systems are TT for the first case and TN-S for the second.

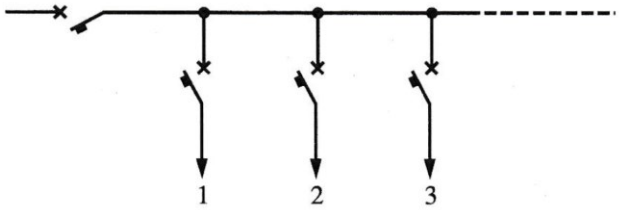
The configuration of the distribution network depends on numerous factors, such as the planimetric development of the system, the need for continuity of service, selectivity with respect to faults, the power and operating mode of the users, the calibration of the protections, the cost of the system.

Excluding the ring distribution, which is rarely used for LV networks, the solutions examined below can be obtained.

LV distribution systems

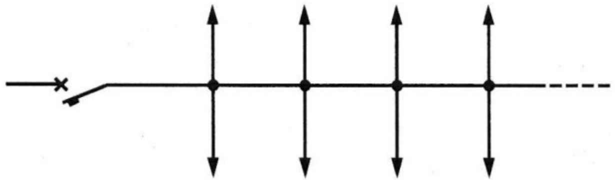
Radial distribution

Each user is powered by its own line starting from the general switchboard; it is suitable for powering a few high-power loads.



Dorsal distribution

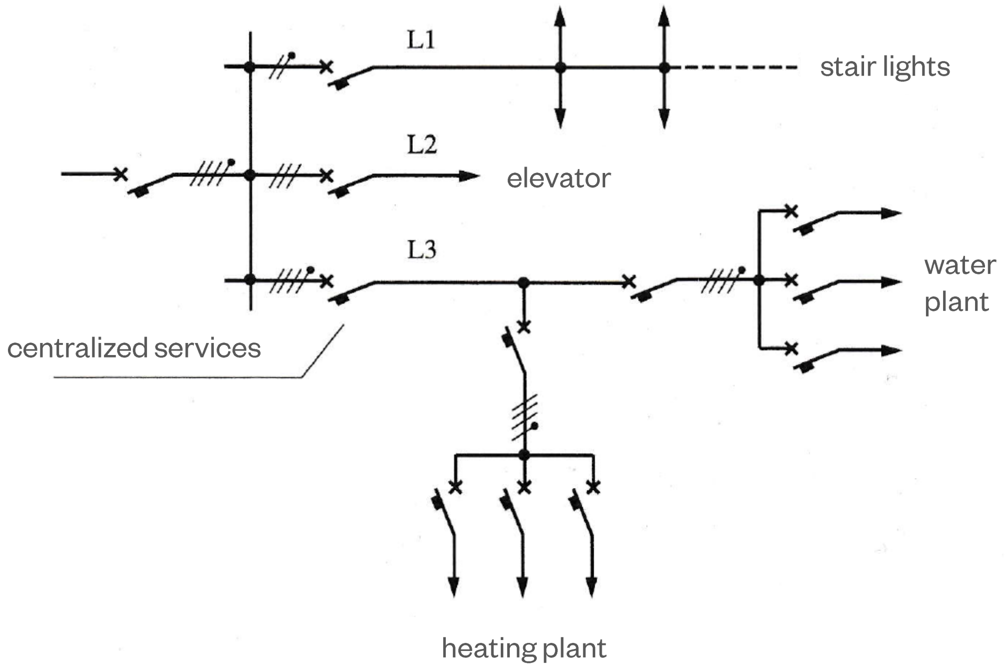
All the loads are powered by a single line, to which all the terminal circuits lead; it is used to power many small power loads operating simultaneously (for example the lighting fixtures in a stairwell).



LV distribution systems

Mixed distribution

Some loads are fed individually and others in groups, with a backbone line; this is in practice the most used system.



LV distribution systems

About the performance offered by the various systems, the following elements can be taken into consideration:

- *Continuity of service*, which is minimal for radial distribution, since a fault on a line interrupts the operation of a single user;
- *Identification of faults*, which is maximum for radial distribution, since the intervention of the protection allows the user or the faulty line to be easily found;
- *Complexity and cost of the system*, for which the backbone distribution is favored, because allows many users to be powered with a single line (the radial instead involves the laying of multiple cables);
- *Use of the cables' ampacity*, poor in the case of radial power supply of low-power loads (due to the minimum constraints on the cross-sections).

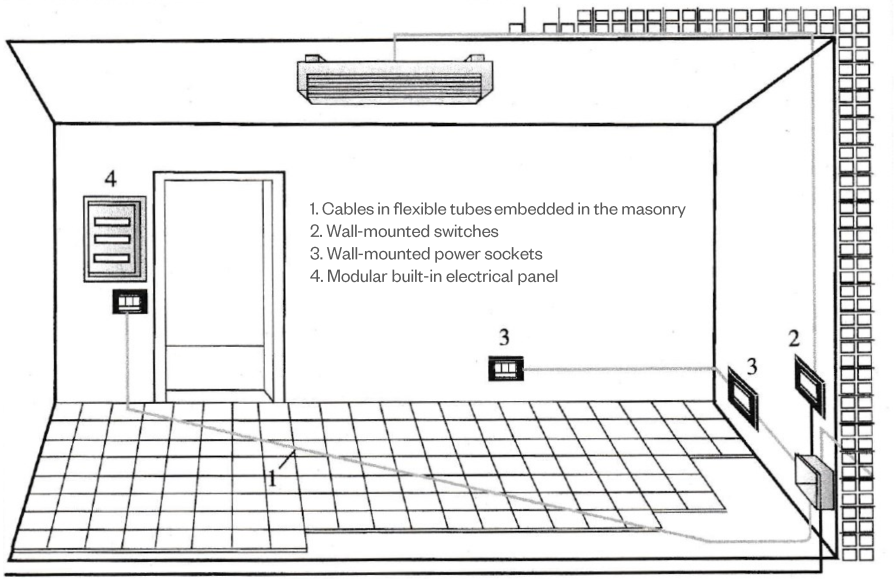
Implementation methods for LV distribution

LV distribution systems are built in various ways, which depend on the way the conduits and the electrical appliances are laid and the installation environments.

Systems with conductors inside protective tubes

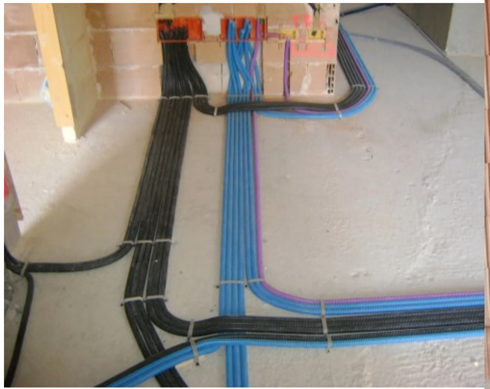
The conductors are laid inside protective metal or plastic tubes. The joints are made with special junction boxes and other accessories.

The tubes can be embedded in the masonry of walls, ceilings and floors (widely used in the civil sector), or the tubes can be exposed, directly fixed to the walls or ceiling (used in the industrial sector for low-power applications, or in the civil sector for systems with minimal aesthetic requirements).



Implementation methods for LV distribution

Systems with conductors inside protective tubes



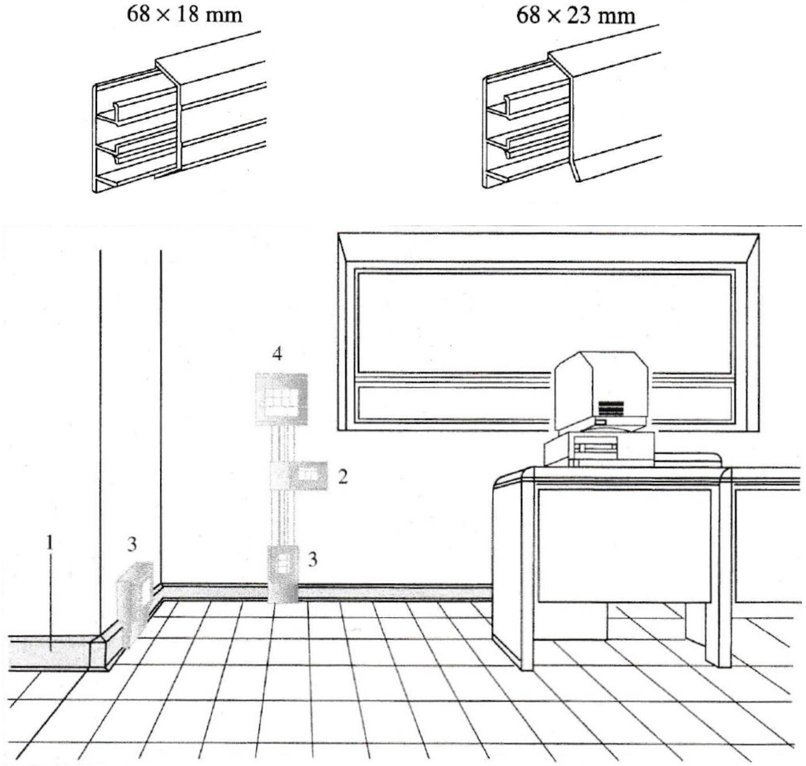
Implementation methods for LV distribution

Systems within exposed ducts

The conductors are laid inside plastic ducts applied to the walls which, in the horizontal sections, can act as skirting boards. The ducts can be divided into several compartments, to allow the installation of different types of services (electrical system, TV, wired network, etc.).

The advantages are the ease of expansion, maintenance and repair and the speed of installation. The disadvantages are the difficulty of supplying power to users far from the walls, the difficulties in painting the walls, and the aesthetic aspect.

They are widely used in the tertiary sector.



Implementation methods for LV distribution

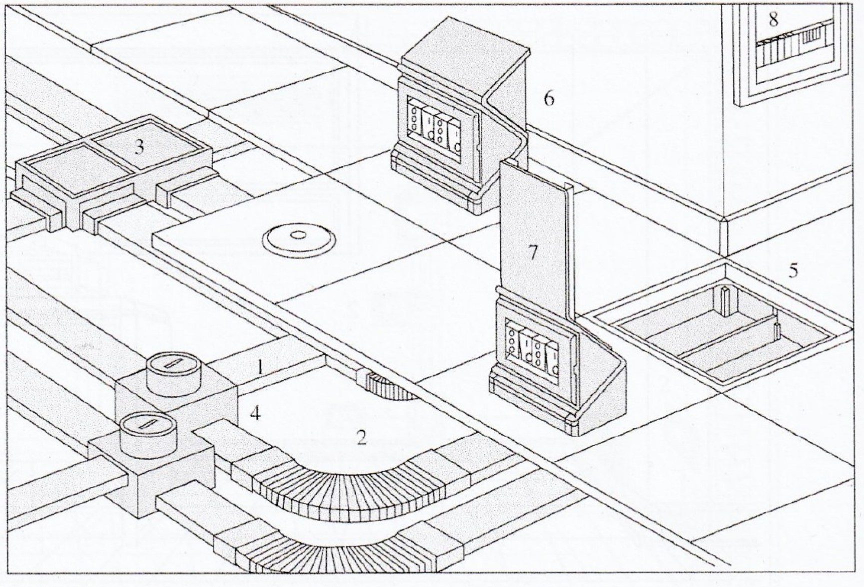
Systems within exposed ducts

Implementation methods for LV distribution

Underfloor systems

Used in offices and large rooms with users far from the walls. The conductors are laid in underfloor ducts (embedded in the subfloor or laid in cavities) and emerge on the surface with turrets containing the sockets, telephone and other services. It can be integrated with other types of systems.

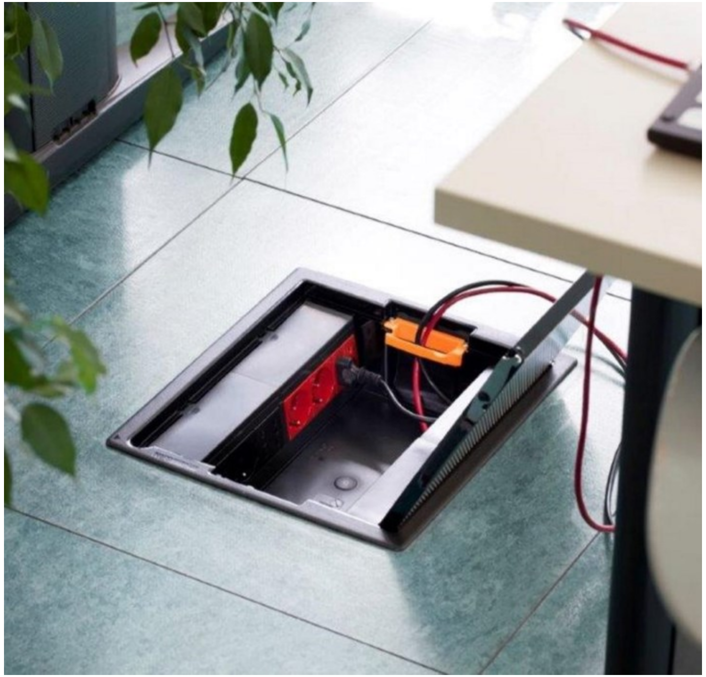
The advantages are greater when the installation is carried out in the cavity of a raised floor, and consist in the ease of modifying the routes, the availability of electrical terminals in points far from the walls, the adaptability to the movement of furniture and workstations. The disadvantage is given by the floor space of the turrets.



