Electrical installation guide

According to IEC international standards

Schneider Electric

This guide has been written for electrical Engineers who have to design, select electrical equipment, install these equipment and, inspect or maintain low-voltage electrical installations in compliance with international Standards of the International Electrotechnical Commission (IEC).
“Which technical solution will guarantee that all relevant safety rules are met?” This question has been a permanent guideline for the elaboration of this document.

An international Standard such as the IEC 60364 series “Low voltage Electrical Installations” specifies extensively the rules to comply with to ensure safety and correct operational functioning of all types of electrical installations. As the Standard must be extensive, and has to be applicable to all types of equipment and the technical solutions in use worldwide, the text of the IEC rules is complex, and not presented in a ready-to-use order. The Standard cannot therefore be considered as a working handbook, but only as a reference document.

The aim of the present guide is to provide a clear, practical and step-by-step explanation for the complete study of an electrical installation, according to IEC 60364 series and other relevant IEC Standards. The first chapter (A) presents the methodology to be used, and refers to all chapters of the guide according to the different steps of the study.

We all hope that you, the reader, will find this handbook genuinely helpful.

Schneider Electric S.A.

This technical guide is the result of a collective effort. Responsible for the coordination of this edition: Laurent MISCHLER

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The Electrical Installation Guide is a single document covering the techniques and standards related to low-voltage electrical installations.
It is intended for electrical professionals in companies, design offices, inspection organisations, etc.

This Technical Guide is aimed at professional users and is only intended to provide them guidelines for the definition of an industrial, tertiary or domestic electrical installation. Information and guidelines contained in this Guide are provided AS IS. Schneider Electric makes no warranty of any kind, whether express or implied, such as but not limited to the warranties of merchantability and fitness for a particular purpose, nor assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed in this Guide, nor represents that its use would not infringe privately owned rights.
The purpose of this guide is to facilitate the implementation of International installation standards for designers & contractors, but in all cases the original text of International or local standards in force shall prevail.

This new edition has been published to take into account changes in techniques, standards and regulations, in particular electrical installation standard IEC 60364 series.

We thank all the readers of the previous edition of this guide for their comments that have helped improve the current edition.
We also thank the many people and organisations, too numerous to name here, who have contributed in one way or another to the preparation of this guide.

Acknowlegements

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We shall mention particularly the following experts and their area of expertise:

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Tools for more efficiency in electrical installation design

Electrical installation Wiki

The Electrical Installation Guide is also available on-line as a wiki in 4 languages:

- > in English en.electrical-installation.org
- > in Russian ru.electrical-installation.org
- > in Chinese cn.electrical-installation.org
- > in German de.electrical-installation.org

English

Russian

Chinese

German

Our experts constantly contribute to its evolution. Industry and academic professionals can collaborate too!

Power Management Blog

In the Schneider Electric blog, you will find the best tips about standards, tools, software, safety and latest technical news shared by our experts. You will find even more information about innovations and business opportunities. This is your place to leave us your comments and to engage discussion about your expertise. You might want to share with your Twitter or LinkedIn followers.

blog.schneider-electric.com/power-management-metering-monitoring-power-quality

Online tools

Online Electrical calculation Tools

A set of tools designed to help you:
- display on one chart the time-current curves of different circuit-breakers or fuses
- check the discrimination between two circuit-breakers or fuses, or two Residual Current devices (RCD), search all the circuit-breakers or fuses that can be selective/cascading with a defined circuit-breaker or fuse
- calculate the Cross Section Area of cables and build a cable schedule
- calculate the voltage drop of a defined cable and check the maximum length

hto.power.schneider-electric.com/int/en

Ecodial Advanced Calculation 4

The new Ecodial Advanced Calculation 4 software is dedicated to electrical installation calculation in accordance with IEC60364 international standard or national standards.

This 4th generation offers new features like:
- management of operating mode (parallel transformers, back-up generators…)
- discrimination analysis associating curves checking and discrimination tables, direct access to protection settings

Foreword

Etienne TISON, International Electrotechnical Commission (IEC) TC64 Chairman.
The task of the IEC Technical Committee 64 is to develop and keep up-to-date requirements
- for the protection of persons against electrical shock, and
- for the design, verification and implementation of low voltage electrical installations.

Series of standard such as IEC 60364 developed by IEC TC64 is considered by the international community as the basis of the majority of national low-voltage wiring rules.