1. Rigid ducts
2. Flexible fittings
3. Junction, branch and connection boxes
4. Junction and branching elements
5. Multi-section boxes
6. Turrets
7. Plates for mounting additional sockets
8. Electrical distribution panel

Implementation methods for LV distribution

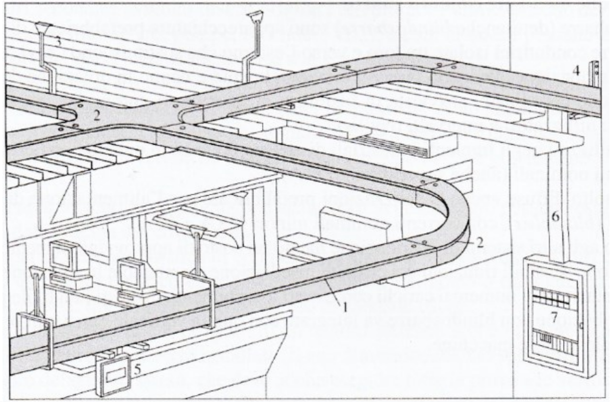
Underfloor systems

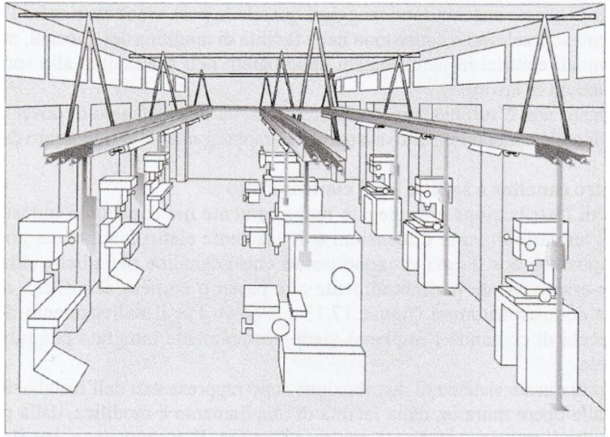


Implementation methods for LV distribution

Ceiling/false ceiling duct systems

Used in industrial warehouses and tertiary environments of large size and densely electrified. The cables are laid in closed or open metal ducts, fixed to the perimeter of the walls or suspended from the ceiling, exposed or covered by false ceilings. Pipes and ducts fixed to the wall are used for connection to sockets and control devices. The advantages are rapid installation, free from masonry work, ease of expansion and modification, and the possibility of hiding the route from view. It is disadvantageous in terms of cost and size.





1. Closed cable ducts
2. Fittings
3. Ceiling suspensions
4. Wall mounting brackets
5. Suspension accessories or outlet elements
6. Electrical panel fittings
7. Electrical distribution panel

Implementation methods for LV distribution

False ceiling duct systems

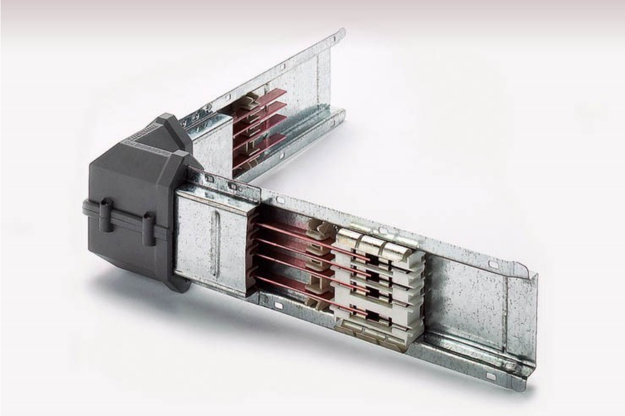
Implementation methods for LV distribution

Ceiling duct systems

Implementation methods for LV distribution

Distribution via busbar trunking

Busbar trunking systems are a prefabricated series of equipment, consisting of conductor bars insulated from each other and from the outside, which replace cables in distribution systems. They are mounted horizontally and are equipped with tap-off boxes along the length of the busbar, equipped with fuses or automatic breakers, to make the descents to the users at regular intervals.



Implementation methods for LV distribution

They are used in high-power industrial plants because they are characterized by high nominal currents (even > 1000 A). Prefabricated ducts for the power supply of lighting fixtures are also widespread, with lower nominal currents (25 – 40 A).

Compared to other distribution systems, they have a higher purchase cost, but allow significant reductions in installation costs, therefore they are the preferable solution for the power supply of numerous loads with high absorption arranged in parallel rows.

It must be integrated with vertical distribution using protective pipes for the descent to the individual machines.

Low voltage electrical panels

An *electrical panel* is a component of the electrical system, consisting of a casing and the various protection, maneuver, control, regulation and measurement equipment contained therein, which are assembled under the responsibility of the manufacturer, with all the internal mechanical and electrical interconnections, including the structural support elements.

Being a component, even if made up of various elementary components, an electrical panel must be identified by the manufacturer's name or trademark and by the type, number or other means of identification.

The design of an electrical panel is not the responsibility of the designer of the system in which it will be installed but is the responsibility of the technical office of the manufacturer of the panel itself. The latter must also carry out all the tests and checks required by the regulations and issue the relevant declaration of conformity of the panel.

Low voltage electrical panels

Classification of electrical panels

Electrical panels can be classified according to the function to which they are dedicated:

- *Main distribution panels* or Power Center (PC), of high power, generally installed immediately downstream of the MV/LV transformers or generators, include one or more input units for connection to the power line (or lines) and a small number of output units since they generally do not directly supply the users;
- *Secondary distribution panels*, used for the distribution of energy to the various points of the system, generally have a single input unit and numerous output units;
- *Motor control panels* or Motor Control Center (MCC), used for the centralization of the control and protection systems of the electrical motors;
- *Control, regulation and protection panels*, which contain all the devices necessary for the operation of an operating unit, also belonging to this category are the on-board machine panels, used for the control, regulation and protection functions of a single machine;

Low voltage electrical panels

- *Control pulpits and push-button panels*, used when the control devices must be moved away from the electrical panel to be easily accessible by the operator;
- *Construction site panels*, generally mobile or transportable and built with special safety features in relation to the place where they are used, range from simple units with plug sockets to secondary distribution panels.

Depending on the construction type, panels are divided into closed and open. *Closed panels* are equipped with protective panels on all sides, so as to guarantee at least the IPXXB protection level against direct contact. *Open panels* have accessible live parts, possibly with only the front protection. The latter can only be used in electrical workshops (substations, etc.) accessible only to trained personnel.

Low voltage electrical panels

Main distribution panels or Power Center (PC)

Low voltage electrical panels

Secondary distribution panels

Low voltage electrical panels

Motor control panels or Motor Control Center (MCC)

Low voltage electrical panels

Control, regulation and protection panels

Low voltage electrical panels

Control pulpits and push-button panels

Low voltage electrical panels

Construction site panels

Low voltage electrical panels

Depending on the installation conditions, switchboards are classified as:

- *Indoor switchboards*, intended to be installed only in rooms where there are specific environmental conditions specified by the legislation (altitude ≤ 2000 m; maximum temperature ≤ 40 °C, maximum average temperature in 24 hours ≤ 35 °C, minimum temperature ≥ -5 °C, relative humidity ≤ 50% at 40 °C and 90% at 20 °C);
- *Outdoor switchboards*, built to be installed outside buildings in specified environmental conditions (altitude ≤ 2000 m; maximum temperature ≤ 40 °C, maximum average temperature in 24 hours ≤ 35 °C, minimum temperature ≥ -25 °C and at -50 °C for arctic climates, relative humidity 100% at 25 °C);

- *Fixed switchboards* if they are built to be fixed at the installation site;
- *Movable switchboards* if they can be easily moved from one place of use to another.

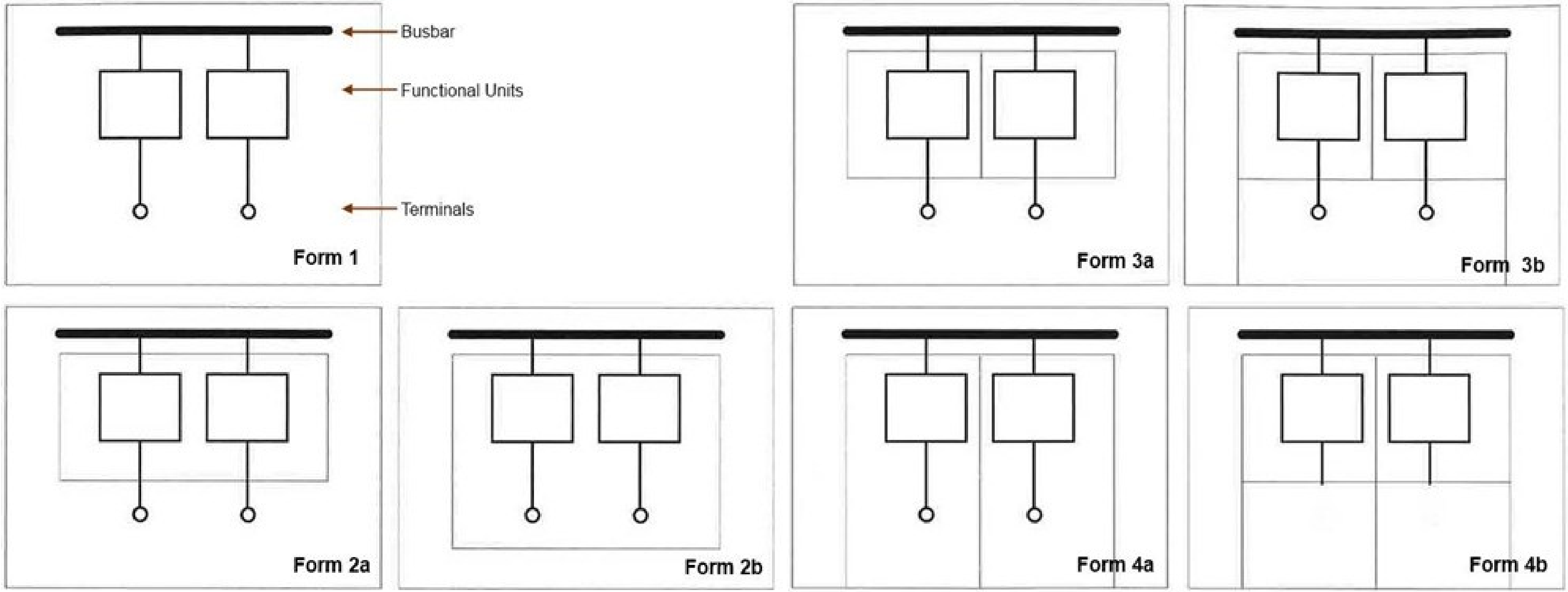
Low voltage electrical panels

Another classification of switchboards concerns the segregation of internal parts, i.e. the internal separation obtained by interposing barriers or diaphragms, made of metallic or non-metallic material. The standard introduced the concept of form, providing for the following types:

- *Form 1* - no internal separation of the busbars, functional units and terminals from each other.
- *Form 2a* - separation of the busbars from the functional units. Terminals are not separated from the busbars.
- *Form 2b* - as for 2a, but with the terminals are not separated from the functional units.
- *Form 3a* - separation of the busbars from the functional units and each functional unit from the other units. Terminals of each functional unit are not separated from each other. Terminals are not separate from the busbars.
- *Form 3b* - as per 3a, but with the terminals separated from the busbar (and functional units)
- *Form 4a* - separation of the busbars from the functional units and each functional unit from the other units. Separation of the terminals for a functional unit from the busbars and those of any other unit. Terminals enclosed in the same compartment as the functional unit.
- *Form 4b* - as per 4a, but with the terminals for each functional unit enclosed in their own space.

Low voltage electrical panels

Separation of the internal parts of an electrical panel



Application example

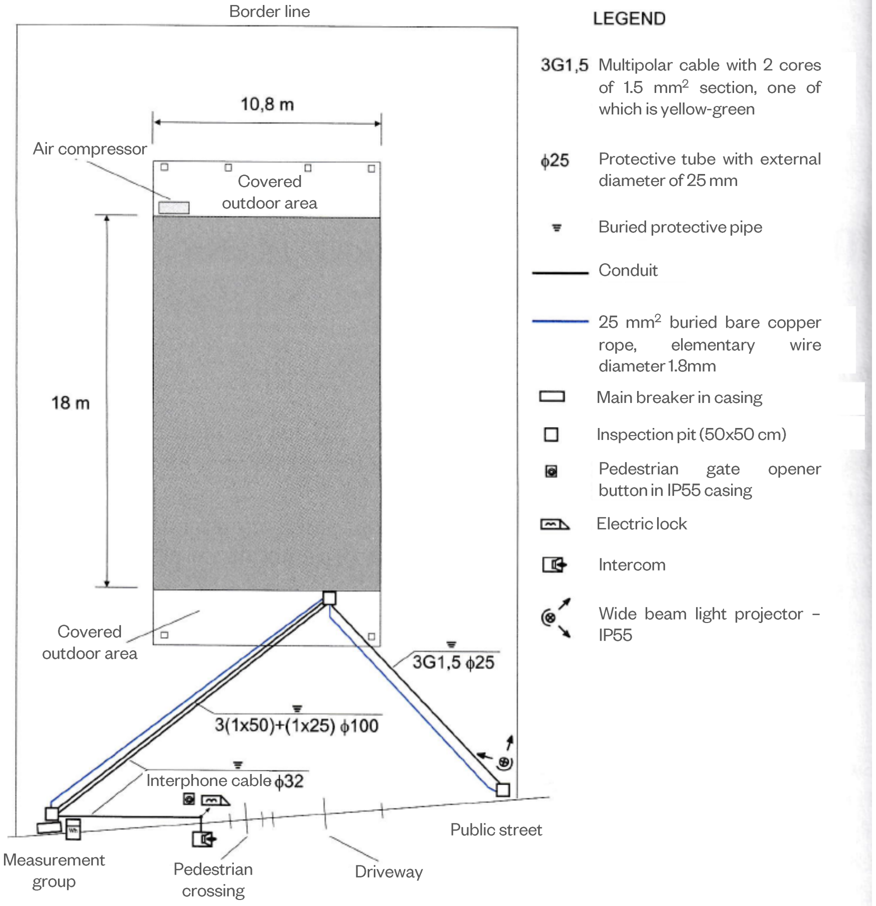
Electrical system in a metalworking workshop

General information

The electrical system of a metalworking workshop of approximately 190 m^2 is described, located in a warehouse with the availability of a fenced, partially covered outdoor area.

The workshop is used for processing ferrous materials on behalf of third parties and consists of an area for processing and storage, a small office and toilets.

The table on the following page shows the main electrical utilities of the plant. In addition to these, the following auxiliary systems are present: telephone, data transmission and intercom.



Application example

Load	Installed power (kW)	Simultaneity factor	Calculated power (kW)
Welders (4 x 12 kW)	48	0,75	36
Press	7	0,4	2,8
Pillar drill	1	0,4	0,4
Air compressor	7,5	0,4	3
Portable tools (grinders, drills, etc.)	3	0,4	1,2
1.5t overhead crane	4	0,4	1,6
Interior lighting (15 W/m^2 x 190 m^2)	2,85	1	2,85
Outdoor lighting	0,3	1	0,3
TOTAL	73,65		48,15

Application example

The contractual power is 50 kW, with three-phase supply at 230/400 V.

The prospective short-circuit current at the PCC is 15 kA (data provided by the electric distributor).

The measuring group (without limiter) is located outside, in a special container without masses embedded in the property's boundary wall, on the street open to the public.

The building heating is autonomous, and gas based, with thermal potential less than 35 kW.

Application example

Electrical diagram and panels

The electrical system is sized for a power 35% higher than the power used, i.e., 67,5 kW.

Assuming a power factor of 0,95 (power factor corrected system), a current of use I_B = 103 A is obtained.

Immediately downstream of the measuring group is the main breaker, housed in an insulating container with IP55 protection rating (excessive) and a front door equipped with a key lock (to prevent others from maneuvering the breaker, given that the panel is accessible to anyone).

The main breaker consists of a four-pole magnetothermal automatic breaker, I_n = 160 A adjustable, calibrated at 120 A considering the ampacity of the riser cable I_Z = 135 A (as specified below) and the operating current I_B = 103 A.

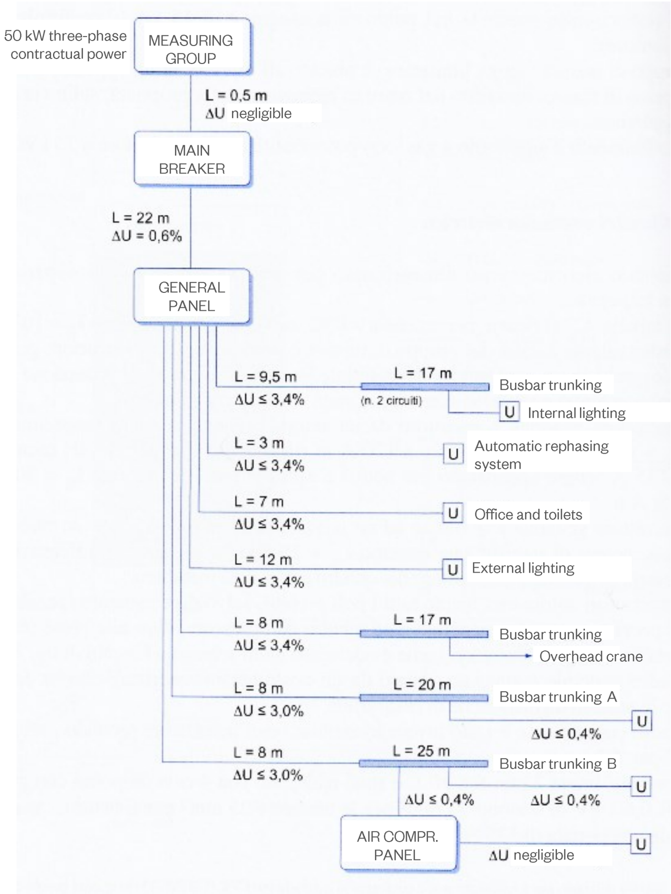
The main breaker is combined with a differential module I_{dn} = 1 A, delay of 300 ms, extreme breaking capacity I_{cu} = 25 kA. The differential protection is necessary because the container of the main switchboard (downstream) is metal (it constitutes a mass).

The automatic breakers have all poles protected, unless otherwise specified.

Application example

A general panel and an air compressor panel are provided, in addition to the sockets for powering the users, as shown in the block diagram.

The general panel is purchased from a manufacturer (panel builder), who also provides the relevant declaration of conformity. The air compressor panel is instead assembled by the installer, according to the criteria given by the relevant standards (in this case, CEI 23-51 *Requirements for the construction, verification and testing of distribution panels for fixed installations for domestic and similar use* and related).



Application example

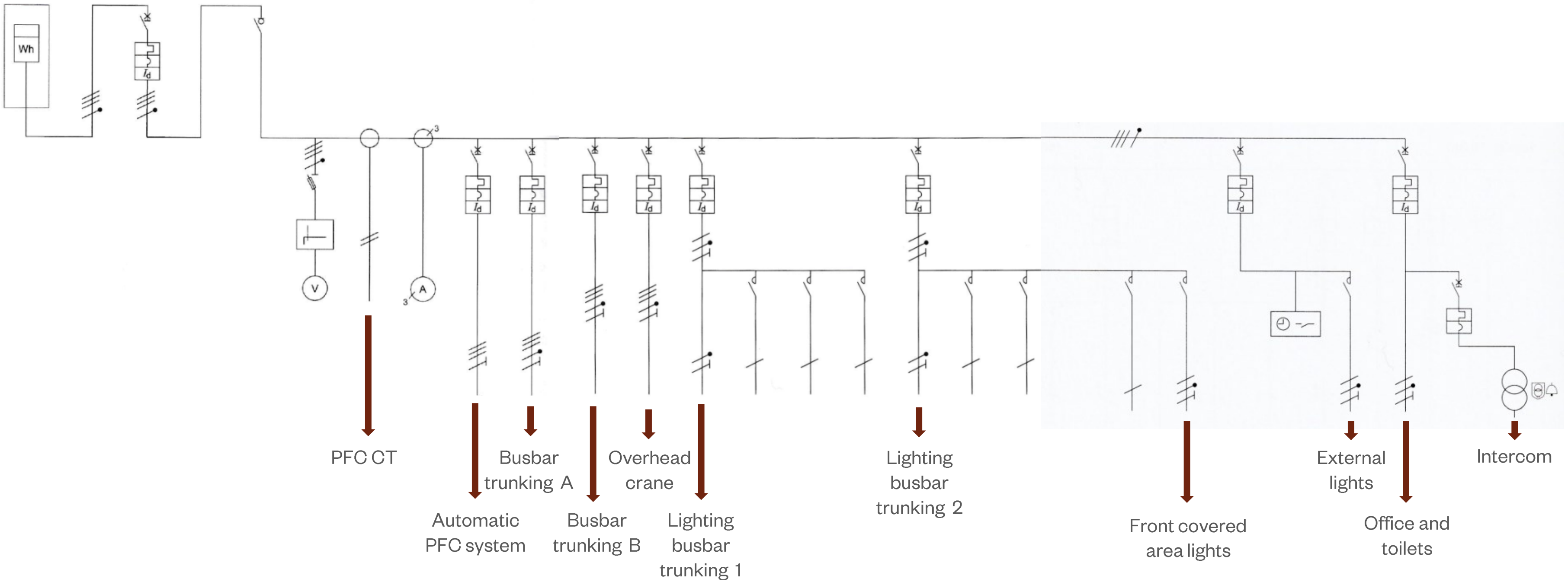
The 22 m long riser is made with 4 single-core cables with FG7R 0.6/1 kV sheath, with a section of 50 mm^2 for the three phases and 25 mm^2 for the neutral, corresponding to an ampacity of 135 A (calculated using CEI UNEL 35026 standard, for three active conductors, balanced load, laid in an underground PVC protective tube with an external diameter of 100 mm).

It is possible to verify that this section leads to voltage drops of approximately 0.6% at the switch regulation current I_r = 120 A.

The prospective short-circuit current I_{cp} at the point where the main switchboard is installed is greater than 10 kA, given the prospective short-circuit current at the PCC and the characteristics of the riser.

Application example

General switchboard wiring diagram



Application example

Four-pole breakers with a breaking capacity of 15 kA and two-pole breakers with a breaking capacity of 6 kA are installed in the switchboard, in association with the upstream main breaker, an automatic 160 A (I_r = 120 A) of the current limiting type, which acts as a backup protection according to the manufacturer's instructions.

The output circuits from the general switchboard are:

- Automatic PFC unit circuit, three-phase, in FS17 450/750 V cable, section 50 mm^2, ampacity 118 A, protected by a three-pole differential thermomagnetic breaker I_n = 100 A, I_{dn} = 0,3 A.
- Power circuit A, protected by a 4x100 A differential automatic breaker, I_{dn} = 0,3 A, which protects the 100 A busbar trunking A, which in turn supplies the plug sockets on the right side of the workshop. The connection between the switchboard and the busbar trunking is made with a multi-polar FG16OR16 0.6/1 kV cable, section 3x50 + 1x25 mm^2, in a 100x80 mm metal channel, ampacity 123 A (there are two circuits in the same channel: this cable, plus the power circuit B).
- Power circuit B, protected by a 4x100 A differential automatic breaker, I_{dn} = 0,3 A, which protects the 100 A busbar trunking B, which in turn supplies the plug sockets on the left side of the workshop and the air compressor panel. The connection between the switchboard and the busbar trunking is equal to the power circuit A one.

Application example

- Circuit that supplies the 50 A busbar trunking with the trolley dedicated to the power supply of the 4 kW overhead crane (corresponding to I_B = 8,1 A). The connection between the switchboard and the busbar trunking is made with single-core PVC-insulated cables with a cross-section of 10 mm^2, placed inside a rigid PVC pipe laid in sight, with an ampacity of 46 A. The line is protected by a 4x32 A differential circuit breaker, I_{dn} = 0.3 A.
- Two single-phase circuits to supply the 20 A busbar trunking (3F+N+PE) for lighting, consisting of FS17 450/750 V cables, cross-section 2,5 mm^2, ampacity I_Z = 18,5 A, protected by a 2x10 A differential circuit breaker, I_{dn} = 0.03 A. The three phases of the busbar trunking are used for providing power supply (1F + N) to three different lights groups, controlled with buttons and relays (more on this later).
- Single-phase circuit for sockets and for lighting in the office and toilets, FS17 450/750 V cable with a cross-section of 2,5 mm^2, rated 23 A, placed inside tubes embedded in the masonry, protected by a 2x16 A differential circuit breaker, I_{dn} = 0,03 A.

Application example

- External lights circuit, in FG16OR16 0.6/1 kV cable with a section of 3G1,5 mm^2, ampacity 21 A, laid in an underground pipe and protected by a 2x10 A differential circuit breaker, I_{dn} = 0.03 A, controlled by a time switch.
- Circuit for the intercom power supply, made with FS17 450/750 V cable with a section of 1,5 mm^2, ampacity 16,5 A, protected by a 2x6 A automatic circuit breaker.

The general switchboard, lockable, is metal and earthed, protected by the general differential breaker located near the meter compartment.

The sockets used in the office are of the type for domestic and similar use: italian-dual-size P17/11 2P+T 10/16 A sockets, and italian-dual-size/german std. P40 2P+T 10/16 A sockets.

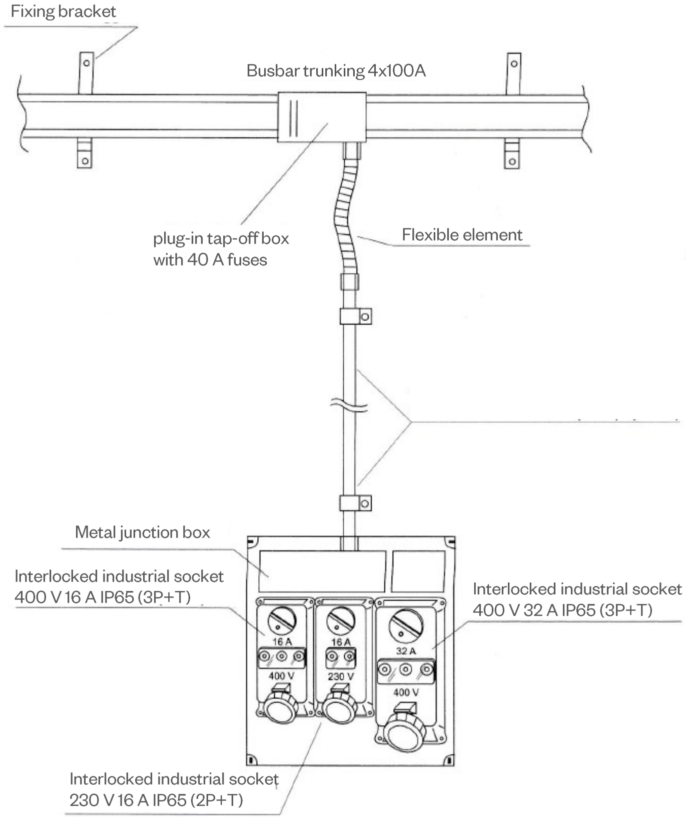
Application example

In the workshop area, 8 groups of sockets are installed:

- 4 groups composed of three industrial-type sockets, interlocked with fuses: 3P+N+T 32 A / 400V, 3P+T 16 A / 400 V, 2P+T 16 A / 230 V;
- 4 groups composed of two industrial-type sockets, interlocked with fuses: 3P+T 16 A / 400 V, 2P+T 16 A / 230 V.

The groups of 3 sockets are connected to the busbar trunking with plug-in tap-off boxes with fuses (I_n = 40 A) and a 16 mm^2 FS17 450/750 V cable (ampacity I_Z = 62 A) laid inside a metal tube with external diameter 40 mm, suitable for five conductors.

The groups of 2 sockets are connected to the busbar trunking with plug-in tap-off boxes with fuses (I_n = 25 A) and a 6 mm^2 FS17 450/750 V cable (ampacity I_Z = 34 A) laid inside a metal tube with an external diameter of 32 mm, suitable for five conductors.