IEC 60364 series is mainly focussed on safety due the use of electricity by people who may not be aware of risk resulting from the use of electricity.

But modern electrical installations are increasingly complex, due to external input such as
- electromagnetic disturbances
- energy efficiency
- ...

Consequently, designers, installers and consumers need guidance on the selection and installation of electrical equipment.

Schneider Electric has developed this Electrical Installation Guide dedicated to low voltage electrical installations. It is based on IEC TC64 standards such as IEC 60364 series and provides additional information in order to help designers, contractors and controllers for implementing correct low-voltage electrical installations.

As TC64 Chairman, it is my great pleasure and honour to introduce this guide. I am sure it will be used fruitfully by all persons involved in the implementation of all low-voltage electrical installations.

Etienne TISON

Etienne TISON has been working with Schneider Electric since 1978. He has been always involved is various activities in low voltage field.
In 2008, Etienne TISON has been appointed Chairman of IEC TC64 as well as Chairman of CENELEC TC64.

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1 Methodology

For the best results in electrical installation design it is recommended to read and to use all the chapters of this guide in the order in which they are presented.

A - General rules of electrical installation design

Rules and statutory regulations

Range of low-voltage extends from 0 V to 1000 V in a.c. and from 0 V to 1500 V in d.c. One of the first decision is the selection of type of current between the alternative current which corresponds to the most common type of current through out the world and the direct current. Then designers have to select the most appropriate rated voltage within these ranges of voltages. When connected to a LV public network, the type of current and the rated voltage are already selected and imposed by the Utility.
Compliance with national regulations is then the second priority of the designers of electrical installation. Regulations may be based on national or international standards such as the IEC 60364 series.
Selection of equipment complying with national or international product standards and appropriate verification of the completed installation is a powerful mean for providing a safe installation with the expected quality. Defining and complying with the verification and testing of the electrical installation at its completion as well as periodic time will guarantee the safety and the quality of this installation all along its life cycle. Conformity of equipment according to the appropriate product standards used within the installation is also of prime importance for the level of safety and quality.
Environmental conditions will become more and more stringent and will need to be considered at the design stage of the installation. This may include national or regional regulations considering the material used in the equipment as well as the dismantling of the installation at its end of life.

A§3 - Installed power loads - Characteristics
A§4 - Power loading of an installation

Installed power loads - Characteristics

A review of all applications needing to be supplied with electricity is to be done. Any possible extensions or modifications during the whole life of the electrical installation are to be considered. Such a review aimed to estimate the current flowing in each circuit of the installation and the power supplies needed.

The total current or power demand can be calculated from the data relative to the location and power of each load, together with the knowledge of the operating modes (steady state demand, starting conditions, non simultaneous operation, etc.)

Estimation of the maximum power demand may use various factors depending on the type of application; type of equipment and type of circuits used within the electrical installation.

From these data, the power required from the supply source and (where appropriate) the number of sources necessary for an adequate supply to the installation is readily obtained.

Local information regarding tariff structures is also required to allow the best choice of connection arrangement to the power-supply network, e.g. at medium voltage or low voltage level.

B - Connection to the MV utility distribution network

Connection to the MV public distribution network

Where this connection is made at the Medium Voltage level a consumer-type substation will have to be studied, built and equipped. This substation may be an outdoor or indoor installation conforming to relevant standards and regulations (the low-voltage section may be studied separately if necessary). Metering at medium-voltage or low-voltage is possible in this case.

C - Connection to the LV utility distribution network

Connection to the LV utility distribution network

Where the connection is made at the Low Voltage level the installation will be connected to the local power network and will (necessarily) be metered according to LV tariffs.

D - MV & LV architecture selection guide

MV & LV architecture selection guide

The whole electrical system including the MV installation and the LV installation is to be studied as a complete system. The customer expectations and technical parameters will impact the architecture of the system as well as the electrical installation characteristics.

Determination of the most suitable architecture of the MV/LV main distribution and LV power distribution level is often the result of optimization and compromise.

Neutral earthing arrangements are chosen according to local regulations, constraints related to the power-supply, and to the type of loads.

The distribution equipment (panelboards, switchgears, circuit connections, ...) are determined from building plans and from the location and grouping of loads.

The type of premises and allocation can influence their immunity to external disturbances.

E - LV Distribution

LV distribution

The system earthing is one protective measure commonly used for the protection against electric shocks. These systems earthings have a major impact on the LV electrical installation architecture and they need to be analysed as early as possible. Advantages and drawbacks are to be analysed for a correct selection.