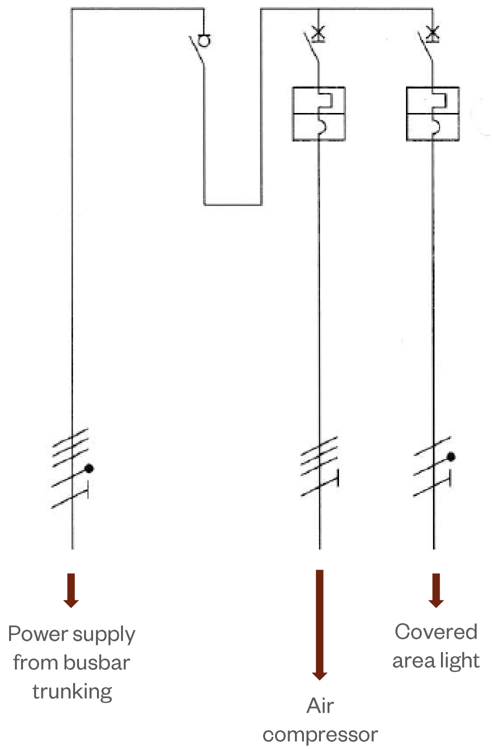


Application example

Air compressor panel wiring diagram

The air compressor panel receives power from busbar trunking B, by means of a wall duct consisting of single-core 3F+N+PE cables, FG16R16 0,6/1 kV 10 mm^2 (PE made with FS17 450/750 V 10 mm^2 yellow-green cable), ampacity I_Z = 60 A, installed in a rigid PVC piping, external diameter 32 mm. The line is derived from the busbar trunking by means of a plug-in tap-off box with 40 A fuses.

The panel contains, in addition to the main switch, two automatic thermomagnetic breakers: one for the air compressor power supply and one for the back covered area light, with timed switch. The main switch-disconnector is protected against overcurrents by the fuses placed in the tap-off box, according to the instructions provided by the manufacturer.



Application example

The three-pole automatic breaker has a breaking capacity of 10 kA and a type D intervention characteristic (to allow the air compressor to start); the bipolar one has a 6 kA breaking capacity, with a type C intervention characteristic.

The cable section is determined using the criteria already presented. For the lighting circuit, an operating current of $I_b = 10$ A was considered, equal to the nominal current of the protection breaker.

Application example

Voltage drop

The voltage drop on the riser is 0,6% and the downstream circuits are sized for a voltage drop of 3,4% (to comply with the IT rules recommendation of maximum 4% drop between PCC and the loads).

As an example, the voltage drop check on the most distant three-phase socket (powered by busbar trunking B) is shown.

For the switchboard-busbar trunking connection, section 50 mm^2, breaker I_n = 100 A, a voltage drop of within 0,16% is obtained.

The busbar trunking is 25 m long, while the voltage drop indicated by the manufacturer for a 100 m long busbar trunking, carrying a current of 1 A, is equal to 0,08 V. The result is therefore:

$$\Delta U\% = \frac{(100 * 0{,}08 \frac{V}{A * m}) * 100\ A * 25\ m}{100 * \ 400\ V} = 0{,}5\ \%$$

Application example

For the busbar trunking-socket group branch, with a section of 16 mm^2, protected by fuses with I_n = 40 A, a voltage drop of 0,1% is obtained.

Therefore, for the socket circuit the voltage drop is the sum of the ones in the riser (0,6%), in the cable conduit connecting the panel and the busbar trunking (0,16%), in the busbar trunking (0,5%) and finally in the branch from the busbar trunking to the sockets (0,1%). The total voltage drop is therefore equal to 1,37% (well below the prospected limit of 4%)

A similar check is carried out for all the circuits, with a positive result.

Application example

Short circuit protection of busbar trunking

The value of the prospective short-circuit current at the power supply point of the power busbar trunking is approximately 10,5 kA, obtained through a simplified calculation approach provided by the IT regulations. It is also possible to obtain it by simple calculations starting from the prospective short-circuit current at the PCC and the cables' data.

The busbar trunking, protected by the 100 A circuit breaker, has a conditional short-circuit current of 15 kA (value of the prospective short-circuit current, declared by the component manufacturer, that the component itself can withstand, during the opening time of the short-circuit protection device, under the specified conditions), so it is fine.

The busbar trunking used for lighting has a short-time withstand current of 2.5 kA. The short-circuit current at the supply point of these ducts is 2.5 kA (they are three-phase ducts, but used with single-phase circuits), so the busbar trunking is protected.

Application example

Power factor correction

The lighting fixtures are individually corrected.

For the other users, an initial power factor of 0,7 and a final one of 0,95 are assumed. Given the contractual power of 50 kW, the total maximum reactive power for providing the required correction is 34,5 kvar.

An automatic PFC system is chosen, with a power of 40 kvar, corresponding to a nominal current I_n = 58 A Therefore, an operating current I_b = 87 A is assumed, equal to 1,5 times the nominal current of the capacitor bank (as required by the CEI 33-8 standard).

Application example

Grounding system

A ground electrode made of copper wire with a cross-section of 25 mm^2 and a total length of 30 m is installed.

The earth resistance of a horizontal ground electrode of length L is approximately $2\rho/L$. The ground where the workshop is located is made of gravel, so ρ = 200 Ωm is assumed, which results in R_E = 2*200/30 = 13 Ω.

The maximum admissible earth resistance value, having installed a 1 A differential switch, is 50 Ω, so the sizing satisfies the conditions for ensuring safety against indirect contacts.

At the end of the work, an earth resistance of 12 Ω was measured, so the verification is satisfied and protection from indirect contacts is ensured.

The earth conductor (consisting of the above-ground part of the 25 mm^2 cord) and the workshop protection conductor are connected to the earth collector, located near the switchboard.

The main equipotential connection for the water pipes is not necessary as they are made of insulating material. The gas supply pipe is connected to the earth collector by means of a 6 mm^2 equipotential conductor.

Application example

Structured cabling

For structured cabling (telephone system and data transmission) separate and independent pipes, boxes and cassettes are provided. The system is installed only in the office, with an additional ringer for the telephone on the external wall of the office.

Intercom system

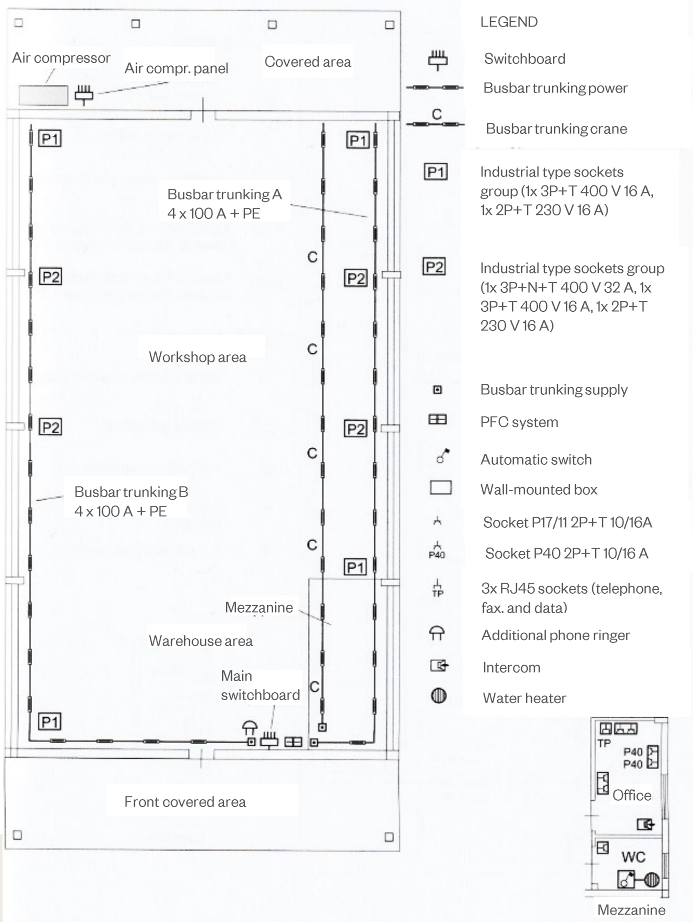
An intercom system is to be installed, with an external station on the pedestrian gate and an internal station in the office. The power supply is 12 V SELV, with independent pipes and junction boxes and pits with separation insulated sectors from the energy circuits.

The lock of the pedestrian gate is also powered in SELV with a control button incorporated in the office intercom; the same piping as the intercom system is used.

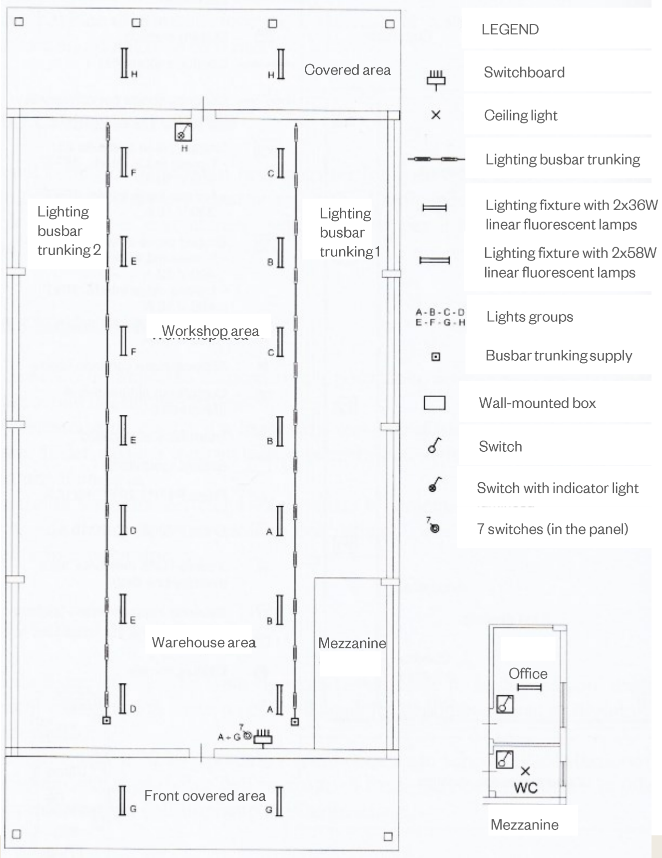
Application example

Component location diagrams

Power and auxiliaries



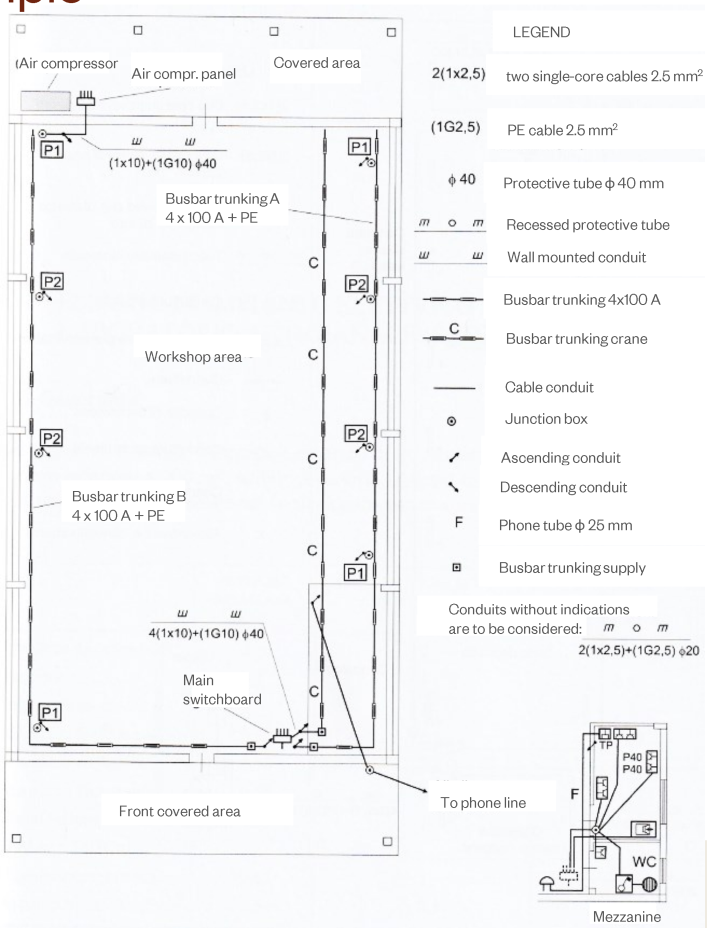
Lighting and controls



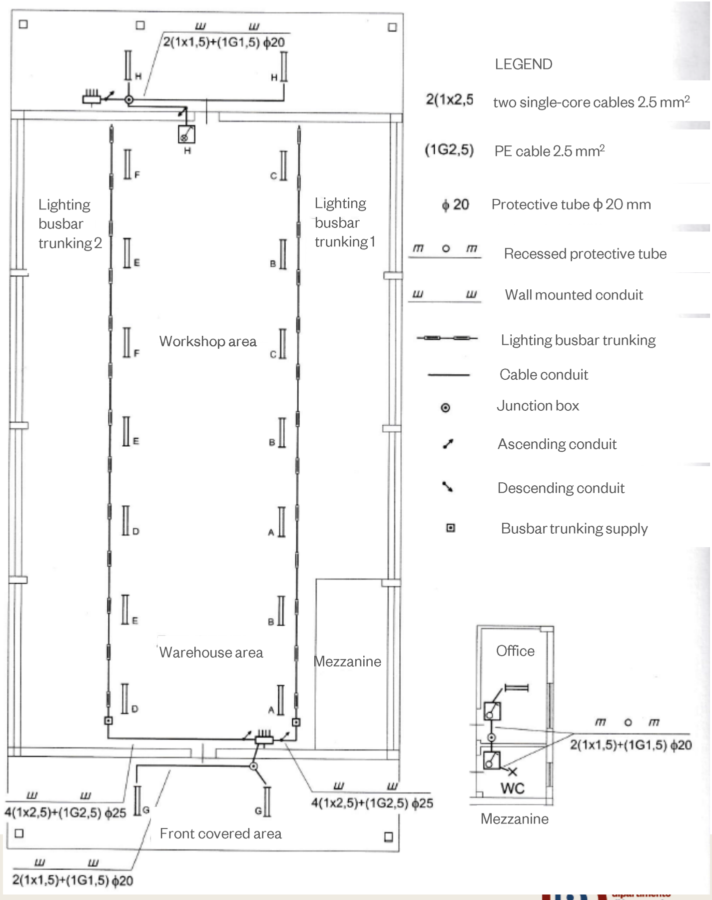
Application example

Installation diagrams in topographic representation

Power



Lighting



Electrical systems in residential environments

Scope of application

Modern standards introduced (In Italy, from 2012) a series of additional requirements for electrical systems in residential real estate units located inside condominiums and for single-family or multi-family housing units not included in condominium complexes (for example, villas, terraced houses, etc.).

The requirements apply to newly installed electrical systems and to complete renovations of existing systems. The electrical systems in the common areas of residential buildings and those in residential units of buildings of artistic and historical value, are excluded from the scope of the standard.

The standard also considers the electronic systems of the real estate unit (TV antenna, telephony and data transmission, alarm systems), limited to their preparation. In fact, it is specified that the electrical installer must prepare pipes, boxes and junction boxes to allow the subsequent creation of such systems.

Electrical system performance levels

The sizing of the electrical system must always be the subject of agreements between the designer, installer and client, based on the needs of the latter and the quality level of the real estate unit.

Nonetheless, in Italy the CEI 64-8/3 standard provides the *minimum sizing criteria* and the *minimum equipment* that the system must have, referring to three levels of performance defined in increasing order of complexity:

- *Level 1*, the minimum required by the standard, to be considered mandatory for having a power system compliant with the requirements of the standard itself; it guarantees the user a system with a sufficient functional level;
- *Level 2*, is the intermediate level, which gives the power system greater usability, also taking into account the other systems that may be present;
- *Level 3*, is the highest level, for real estate units with large and innovative power system equipment; it also integrates a certain number of home automation functions.

Electrical system performance levels

With regard to level 3 systems, the CEI 64-8/3 standard specifies that this level, to be considered a home automation system, must manage at least four of the following functions:

- intrusion detection;
- load control;
- light control management;
- temperature management (if separate management is not provided);
- scenario management (shutters, etc.);
- remote control;
- sound diffusion system;
- fire detection (if separate management is not provided);
- anti-flooding system and/or gas detection.

The integration of individual home automation functions can also be foreseen for level 1 and 2 systems.

Power and minimum equipment

Design power

The value of the *contractual power* (the power for which the electricity supply contract is stipulated) for which the system must be sized (in particular for the riser and the switchboard) is a function of the *living area S*.

The latter is the walkable surface area of the real estate unit, excluding the external areas of terraces, porches, etc. and any appurtenances of the home (garages and garden).

The values indicated by the CEI 64-8/3 standard are:

- $P = 3$ kW for $S \leq 75$ m^2;
- $P = 6$ kW for $S > 75$ m^2.

For example, for a 50 m^2 apartment the system must be sized so that the user can stipulate a contract of up to 3 kW, while for an 80 m^2 apartment the system must already be planned for a power of at least 6 kW, even if the user will stipulate a 3 kW contract.

However, nothing prevents sizing for higher powers upon request of the client.

Power and minimum equipment

Minimum equipment for each housing unit

Minimum equipment	S (m^2)	Level 1	Level 2	Level 3
Number of circuits (excluding those for powering appliances such as boilers, air conditioners, etc. and circuits for garages, cellars and attics)	S ≤ 50	2	3	3
	50 < S ≤ 75	3	3	4
	75 < S ≤ 125	4	5	5
	S > 125	5	6	7
Telephone and/or data sockets	S ≤ 50	1	1	1
	50 < S ≤ 100	2	2	3
	S > 100	3	3	4
Safety lighting devices	S ≤ 100	1	2	2
	S > 100	2	3	3
Auxiliaries and energy saving systems		Doorbell, intercom or video intercom	Doorbell, video intercom, intrusion detection, load control	Doorbell, video intercom, intrusion detection, load control, home automation

Power and minimum equipment

Minimum equipment for each room

The standard also defines the minimum number of power sockets, light points and radio/TV sockets *for each type of room*, depending on its size (surface area A or length L) and the performance level of the system. The tables of minimum equipment per room for the three levels are provided in the attachment.

It should be noted that a socket point means the power supply point for one or more sockets within the same box. These must be distributed adequately throughout the room to allow for their use.

As an alternative to ceiling and/or wall light points, sockets powered by a dedicated control device (controlled sockets) can also be provided, depending on the future positioning of mobile floor or table lighting fixtures.

In the case of renovations of existing real estate units that are part of a condominium, the requirements relating to TV, video intercom and intercom systems do not apply for the identification of the performance level of the system, if these are incompatible with the existing condominium system.

Connection line between the delivery point and the switchboard

The connection line between the meter at the PCC and the switchboard of the real estate unit (called *riser*) must be sized taking into account the operating current and the voltage drop. Generally, a voltage drop of 2% is assumed for the riser, reserving the additional 2% (to reach the limit of 4% recommended by rule 525 of CEI 64-8/5) for the lines starting from the switchboard.

The CEI 64-8/3 standard prescribes that *the section of the riser must be no less than 6 mm²*, regardless of the length and the operating current.

For the protection of the riser, the requirements of the CEI 0-21 standard for passive users with limited supply, shown previously, must be taken into account. In the case in question, the following apply:

- it is possible to use the meter's power limiting breaker for short-circuit protection by coordinating it with the characteristics of the cable, and it is possible to carry out overload protection using the general line devices (DGL) that protect the circuits starting from the switchboard, but only if the ampacity of the riser is not less than the nominal current of the general device (DG), or the sum of the nominal currents of the DGL;

Connection line between the delivery point and the switchboard

- It is good practice to provide an automatic overcurrent protection breaker at the base of the riser, immediately downstream of the meter, to separate the protection function of the user system from the power limitation function of the distributor;
- if the riser is made without masses, the differential protection must not be installed at the beginning of the riser; the protection against indirect contacts is in fact obtained by double or reinforced insulation for the meter panel, the riser itself, and the switchboard; in this case it is also possible to lay the cables of several real estate units in the same cable duct;
- if the riser or switchboards require protection from indirect contacts by automatic opening of the circuit, it is necessary to install a differential switch coordinated with the grounding system that must guarantee total selectivity with respect to the differential switches installed downstream;
- to choose the breaking capacity of the device at the base of the riser, the conventional short circuit current value in the PCC indicated by the CEI 0-21 standard must be used, i.e. 6 kA for single-phase users.

Connection line between the delivery point and the switchboard

There are (old) condominium systems in which the meters are installed inside the real estate unit. In this case the delivery point is located in the single real estate unit, and the connection riser is owned by the distributor (*right of way*).

Often the age of these risers requires an intervention by the distributor in the condominium spaces, due to the risks to the operation of the distribution network due to the degradation of the risers with an age greater than their technical-economic life. In many cases, moreover, the risers are not adequate to satisfy the requests for increased power by users for the consumption of new appliances (for example: air conditioners, induction hobs) or for the connection of production systems and electric vehicles.

Beyond the technical feasibility of the solution adopted (keeping meters in the units or moving to a centralized location), the intervention also represents the opportunity to prepare the infrastructure to be made available to telephone operators for the distribution of FTTH (fiber to the home) and for other interventions (security adjustments or provision of additional services), as well as resolve disputes for interventions on the risers .

Electrical panel of the housing unit

Each housing unit must be equipped with one or more distribution panels and a main breaker, easily accessible to the user and clearly identified, to allow the entire system to be disconnected with a single operation. These features are mandatory for all levels of the system regardless of the installed power and the surface area of the unit.

The CEI 64-8/3 standard also indicates a series of requirements for the housing unit switchboard:

- possibility of future expansions – the switchboard must be sized to provide at least 15% free modules;
- differential protection – in order to guarantee sufficient continuity of operation, at least two differential switches must be installed in the switchboard, regardless of level, surface area and power; generally, it would be advisable to protect each outgoing circuit with a dedicated differential;
- type of switches – the standard recommends installing at least type A differential switches (instead of AC) for circuits that power washing machines and/or fixed air conditioners, to avoid untimely trips due to the pulsating currents absorbed by the electronic systems of the loads;

Electrical panel of the housing unit

- connection to the earthing system – the main PE that connects the earthing system of the building with the housing unit must directly reach the incoming panel in the latter, to allow the correct earthing of any surge arrester (SPD) of the user system;
- in relation to the previous point, the standard specifies that for level 1 and 2 systems, surge arresters must be installed at the incoming line only if they are necessary to make the type 1 risk (loss of human life) tolerable according to the assessment provided for by the CEI EN 62305 standard; for level 3 systems, however, protection against overvoltages capable of causing damage to the equipment must also be guaranteed.

Light control in residential and similar systems

One of the most frequent and pervasive applications of electrical systems is powering lights. In residential systems the light load is the most frequently used (even if not the most powerful in absolute terms or the most energy-intensive). In the tertiary and industrial sectors, the lighting system is still an important part of the electrical system.

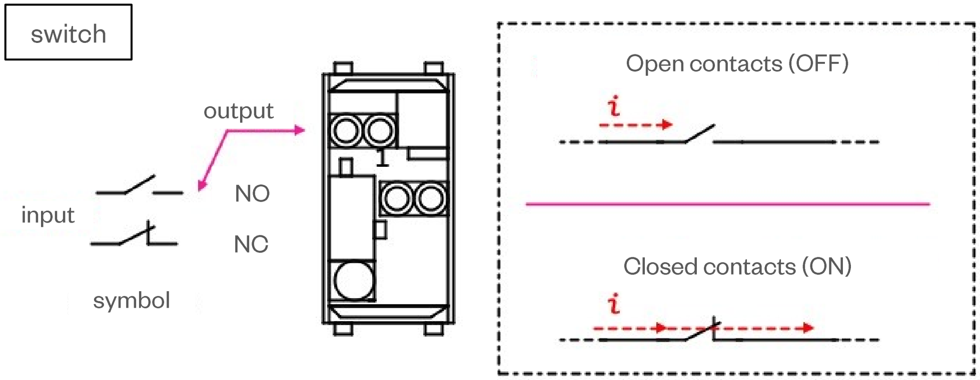
It is therefore significant to provide some information on how it is possible to control (switch on and off) the lights in electrical systems. Reference is made to residential and similar systems, as they usually present the widest variety of cases for the light control.

Electromechanical light control

There are some basic diagrams that can be used to control a light in a civil electrical system, using electromechanical devices (switch, diverter, inverter).

Light control in residential and similar systems

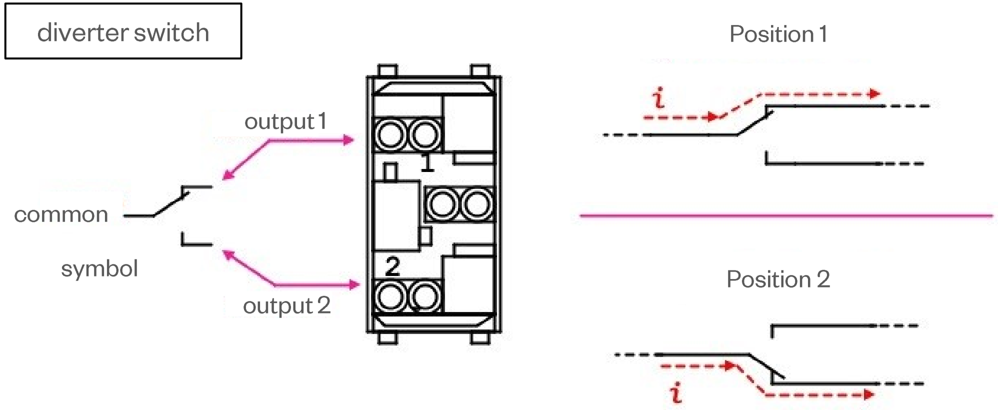
The switch is an electrical device that is connected in series to the phase conductor of a load. It has two positions, one open (open contacts = OFF) and one closed (closed contacts = ON) in which it remains in the absence of external force. It can open and close the circuit, powering or de-powering the load. It can be unipolar (it interrupts only one power pole, the phase one) or bipolar (it interrupts two power poles: both the phase one and the neutral one).



NO = normally open, NC = normally closed

Light control in residential and similar systems

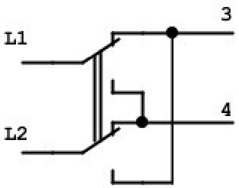
The diverter switch has three terminals for connecting cables, one of these is known as the “common” and the other two are the “outputs”. It allows to direct the current from the common to one of the two outputs, alternatively (either one or the other)



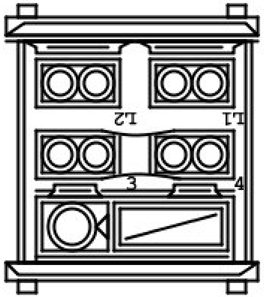
Light control in residential and similar systems

The change-over switch has four terminals for its connection, as indicated and represented by its symbol; once activated it simultaneously reverses the path of the current on a pair of contacts (the connection is inverted between the inputs and outputs) and is equivalent to the simultaneous control of two diverter switches.

change-over switch



symbol



Light control in residential and similar systems

The basic circuits for light control take their name from the device used to control the light, therefore we have:

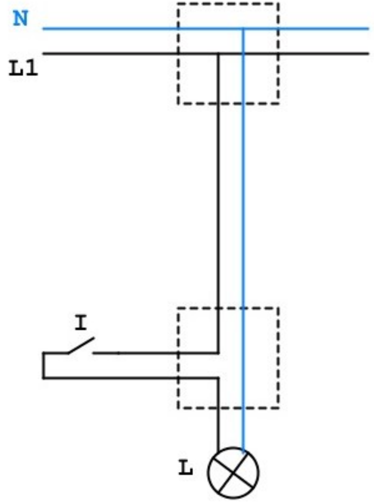
- Interrupted, as it uses a switch to control a light point from a single position,
- Diverted, which uses the diverter switch to achieve the command of the light from two different positions,
- Change-over, which uses the change-over switch together with the diverter switches to obtain multiple command positions.