Another aspect needing to be considered at the earlier stage is the external influences. In large electrical installation, different external influences may be encountered and need to be considered independently. As a result of these external influences proper selection of equipment according to their IP or IK codes has to be made.

F - Protection against electric shocks & electric fires

Protection against electric shocks & electric fires

Protection against electric shock consists in providing provision for basic protection (protection against direct contact) with provision for fault protection (protection against indirect contact). Coordinated provisions result in a protective measure. One of the most common protective measures consists in “automatic disconnection of supply” where the provision for fault protection consists in the implementation of a system earthing. Deep understanding of each standardized system (TT, TN and IT system) is necessary for a correct implementation.

Electrical fires are caused by overloads, short circuits and earth leakage currents, but also by electric arcs in cables and connections. These dangerous electric arcs are not detected by residual current devices nor by circuit breakers or fuses. The arc fault detector technology makes it possible to detect dangerous arcs and thus provide additional protection of installations. See chapter F §9 for more information.

G - Sizing and protection of conductors

Sizing and protection of conductors

Selection of cross-sectional-areas of cables or isolated conductors for line conductors is certainly one of the most important tasks of the design process of an electrical installation as this greatly influences the selection of overcurrent protective devices, the voltage drop along these conductors and the estimation of the prospective short-circuit currents: the maximum value relates to the overcurrent protection and the minimum value relates to the fault protection by automatic disconnection of supply. This has to be done for each circuit of the installation. Similar task is to be done for the neutral conductor and for the Protective Earth (PE) conductor.

H - LV switchgear: functions & selection

LV switchgear: functions & selection

Once the short-circuit current are estimated, protective devices can be selected for the overcurrent protection. Circuit breakers have also other possible functions such as switching and isolation. A complete understanding of the functionalities offered by all switchgear and controlgear within the installation is necessary. Correct selection of all devices can now be done.

A comprehensive understanding of all functionalities offered by the circuit breakers is of prime importance as this is the device offering the largest variety of functions.

J - Overvoltage protection

Overvoltage protection

Direct or indirect lightning strokes can damage electrical equipment at a distance of several kilometres. Operating voltage surges, transient and industrial frequency over-voltage can also produce the same consequences. All protective measures against overvoltage need to be assessed. One of the most used corresponds to the use of **S**urge **P**rotective **D**evices (SPD). Their selection; installation and protection within the electrical installation request some particular attention.

K – Energy efficiency in electrical distribution

Energy efficiency in electrical distribution

Implementation of active energy efficiency measures within the electrical installation can produce high benefits for the user or owner: reduced power consumption, reduced cost of energy, better use of electrical equipment. These measures will most of the time request specific design for the installation as measuring electricity consumption either per application (lighting, heating, process…) or per area (floor, workshop) present particular interest for reducing the electricity consumption still keeping the same level of service provided to the user.

L - Power Factor Correction

Reactive energy

The power factor correction within electrical installations is carried out locally, globally or as a combination of both methods. Improving the power factor has a direct impact on the billing of consumed electricity and may also have an impact on the energy efficiency.

M - Harmonic management

Harmonics

Harmonic currents in the network affect the quality of energy and are at the origin of many disturbances as overloads, vibrations, ageing of equipment, trouble of sensitive equipment, of local area networks, telephone networks. This chapter deals with the origins and the effects of harmonics and explain how to measure them and present the solutions.

N - Characteristics of particular sources and loads

Particular supply sources and loads

Particular items or equipment are studied:

- Specific sources such as alternators or inverters
- Specific loads with special characteristics, such as induction motors, lighting circuits or LV/LV transformers
- Specific systems, such as direct-current networks.

P - Photovoltaic Installations

A green and economical energy

The solar energy development has to respect specific installation rules.

Q - Residential and other special locations

Generic applications

Certain premises and locations are subject to particularly strict regulations: the most common example being residential dwellings.

R - EMC guidelines

EMC Guidelines

Some basic rules must be followed in order to ensure Electromagnetic Compatibility. Non observance of these rules may have serious consequences in the operation of the electrical installation: disturbance of communication systems, nuisance tripping of protection devices, and even destruction of sensitive devices.

S - Measurement

Measurement

Measurement is becoming more and more an essential part of the electrical installations. Chapter S is an introduction to the different applications of measurements, such as energy efficiency, energy usage analysis, billing, cost allocation, power quality ... It also provides a panorama of the relevant standards for these applications, with a special focus on the IEC 61557-12 related to Power Metering and monitoring devices (PMD).