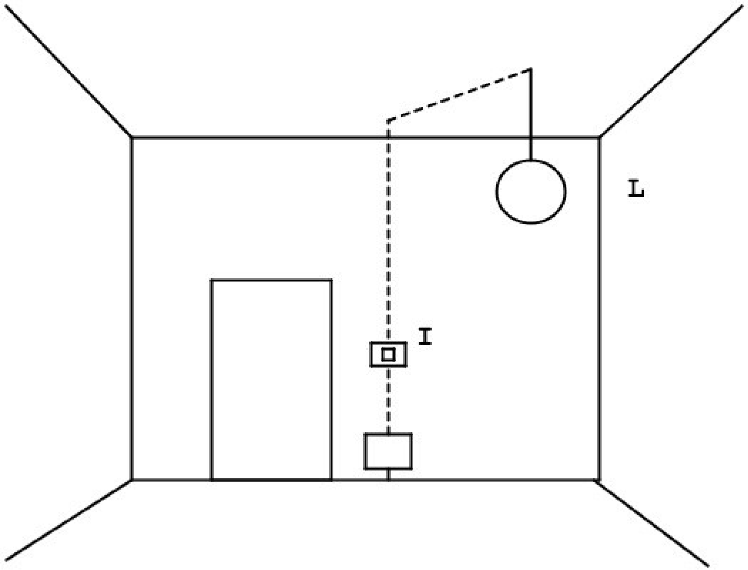
The diagrams that follow clarify the methods of use of the various components and the connections between them, to achieve the desired type of command.

In the diagrams that follow, the yellow-green protective or earth conductor has been omitted, which in practical implementation must always be present in every light point, and the neutral conductor (N) that will be connected directly to the light point has been indicated in blue, while (not colored in the drawings) the phase conductor (L1 or F) must be the one that will be interrupted to control the light point.

Light control in residential and similar systems

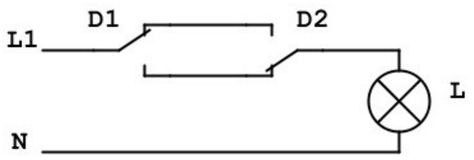
The single-pole switch is used as a single control point for a light point, according to the well-known interrupted circuit breaker scheme in which the switch connected in series to the light point's power supply interrupts the phase conductor.

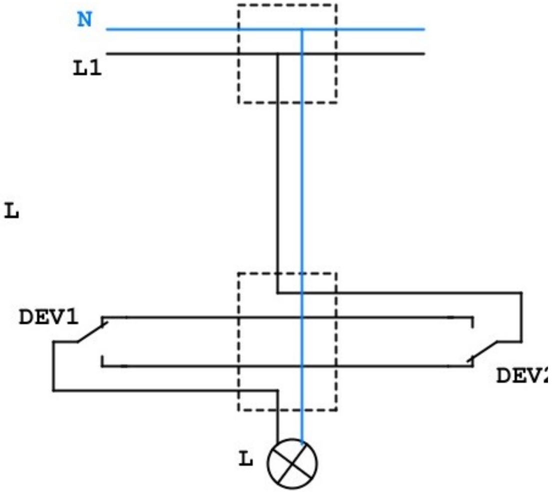


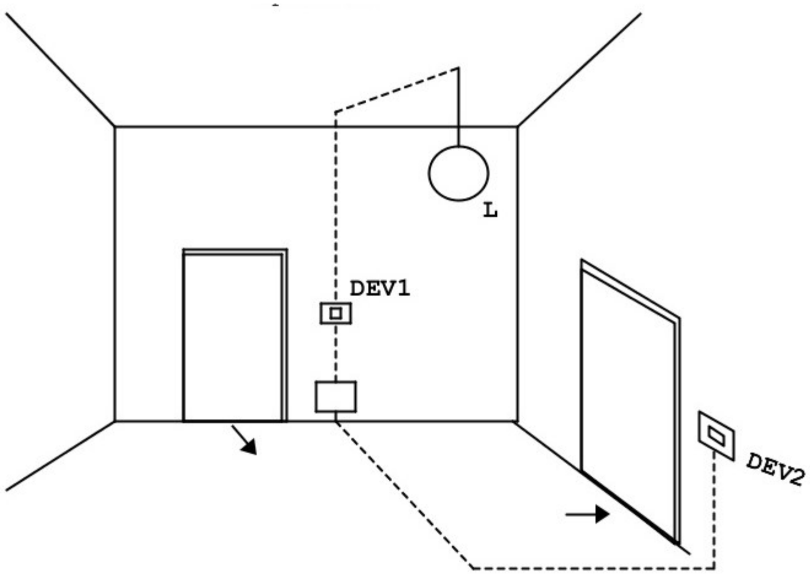


Light control in residential and similar systems

The diverter switches are always used in pairs because allows to control a light point from two different points, according to the scheme below

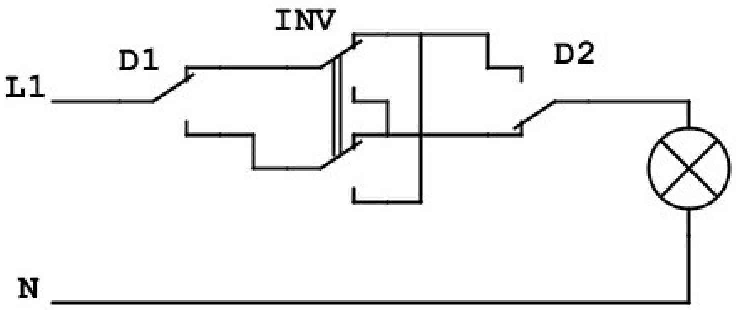


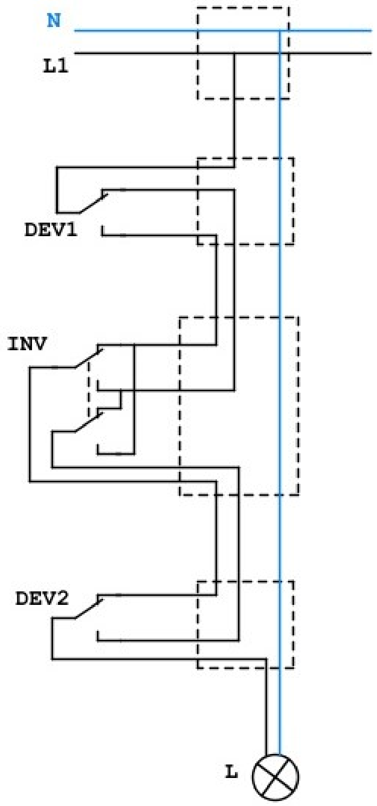




Light control in residential and similar systems

The change-over, always used in combination with a pair of diverter switches, allows to control a light from three or more different points. For each additional control point, it is required to add an inverter. Note that the wires must pass through all the command points before reaching the light.





Light control in residential and similar systems

Relay and button light control

The operating principle of the contactor (previously shown) is used at all power levels. Usually, a contactor for low power applications is simply called a “relay” (which creates some confusion with protection relays, but it is because a relay is any device that carries out an action based on an input).

It is possible to use a particular type of relay, called a cyclic relay, to carry out the light control. A cyclic relay is a bistable device, which at each control pulse switches its contacts between open and closed positions.

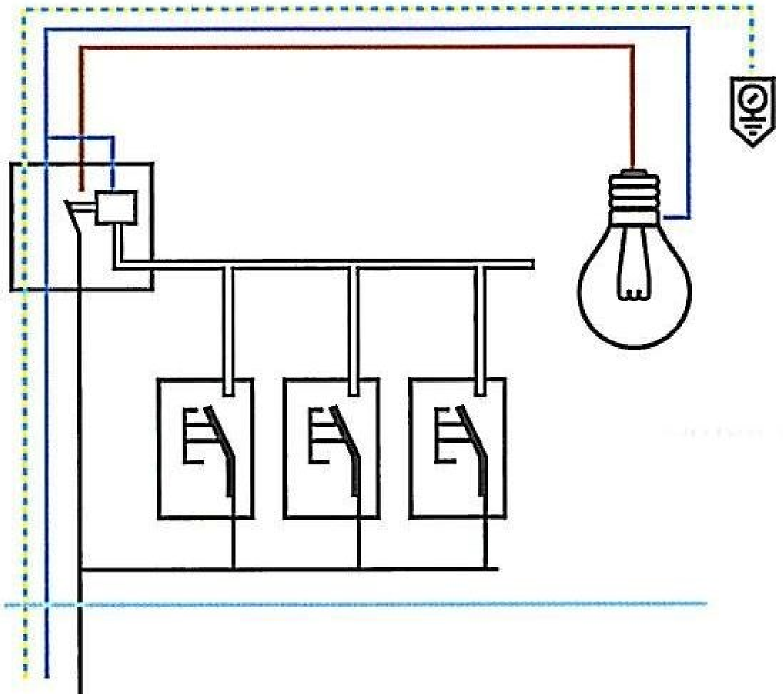
This pulse can be provided with one or more buttons, constructively like switches but monostable (rest position with open contacts), therefore using the relay contacts to control one or more light points.

Light control in residential and similar systems

The relay can have the control section (the one activated by the buttons) at the same voltage as the load, or at a lower voltage (usually 12 V).

The relay light control allows to add any number of control points very easily; by directly connecting two wires to the relay (in the change-over solution, the wires must pass through all the control points).

It is also suitable for powering high power light loads (many lamps together) limiting the cost of the cables, as the control wires can have a very small section (they carry only the current needed to trigger the relay, not the entire load current).



Light control in residential and similar systems

A relay lighting control system can also be easily integrated with home automation systems, as it is conceptually possible to implement a remote control by applying a pulse to the relay control itself, with an additional device (which behaves like an additional button), or by replacing the pulse relay with a relay that also allows for remote actuation (via Wi-Fi or other means).

Building automation

Building automation (*BAS*) or *building management system* (*BMS*) or *building energy management system* (*BEMS*): automatic centralized control of a building's HVAC (heating, ventilation and air conditioning), electrical, lighting, shading, access control, security systems, and other interrelated systems.

<u>Objectives</u>: improved occupant comfort, efficient operation of building systems, reduction in energy consumption, reduced operating and maintaining costs, increased security, etc.

<u>Examples of BMS functions</u>: keep a buildings climate within a specified range, provide light to rooms based on occupancy, monitor performance and device failures, provide malfunction alarms to building maintenance staff.

Most commercial, institutional, and industrial buildings built after 2000 include a BMS, whilst older buildings may be retrofitted with a new BMS. A building controlled by a BAS is often referred to as an intelligent building, a *smart building*, or (if a residence) a *smart home*.

Almost all multi-story green buildings are designed to accommodate a BMS for the energy, air and water conservation characteristics. Electrical device demand response is a typical function of a BMS, as is the more sophisticated ventilation and humidity monitoring required of tight insulated buildings.

Building automation

A BMS in its basic form is made by a central control unit, a set of sensors (temperature, light, etc.) and control (switches, user panels, etc.) points, and suitable actuators (valves, motors, etc..), interconnected by a suitable data network.

Commercial and industrial buildings have historically relied on physical cables (ethernet or other types) and robust proven protocols (like BACnet), while proprietary protocols (like X-10) were used in homes.

With the advent of the Internet of Things, an increasing number of smart buildings are resorting to using low-power wireless communication technologies such as Zigbee, Bluetooth Low Energy and LoRa to interconnect the local sensors, actuators and processing devices.

Building management systems are most commonly implemented in large projects with extensive mechanical, HVAC, and electrical systems. Systems linked to a BMS typically represent 40% of a building's energy usage; if lighting is included, this number approaches to 70%.

Building automation

Sometimes BMS integrate access control or other security systems functions, like closed-circuit television (CCTV) and motion detectors.

Fire alarm systems and elevators are also sometimes integrated with the BMS for monitoring and fire-fighting actions. E.g., in case a fire is detected it is required to close dampers in the ventilation system to stop smoke spreading, shut down air handlers, start smoke evacuation fans, and send all the elevators to the ground floor and park them to prevent people from using them. Integration between the fire-fighting system and BMS makes it easier to acquire such functions.

Point of attention: BMS cybersecurity is a point of concern! BMS can be exploited to measure or change their environment: sensors allow surveillance (e.g. monitoring movements of employees or habits of inhabitants) while actuators allow to perform actions in buildings (e.g. opening doors or windows for intruders). Several vendors and committees started to improve the security features in their products and standards, including KNX, Zigbee and BACnet (see recent standards or standard drafts). However, researchers report several open problems in building automation security.

Home automation

Home automation or *domotics* is building automation for a home. A home automation system monitors and/or controls home attributes such as lighting, climate, entertainment systems, and appliances. It may also include home security, such as access control and alarm systems.

The term *smart home* refers to home automation devices that have internet access. Home automation, a broader category, includes any device that can be monitored or controlled via wireless radio signals, not just those having internet access. When connected with the Internet, home sensors and activation devices are an important component of the *Internet of Things* (*IoT*).

A home automation system typically connects controlled devices to a central smart home hub (sometimes called a *gateway*). The user interface for control of the system uses either wall-mounted terminals, tablet or desktop computers, a mobile phone application, or a Web interface that may also be accessible off-site through the Internet.

Home automation

Home automation is prevalent in a variety of different applications, including:

- Heating, ventilation and air conditioning (HVAC): it is possible to have remote control over the internet incorporating a simple and friendly user interface
- Lighting control system: a "smart" network that incorporates communication between various lighting system inputs and outputs, using one or more central computing devices
- Occupancy-aware control system: it is possible to sense the occupancy of the home using smart meters[and environmental sensors like CO_2 sensors, which can be integrated into the building automation system to trigger automatic responses for energy efficiency and building comfort applications
- Appliance control and integration with the smart grid and a smart meter, taking advantage, for instance, of high solar panel output in the middle of the day to run washing machines
- Home robots and security: a household security system integrated with a home automation system can provide additional services such as remote surveillance of security cameras over the Internet, or access control and central locking of all perimeter doors and windows

Home automation

- Leak detection, smoke and CO detectors
- Laundry-folding machine, self-making bed
- Indoor positioning systems
- Home automation for the elderly and disabled
- Pet and baby care, for example tracking the pets and babies' movements and controlling pet access rights
- Air quality control (inside and outside)
- Smart kitchen, with refrigerator inventory, premade cooking programs, cooking surveillance, etc.
- Voice control devices like Amazon Alexa or Google Nest used to control home appliances or systems.