A companion tool of the Electrical Installation Guide

Ecodial software

Ecodial software[1] provides a complete design package for LV installations, in accordance with IEC standards and recommendations.

The following features are included:

- Construction of one-line diagrams
- Calculation of short-circuit currents according to several operating modes (normal, back-up, load shedding)
- Calculation of voltage drops
- Optimization of cable sizes
- Required ratings and settings of switchgear and fusegear
- Discrimination of protective devices
- Optimization of switchgear using cascading
- Verification of the protection of people and circuits
- Comprehensive print-out of the foregoing calculated design data

There is a number of tools which can help to speed-up the design process. As an example, to choose a combination of components to protect and control an asynchronous motor, with proper coordination (type 1, 2 or total, as defined in international standard IEC 60947-4-1), rather than selecting this combination using paper tables, it is much faster to use tools such as the Low Voltage Motor Starter Solution Guide.

(1) Ecodial is a Schneider Electric software available in several languages and according to different electrical installation standards.

Low-voltage installations are usually governed by a number of regulatory and advisory texts, which may be classified as follows:

- Statutory regulations (decrees, factory acts, etc.)
- Codes of practice, regulations issued by professional institutions, job specifications
- National and international standards for installations
- National and international standards for products

2.1 Definition of voltage ranges

IEC voltage standards and recommendations

Three-phase four-wire or three-wire systems Nominal voltage (V)		**Single-phase three-wire systems Nominal voltage (V)**
50 Hz	60 Hz	60 Hz
–	120/208	120/240[d]
230[c]	240[c]	–
230/400[a]	230/400[a]	–
–	277/480	–
–	480	–
–	347/600	–
–	600	–
400/690[b]	–	–
1000	600	–

(a) The value of 230/400 V is the result of the evolution of 220/380 V and 240/415 V systems which has been completed in Europe and many other countries. However, 220/380 V and 240/415 V systems still exist.
(b) The value of 400/690 V is the result of the evolution of 380/660 V systems which has been completed in Europe and many other countries. However, 380/660 V systems still exist.
(c) The value of 200 V or 220 V is also used in some countries.
(d) The values of 100/200 V are also used in some countries on 50 Hz or 60 Hz systems.

Fig. A1: Standard voltages between 100 V and 1000 V (IEC 60038 Edition 7.0 2009-06) [(1)]

Series I			**Series II**	
Highest voltage for equipment (kV)	**Nominal system voltage (kV)**		**Highest voltage for equipment (kV)**	**Nominal system voltage (kV)**
3.6[b]	3.3[b]	3[b]	4.40[b]	4.16[b]
7.2[b]	6.6[b]	6[b]	–	–
12	11	10	–	–
–	–	–	13.2[c]	12.47[c]
–	–	–	13.97[c]	13.2[c]
–	–	–	14.52[b]	13.8[b]
(17.5)	–	(15)	–	–
24	22	20	–	–
–	–	–	26.4[c, e]	24.94[c, e]
36[d]	33[d]	30[d]	–	–
–	–	–	36.5[c]	34.5[c]
40.5[d]	–	35[d]	–	–

Note 1: It is recommended that in any one country the ratio between two adjacent nominal voltages should be not less than two.
Note 2: In a normal system of Series I, the highest voltage and the lowest voltage do not differ by more than approximately ±10 % from the nominal voltage of the system. In a normal system of Series II, the highest voltage does not differ by more than +5 % and the lowest voltage by more than -10 % from the nominal voltage of the system.
(a) These systems are generally three-wire systems, unless otherwise indicated. The values indicated are voltages between phases.
The values indicated in parentheses should be considered as non-preferred values. It is recommended that these values should not be used for new systems to be constructed in future.
(b) These values should not be used for new public distribution systems.
(c) These systems are generally four-wire systems and the values indicated are voltages between phases. The voltage to neutral is equal to the indicated value divided by 1.73.
(d) The unification of these values is under consideration.
(e) The values of 22.9 kV for nominal voltage and 24.2 kV or 25.8 kV for highest voltage for equipment are also used in some countries.

Fig. A2: AC 3 phases Standard voltages above 1 kV and not exceeding 35 kV (IEC 60038 Edition 7.0 2009) [(a)]

(1) ■ the lower values in the first and second columns are voltages to neutral and the higher values are voltages between phases. When one value only is indicated, it refers to three-wire systems and specifies the voltage between phases. The lower value in the third column is the voltage to neutral and the higher value is the voltage between lines.

■ voltages in excess of 230/400 V are intended for heavy industrial applications and large commercial premises.

■ concerning supply voltage range, under normal operating conditions, the supply voltage should not differ from the nominal voltage of the system by more than ±10 %.

2.2 Regulations

In most countries, electrical installations shall comply with more than one set of regulations, issued by National Authorities or by recognized private bodies. It is essential to take into account these local constraints before starting the design. These regulations may be based on national standards derived from the IEC 60364: Low-voltage electrical installations.

2.3 Standards

This Guide is based on relevant IEC standards, in particular IEC 60364. IEC 60364 has been established by engineering experts of all countries in the world comparing their experience at an international level. Currently, the safety principles of IEC 60364 series, IEC 61140, 60479 series and IEC 61201 are the fundamentals of most electrical standards in the world (see table below and next page).

IEC 60038	IEC standard voltages
IEC 60051 series	Direct acting indicating analogue electrical measuring instruments and their accessories
IEC 60071-1	Insulation co-ordination - Definitions, principles and rules
IEC 60076-1	Power transformers - General
IEC 60076-2	Power transformers - Temperature rise for liquid immersed transformers
IEC 60076-3	Power transformers - Insulation levels, dielectric tests and external clearances in air
IEC 60076-5	Power transformers - Ability to withstand short-circuit
IEC 60076-7	Power transformers - Loading guide for oil-immersed power transformers
IEC 60076-10	Power transformers - Determination of sound levels
IEC 60076-11	Power transformers - Dry-type transformers
IEC 60076-12	Power transformers - Loading guide for Dry-type power transformers
IEC 60146-1-1	Semiconductor converters - General requirements and line commutated converters - Specifications of basic requirements
IEC 60255-1	Measuring relays and protection equipment - Common requirements
IEC 60269-1	Low-voltage fuses - General requirements
IEC 60269-2	Low-voltage fuses - Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) - Examples of standardized systems of fuses A to K
IEC 60282-1	High-voltage fuses - Current-limiting fuses
IEC 60287-1-1	Electric cables - Calculation of the current rating - Current rating equations (100 % load factor) and calculation of losses - General
IEC 60364-1	Low-voltage electrical installations - Fundamental principles, assessment of general characteristics, definitions
IEC 60364-4-41	Low-voltage electrical installations - Protection for safety - Protection against electric shock
IEC 60364-4-42	Low-voltage electrical installations - Protection for safety - Protection against thermal effects
IEC 60364-4-43	Low-voltage electrical installations - Protection for safety - Protection against overcurrent
IEC 60364-4-44	Low-voltage electrical installations - Protection for safety - Protection against voltage disturbances and electromagnetic disturbances
IEC 60364-5-51	Low-voltage electrical installations - Selection and erection of electrical equipment - Common rules
IEC 60364-5-52	Low-voltage electrical installations - Selection and erection of electrical equipment - Wiring systems
IEC 60364-5-53	Low-voltage electrical installations - Selection and erection of electrical equipment - Isolation, switching and control
IEC 60364-5-54	Low-voltage electrical installations - Selection and erection of electrical equipment - Earthing arrangements and protective conductors
IEC 60364-5-55	Low-voltage electrical installations - Selection and erection of electrical equipment - Other equipment
IEC 60364-6	Low-voltage electrical installations - Verification
IEC 60364-7-701	Low-voltage electrical installations - Requirements for special installations or locations - Locations containing a bath or shower
IEC 60364-7-702	Low-voltage electrical installations - Requirements for special installations or locations - Swimming pools and fountains
IEC 60364-7-703	Low-voltage electrical installations - Requirements for special installations or locations - Rooms and cabins containing sauna heaters
IEC 60364-7-704	Low-voltage electrical installations - Requirements for special installations or locations - Construction and demolition site installations
IEC 60364-7-705	Low-voltage electrical installations - Requirements for special installations or locations - Agricultural and horticultural premises
IEC 60364-7-706	Low-voltage electrical installations - Requirements for special installations or locations - Conducting locations with restrictive movement
IEC 60364-7-708	Low-voltage electrical installations - Requirements for special installations or locations - Caravan parks, camping parks and similar locations
IEC 60364-7-709	Low-voltage electrical installations - Requirements for special installations or locations - Marinas and similar locations
IEC 60364-7-710	Low-voltage electrical installations - Requirements for special installations or locations - Medical locations
IEC 60364-7-711	Low-voltage electrical installations - Requirements for special installations or locations - Exhibitions, shows and stands
IEC 60364-7-712	Low-voltage electrical installations - Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
IEC 60364-7-713	Low-voltage electrical installations - Requirements for special installations or locations - Furniture
IEC 60364-7-714	Low-voltage electrical installations - Requirements for special installations or locations - External lighting installations
IEC 60364-7-715	Low-voltage electrical installations - Requirements for special installations or locations - Extra-low-voltage lighting installations
IEC 60364-7-717	Low-voltage electrical installations - Requirements for special installations or locations - Mobile or transportable units
IEC 60364-7-718	Low-voltage electrical installations - Requirements for special installations or locations - Communal facilities and workplaces
IEC 60364-7-721	Low-voltage electrical installations - Requirements for special installations or locations - Electrical installations in caravans and motor caravans
IEC 60364-7-729	Low-voltage electrical installations - Requirements for special installations or locations - Operating or maintenance gangways
IEC 60364-7-740	Low-voltage electrical installations - Requirements for special installations or locations - Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses
IEC 60364-7-753	Low-voltage electrical installations - Requirements for special installations or locations - Heating cables and embedded heating systems
IEC 60364-8-1	Low-voltage electrical installations - Energy efficiency
IEC 60446	Basic and safety principles for man-machine interface, marking and identification - Identification of equipment terminals, conductors terminations and conductors
IEC 60479-1	Effects of current on human beings and livestock - General aspects
IEC 60479-2	Effects of current on human beings and livestock - Special aspects
IEC 60479-3	Effects of current on human beings and livestock - Effects of currents passing through the body of livestock
IEC 60529	Degrees of protection provided by enclosures (IP code)
IEC 60644	Specification for high-voltage fuse-links for motor circuit applications