Home automation

Use of home automation could enable intelligent energy-saving techniques. By integrating information and communication technologies (ICT) with renewable energy systems, homes can autonomously make decisions about whether to store energy or expend it for a given appliance, leading to overall positive environmental impacts and lower electricity bills for the consumer.

The inclusion of a variety of smart security systems and surveillance setups in home automation also has a large potential regarding family safety and security. This allows consumers to monitor their homes while away, and to give trusted family members access to that information in case anything bad happens.

While there are many competing vendors, there are increasing efforts towards open-source systems. However, there are issues with the current state of home automation including a lack of standardized security measures and deprecation of older devices without backwards compatibility. This is aggravated by the platform fragmentation and lack of technical standards, a situation where the variety of home automation devices, in terms of both hardware variations and differences in the software running on them, makes the task of developing applications that work consistently between different inconsistent technology ecosystems hard.

Home automation

Like BMS, also home automation systems and its devices can be a problem for security, data security and data privacy, since patches to bugs found in the core operating system often do not reach users of older and lower-price devices.

Concerns have been raised by tenants renting from landlords who decide to upgrade units with smart home technology. These concerns include weak wireless connections that render the door or appliance unusable or impractical; the security of door passcodes kept by the landlord; and the potential invasion of privacy that comes with connecting smart home technologies to home networks.

Researchers have conducted user studies to determine what the barriers are for consumers when integrating home automation devices or systems into their daily lifestyle. One of the main takeaways was regarding ease of use, as consumers tend to steer towards "plug and play" solutions over more complicated setups. One study found that there were large gaps in the mental-models generated by users regarding how the devices work. Specifically, the findings showed that there was a lot of misunderstanding related to where the data collected by smart devices was stored and how it was used. For example, in a smart light setup, one participant thought that her iPad communicated directly with the light, telling it to either turn-off or on. In reality, the iPad sends a signal to the cloud system that the company uses which then signals to the device.

Home automation

Overall, this field is still evolving and the nature of each device is constantly changing. While technologists work to create more secure, streamlined, and standardized security protocols, consumers also need to learn more about how these devices work and what the implications of putting them in their homes can be. The growth of this field is currently limited not only by technology but also by a user's ability to trust a device and integrate it successfully into his/her daily life.

Application example

Electrical system for condominium services

The condominium consists of three floors above ground (GF, 1F, 2F) with two internal staircases; for each staircase there are two apartments on the first and second floors; porch, external square with garden.

On the ground floor there is the water plant, a communal room, storage rooms and garages for the individual apartments.

The garages face the open sky; therefore, they are not subject to the control of the Fire Brigade.

There are two entrances: one for vehicles with an automatic electric gate and the other for pedestrians with an electric lock.

User	Power (W)	note
Water plant and garden irrigation	2000	1
Electric gate	450	
Porch lighting (5 x 45 W)	225	2
Garden lamps (9 x 83 W)	747	3
Staircase lighting (evening) (14 x 18 W)	252	4
Staircase lighting (night) (6 x 8 W)	48	4
Common room lighting (3 x 45 W) (3 x 8W)	135 24	2 4
Attic lighting (2 x 18 W)	36	4
Wall mounted boiler in common room	200	
Power supply for auxiliary systems	200	
TOTAL	4317	

(1) three phase with neutral
(2) 36W linear fluorescent lamps (9W ballast losses)
(3) metal halide discharge lamps (power supply losses 13 W)
(4) compact fluorescent lamps

Application example

Given the loads, the contractual power is 6 kW three-phase.

The following auxiliary systems are also present: video intercom, centralized TV antenna, telephone distribution.

The meter for the common services and its general panel are installed in the entrance of staircase A.

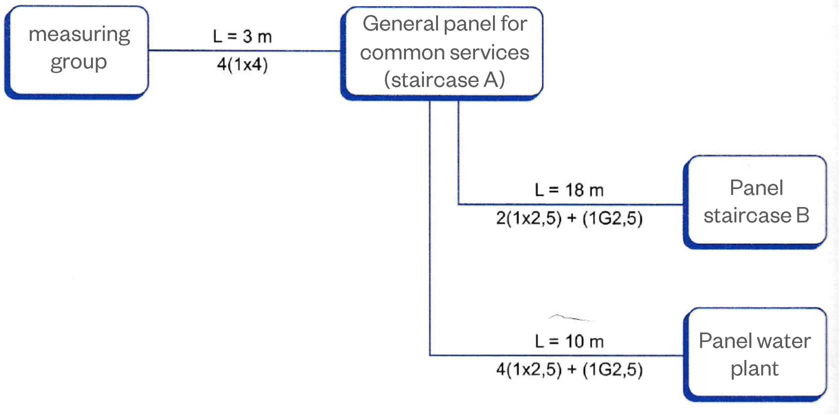
In the meter compartment are positioned: the junction box for the departure of the power lines of the water plant, of the external lights, of the automatic gate and of the internal common parts; the box for the departure of the video intercom risers and of the entrance door call; the box for the telephone distribution risers; the earth bar.

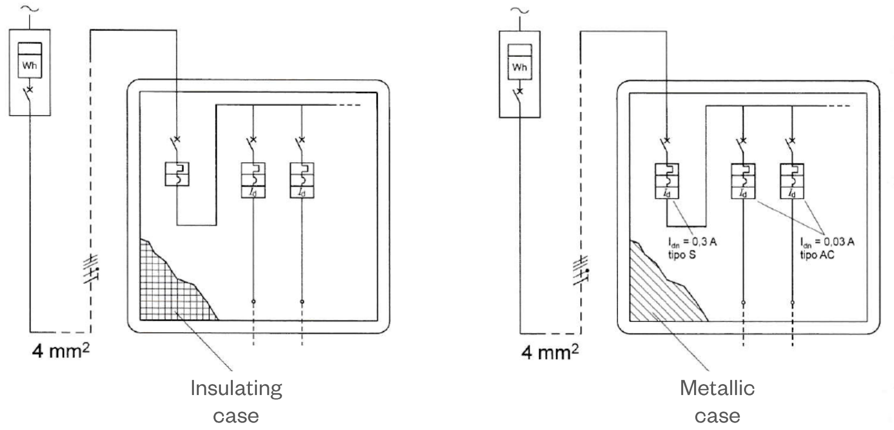
Application example

Electrical diagram

The system is divided into circuits connected to the main switchboard and the secondary switchboards.

Two schemes are proposed for the power supply of the main condominium services switchboard: one for the switchboard with metal casing and one for the switchboard with insulating casing.

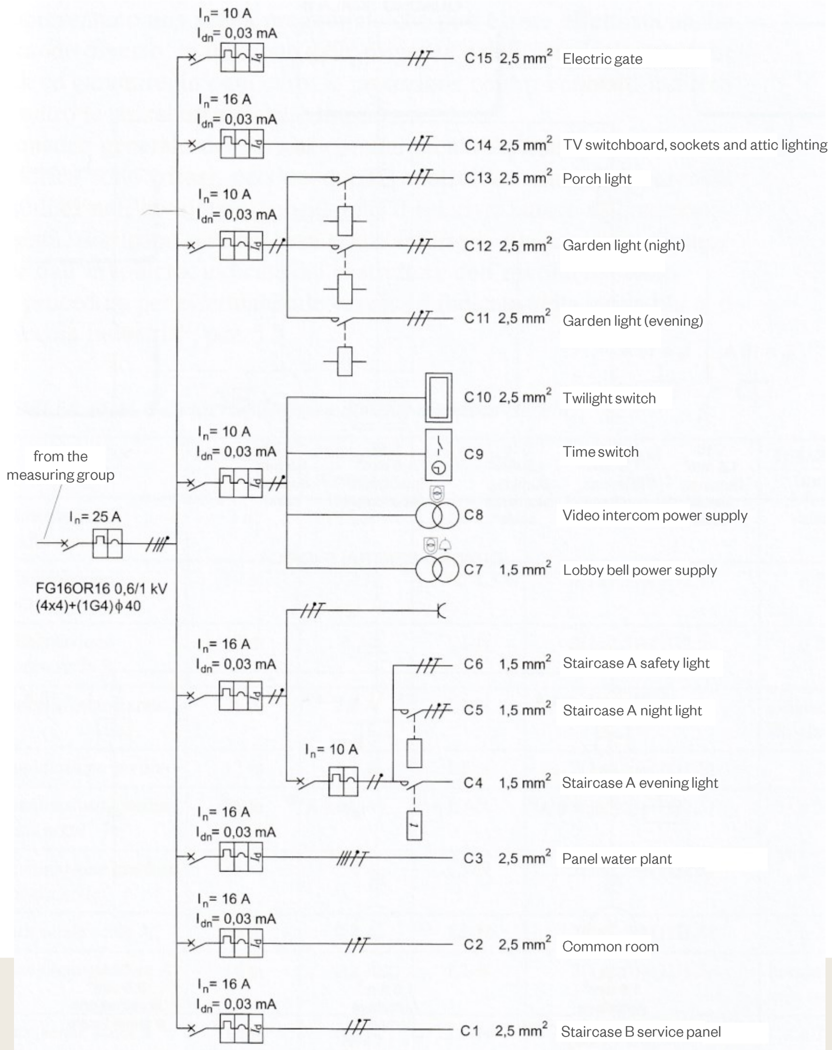




Application example

The division into circuits was carried out according to the power and position of the users.

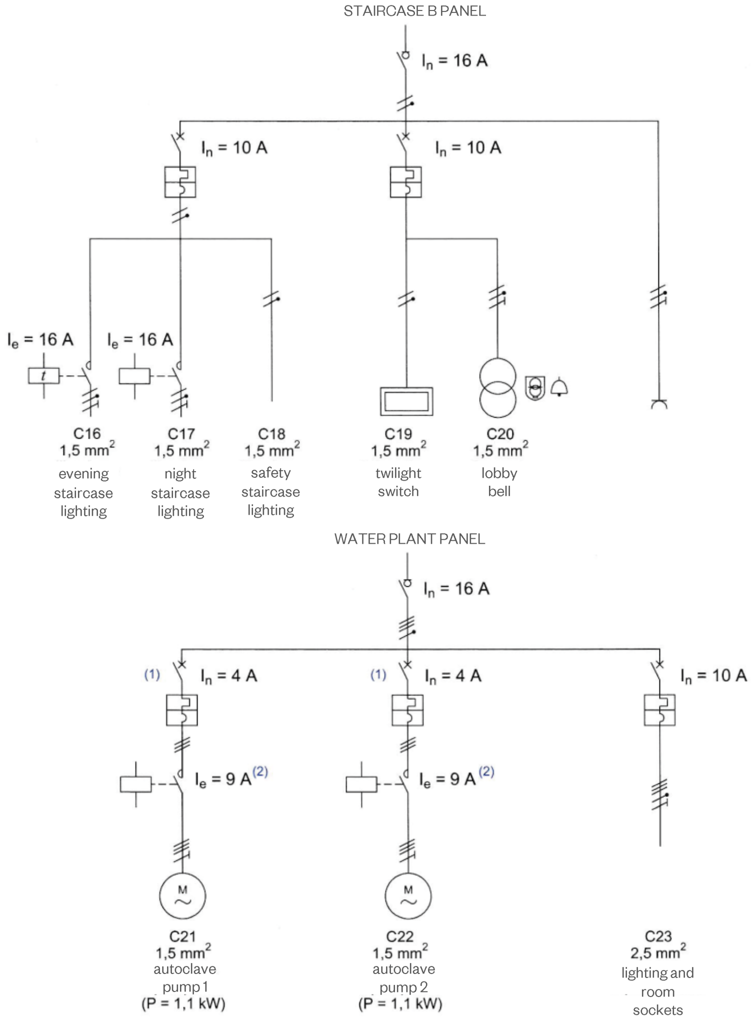
General scheme Staircase A panel



N.B. The contactor control circuits are derived from the respective protection switches placed upstream and have a section of 1.5 mm^2

Application example

General schemes Staircase B and water plant panels



(1) automatic thermo-magnetic breaker with adjustable thermal intervention current (2.5 - 4 A)

(2) rated operational current referred to category AC3 (starting and stopping of squirrel cage motors)

Application example

The division of the circuits and the relative diagrams represent a design choice that can also be made differently, depending on the needs and use of the systems; in any case, protection against indirect contacts and against overcurrents of the lines must be guaranteed.

The general switchboard of the common services (staircase A) and the switchboard of the water plant are three-phase, therefore it is necessary to carry out a check regarding the thermal power dissipated by the installed devices in relation to the one that can be dissipated by the switchboard itself (not covered in this course), as is the case for industrial switchboards.