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IEC 60664	Insulation coordination for equipment within low-voltage systems - all parts
IEC 60715	Dimensions of low-voltage switchgear and controlgear. Standardized mounting on rails for mechanical support of electrical devices in switchgear and controlgear installations.
IEC 60724	Short-circuit temperature limits of electric cables with rated voltages of 1 kV (Um = 1.2 kV) and 3 kV (Um = 3.6 kV)
IEC 60755	General requirements for residual current operated protective devices
IEC 60787	Application guide for the selection of high-voltage current-limiting fuses-link for transformer circuit
IEC 60831-1	Shunt power capacitors of the self-healing type for a.c. systems having a rated voltage up to and including 1000 V - Part 1: General - Performance, testing and rating - Safety requirements - Guide for installation and operation
IEC 60831-2	Shunt power capacitors of the self-healing type for a.c. systems having a rated voltage up to and including 1000 V - Part 2: Ageing test, self-healing test and destruction test
IEC 60947-1	Low-voltage switchgear and controlgear - General rules
IEC 60947-2	Low-voltage switchgear and controlgear - Circuit breakers
IEC 60947-3	Low-voltage switchgear and controlgear - Switches, disconnectors, switch-disconnectors and fuse-combination units
IEC 60947-4-1	Low-voltage switchgear and controlgear - Contactors and motor-starters - Electromechanical contactors and motor-starters
IEC 60947-6-1	Low-voltage switchgear and controlgear - Multiple function equipment - Transfer switching equipment
IEC 61000 series	Electromagnetic compatibility (EMC)
IEC 61140	Protection against electric shocks - common aspects for installation and equipment
IEC 61201	Use of conventional touch voltage limits - Application guide
IEC/TR 61439-0	Low-voltage switchgear and controlgear assemblies - Guidance to specifying assemblies
IEC 61439-1	Low-voltage switchgear and controlgear assemblies - General rules
IEC 61439-2	Low-voltage switchgear and controlgear assemblies - Power switchgear and controlgear assemblies
IEC 61439-3	Low-voltage switchgear and controlgear assemblies - Distribution boards intended to be operated by ordinary persons (DBO)
IEC 61439-4	Low-voltage switchgear and controlgear assemblies - Particular requirements for assemblies for construction sites (ACS)
IEC 61439-5	Low-voltage switchgear and controlgear assemblies - Assemblies for power distribution in public networks
IEC 61439-6	Low-voltage switchgear and controlgear assemblies - Busbar trunking systems (busways)
IEC 61557-1	Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. - Equipment for testing, measuring or monitoring of protective measures - General requirements
IEC 61557-8	Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. - Equipment for testing, measuring or monitoring of protective measures - Insulation monitoring devices for IT systems
IEC 61557-9	Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. - Equipment for testing, measuring or monitoring of protective measures - Equipment for insulation fault location in IT systems
IEC 61557-12	Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. - Equipment for testing, measuring or monitoring of protective measures - Performance measuring and monitoring devices (PMD)
IEC 61558-2-6	Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1100 V - Particular requirements and test for safety isolating transformers and power supply units incorporating isolating transformers
IEC 61643-11	Low-voltage surge protective devices - Surge protective devices connected to low-voltage power systems - Requirements and test methods
IEC 61643-12	Low-voltage surge protective devices - Surge protective devices connected to low-voltage power distribution systems - Selection and application principles
IEC 61643-21	Low voltage surge protective devices - Surge protective devices connected to telecommunications and signalling networks - Performance requirements and testing methods
IEC 61643-22	Low-voltage surge protective devices - Surge protective devices connected to telecommunications and signalling networks - Selection and application principles
IEC 61921	Power capacitors - Low-voltage power factor correction banks
IEC 61936-1	Power installations exceeding 1 kV a.c. - Part 1: Common rules
IEC 62271-1	High-voltage switchgear and controlgear - Common specifications
IEC 62271-100	High-voltage switchgear and controlgear - Alternating-current circuit breakers
IEC 62271-101	High-voltage switchgear and controlgear - Synthetic testing
IEC 62271-102	High-voltage switchgear and controlgear - Alternating current disconnectors and earthing switches
IEC 62271-103	High-voltage switchgear and controlgear - Switches for rated voltages above 1 kV up to and including 52 kV
IEC 62271-105	High-voltage switchgear and controlgear - Alternating current switch-fuse combinations for rated voltages above 1 kV up to and including 52 kV
IEC 62271-200	High-voltage switchgear and controlgear - Alternating current metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
IEC 62271-202	High-voltage switchgear and controlgear - High-voltage/low voltage prefabricated substations
IEC 62305-1	Protection against lightning - Part 1: General principles
IEC 62305-2	Protection against lightning - Part 2: Risk management
IEC 62305-3	Protection against lightning - Part 3: Physical damage to structures and life hazard
IEC 62305-4	Protection against lightning - Part 4: Electrical and electronic systems within structures
IEC 62586-2	Power quality measurement in power supply systems - Part 2: Functional tests and uncertainty requirements
IEC TS 62749	Assessment of power quality - Characteristics of electricity supplied by public networks