Application example

Circuit sizing summary table

Circuit	Length (m)	Current (A)	Supply	Cables (mm^2)	Diam. tube (mm)
General panel power supply	3	12	L1-L2-L3-N	4(1x4)	Canal
Water plant power supply	10	3,4	L1-L2-L3-N	4(1x2,5)+(1G2,5)	25
Power supply Staircase B panel	18	6	L1-N	2(1x2,5)+(1G2,5)	25
Electric gate	36	2,3	L1-N	(2x2,5)+(1G2,5)	in garden lighting pipe
Porch lighting	12	1,1	L3-N	2(1x2,5)+(1G1,5)	20
Garden light (night)	36	1,9	L3-N	2(1x2,5)+(1G2,5)	50
Garden light (evening)	36	2,4	L3-N	2(1x2,5)+(1G2,5)	50
Staircase A evening light	16	0,8	L2-N	2(1x1,5)+(1G1,5)	25
Staircase A night light	16	0,2	L2-N	2(1x1,5)+(1G1,5)	In stairc. A lighting pipe
Staircase B evening light	16	0,8	L1-N	2(1x1,5)+(1G1,5)	25
Staircase B night light	16	0,2	L1-N	2(1x1,5)+(1G1,5)	In stairc. B lighting pipe
Common room	10	6	L2-N	2(1x2,5)+(1G2,5)	20
TV switchboard and attic	18	6	L3-N	2(1x2,5)+(1G2,5)	25

Application example

Electrical system equipment (condominium services)

Premises	Lighting	Sockets	Other	Note
Driveway gate			Motorized gate with photocell, flashing light and 2 key manipulators	Rules UNI EN 12445 and 12453
Garden	9 streetlamps on 3m high poles		Solenoid valves for irrigation (SELV power supply)	Streetlights with 70W metal halide lamps
Portico	5 ceiling light points			Automatic switch-on with twilight switch
Pedestrian gate			8-button keypad, external video intercom point, 1 electric gate lock, gate opener button	External buttons in IP44 case
Entrance hall and stairwell (each)	6 light points in the landings and in the hall with 5 control buttons, 3 safety light points, 3 night lights points		1 entrance door opener button, 1 pedestrian gate opener button (external), 1 electric door lock, 1 4-button keypad	
Staircase A meter compartment		1 outlet		
Meter compartment staircase B		1 outlet		
Common room	3 light points with switch, 3 service light points with 5 controls	4 outlets	Wall mounted boiler connection with automatic breaker	
Water plant	2 light points, 1 switch	2 outlets (single and three-phase industrial type)	2 connection points for electric pump, pressure switch and solenoid valves	Degree of protection IP44, control circuit SELV
Attic	2 light points, 1 switch	2 outlets	1 TV switchboard power supply point	Protection grade IP44

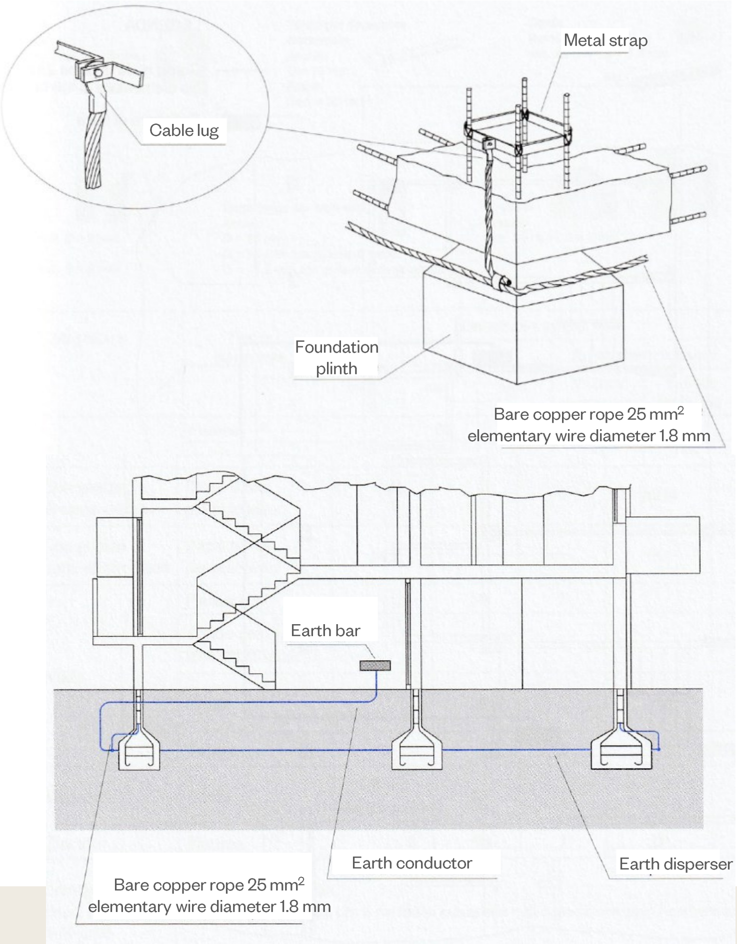
Application example

Grounding system

To create the grounding system, the foundation earth solution is chosen.

The ground conductors that connect the ground rods to the ground collectors are made of 25 mm^2 bare copper rope, with 1.8 mm elementary wire.

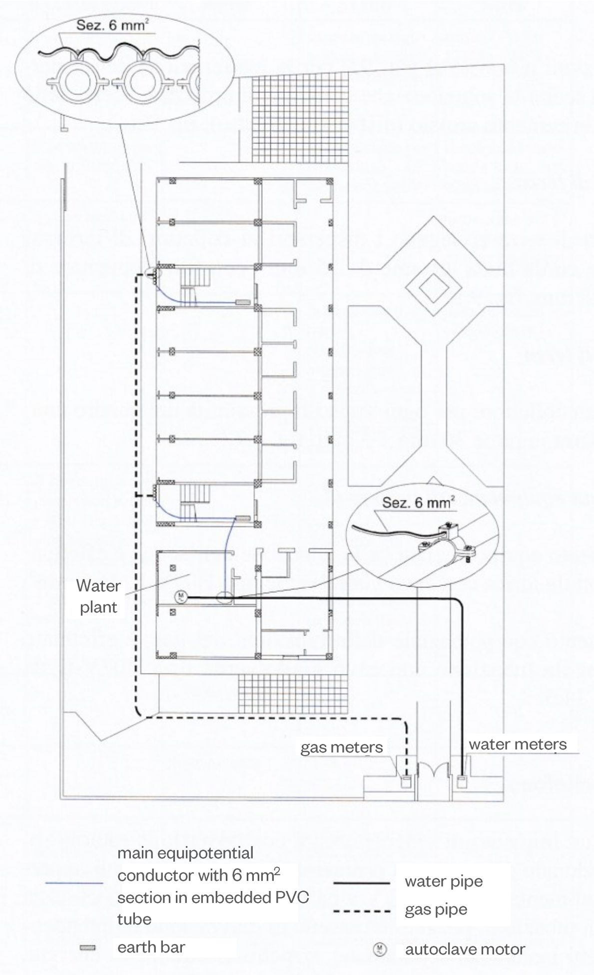
A ground bar is installed for each staircase, near the meter panel, with a 30 x 3 mm copper bar.



Application example

The equipotential connection of the water pipe is made in the water plant with a yellow/green cable type H07V-K 6 mm^2.

The equipotential connection of the gas pipes is made on each individual pipe with a yellow/green cable type H07V-K 6 mm^2.



Application example

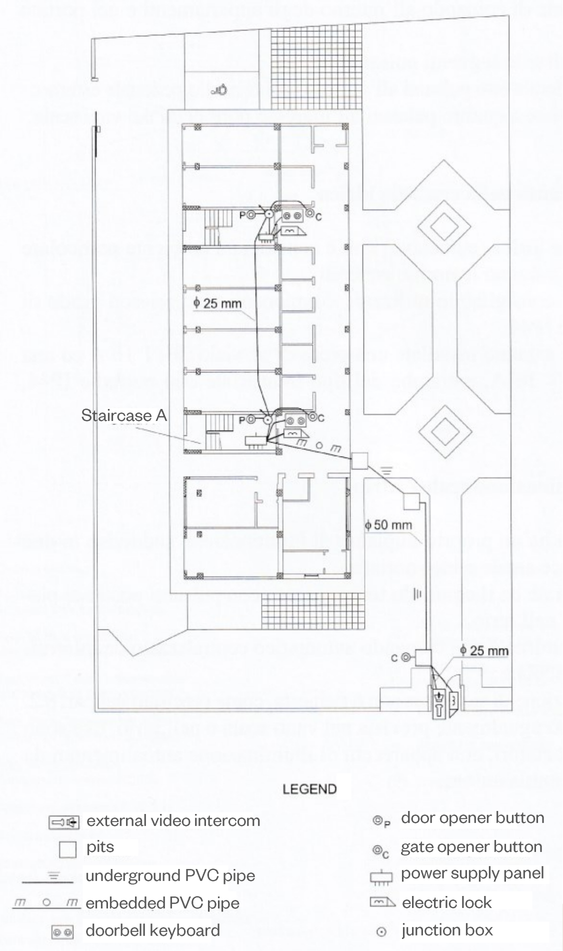
Video intercom

A video intercom system is planned, with an external station on the pedestrian entrance gate and internal stations in the individual apartments. The power supply is SELV at 12 V with independent pipes, pits and junction boxes, or with insulating separation partitions, with respect to the energy circuits.

The electric lock of the pedestrian gate is powered in SELV with a control button inside the apartments and in the external porch.

The following push-button panels are planned:

- 1 push-button panel with 8 buttons at the entrance of the external pedestrian gate;
- 2 push-button panels with 4 buttons at the entrance of the stairwell doors.



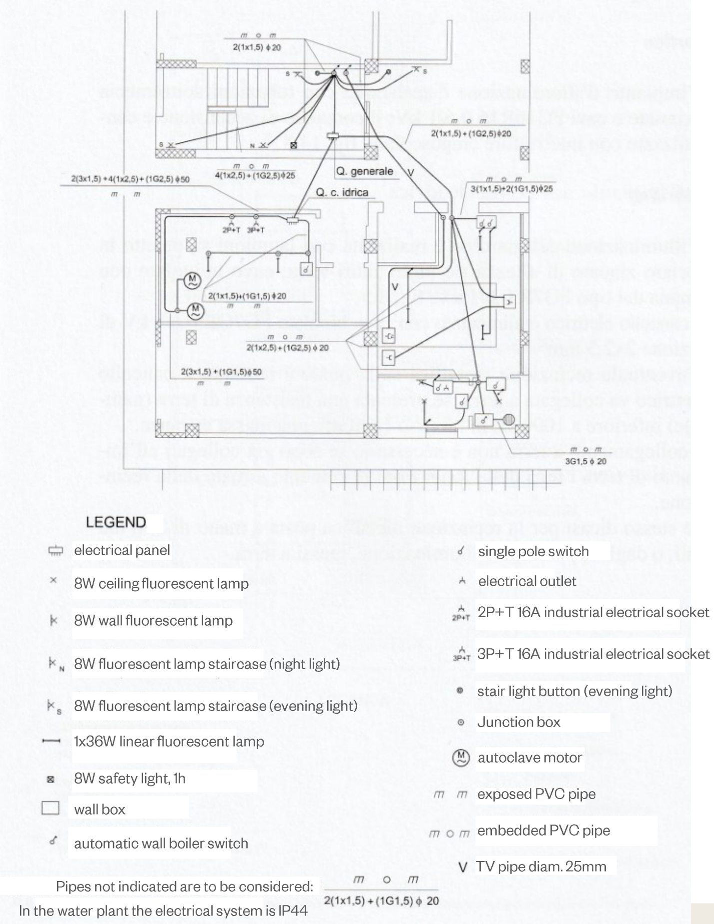
Application example

Electrical system in the water plant

The water plant is not considered a special environment and therefore the general rules apply.

However, it is advisable to use electrical components with IP44 protection rating (i.e., protected against solid foreign objects of 1 mm diameter and greater, protected against splashing water).

The room is equipped with a 2P+T 16 A service socket and a 3P+T 16 A socket, both of the industrial type with IP44 enclosures.



Application example

Staircase and hall lighting

Each staircase has its own lighting system divided into two circuits: evening light and night light.

The evening light has a timed control with buttons located on the landings and in the atrium.

The night light has a centralized automatic control by a twilight switch (it is recommended to install a selector on the control circuit to switch the control from automatic to manual, in case of need).

Safety lighting is not required by current regulations or laws for this type of environment. However, it has been provided in the stairwell and in the atrium, where the meters are located, with self-powered 8 W lighting devices, 1 hour autonomy.

Application example

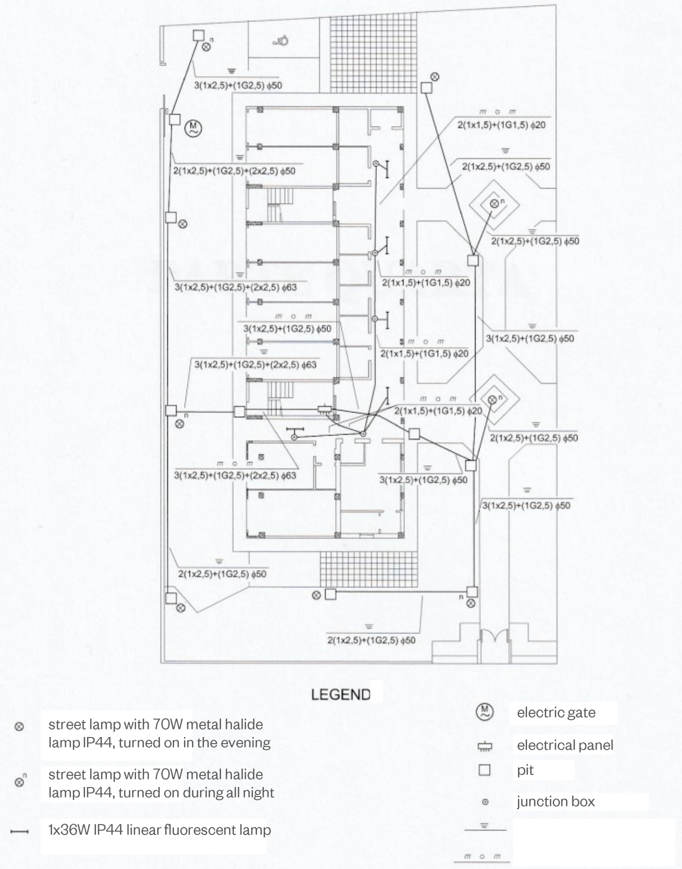
External electrical system

The porch lighting system is made with embedded under-floor pipes and FG16R16 0.6/1 kV cables; the switch-on control is centralized with twilight relay.

The garden lighting is made with street lamps mounted on 3m galvanized steel posts; single-core sheathed cable FG7R 0.6/1 kV.

The electric gate is powered by a FG7OR 0.6/1 kV bipolar cable with a section of 2x2.5 mm^2.

The metal fence on which the electric gate is mounted must be connected to earth if it has an earth resistance < 1000 Ω. The connection is not necessary if the iron of the reinforced concrete foundations of the fence have already been connected to the earth system. The same applies to the metal fence located less than 2 m from the poles or lighting fixtures connected to earth.



the power supply for the street lamps is in cable with sheath while the motorized gate is in bipolar cable with sheath

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dipartimento di ingegneria e architettura

Electrical systems design – part II

Fundamentals of Modern Power Systems

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