(Concluded)

2.4 Quality and safety of an electrical installation

In so far as control procedures are respected, quality and safety will be assured only if:

- The design has been done according to the latest edition of the appropriate wiring rules
- The electrical equipment comply with relevant product standards
- The initial checking of conformity of the electrical installation with the standard and regulation has been achieved
- The periodic checking of the installation recommended is respected.

2.5 Initial testing of an installation

Before a utility will connect an installation to its supply network, strict pre-commissioning electrical tests and visual inspections by the authority, or by its appointed agent, must be satisfied.

These tests are made according to local (governmental and/or institutional) regulations, which may differ slightly from one country to another. The principles of all such regulations however, are common, and are based on the observance of rigorous safety rules in the design and realization of the installation.

IEC 60364-6 and related standards included in this guide are based on an international consensus for such tests, intended to cover all the safety measures and approved installation practices normally required for residential, commercial and (the majority of) industrial buildings. Many industries however have additional regulations related to a particular product (petroleum, coal, natural gas, etc.). Such additional requirements are beyond the scope of this guide.

The pre-commissioning electrical tests and visual-inspection checks for installations in buildings include, typically, all of the following:

- Electrical continuity and conductivity tests of protective, equipotential and earth-bonding conductors
- Insulation resistance tests between live conductors and the protective conductors connected to the earthing arrangement
- Test of compliance of SELV (Safety Extra Low Voltage) and PELV (Protection by Extra Low Voltage) circuits or for electrical separation
- Insulation resistance/impedance of floors and walls
- Protection by automatic disconnection of the supply
  - For TN, by measurement of the fault loop impedance, and by verification of the characteristics and/or the effectiveness of the associated protective devices (overcurrent protective device and RCD)
  - For TT, by measurement of the resistance RA of the earth electrode of the exposed-conductive-parts, and by verification of the characteristics and/or the effectiveness of the associated protective devices (overcurrent protective device and RCD)
  - For IT, by calculation or measurement of the current Id in case of a fist fault at the line conductor or at the neutral, and with the test done for TN system where conditions are similar to TN system in case of a double insulation fault situation, with the test done for TT system where the conditions are similar to TT system in case of a double insulation fault situation.
- Additional protection by verifying the effectiveness of the protective measure
- Polarity test where the rules prohibit the installation of single pole switching devices in the neutral conductor.
- Check of phase sequence in case of multiphase circuit
- Functional test of switchgear and controlgear by verifying their installation and adjustment
- Voltage drop by measuring the circuit impedance or by using diagrams

These tests and checks are basic (but not exhaustive) to the majority of installations, while numerous other tests and rules are included in the regulations to cover particular cases, for example: installations based on class 2 insulation, special locations, etc.
The aim of this guide is to draw attention to the particular features of different types of installation, and to indicate the essential rules to be observed in order to achieve a satisfactory level of quality, which will ensure safe and trouble-free performance.
The methods recommended in this guide, modified if necessary to comply with any possible variation imposed by a utility, are intended to satisfy all precommissioning test and inspection requirements.
After verification and testing an initial report must be provided including records of inspection, records of circuits tested together with the test result and possible repairs or improvements of the installation.

2.6 Put in out of danger the existing electrical installations

This subject is in real progress cause of the statistics with origin electrical installation (number of old and recognised dangerous electrical installations, existing installations not in adequation with the future needs etc.)

2.7 Periodic check-testing of an installation

In many countries, all industrial and commercial-building installations, together with installations in buildings used for public gatherings, must be re-tested periodically by authorized agents.
The following tests should be performed

- Verification of RCD effectiveness and adjustments
- Appropriate measurements for providing safety of persons against effects of electric shock and protection against damage to property against fire and heat
- Confirmation that the installation is not damaged
- Identification of installation defects

Figure A3 shows the frequency of testing commonly prescribed according to the kind of installation concerned.

Type of installation		Testing frequency
Installations which require the protection of employees	■ Locations at which a risk of degradation, fire or explosion exists ■ Temporary installations at worksites ■ Locations at which MV installations exist ■ Restrictive conducting locations where mobile equipment is used	Annually
	Other cases	Every 3 years
Installations in buildings used for public gatherings, where protection against the risks of fire and panic are required	According to the type of establishment and its capacity for receiving the public	From one to three years
Residential	According to local regulations	*Example : the REBT in Belgium which imposes a periodic control each 20 years.*

Fig A3: Frequency of check-tests commonly recommended for an electrical installation

As for the initial verification, a reporting of periodic verification is to be provided.

Conformity of equipment with the relevant standards can be attested in several ways

2.8 Conformity assessement (with standards and specifications) of equipment used in the installation

The conformity assessement of equipment with the relevant standards can be attested:

- By mark of conformity granted by the certification body concerned, or
- By a certificate of conformity issued by a certification body, or
- By a declaration of conformity given by the manufacturer.

Declaration of conformity

As business, the declaration of conformity, including the technical documentation, is generally used in for high voltage equipments or for specific products. In Europe, the CE declaration is a mandatory declaration of conformity.

Note: CE marking

In Europe, the European directives require the manufacturer or his authorized representative to affix the CE marking on his own responsibility. It means that:

- The product meets the legal requirements
- It is presumed to be marketable in Europe.

The CE marking is neither a mark of origin nor a mark of conformity, it completes the declaration of conformity and the technical documents of the equipments.

Certificate of conformity

A certificate of conformity can reinforce the manufacturer's declaration and the customer's confidence. It could be requested by the regulation of the countries, imposed by the customers (Marine, Nuclear,..), be mandatory to garanty the maintenance or the consistency between the equipments.

Mark of conformity

Marks of conformity are strong strategic tools to validate a durable conformity. It consolidates the confidence with the brand of the manufacturer. A mark of conformity

is delivered by certification body if the equipment meets the requirements from an applicable referential (including the standard) and after verification of the manufacturer's quality management system.
Audit on the production and follow up on the equipments are made globally each year.

Quality assurance

A laboratory for testing samples cannot certify the conformity of an entire production run: these tests are called type tests. In some tests for conformity to standards, the samples are destroyed (tests on fuses, for example).

Only the manufacturer can certify that the fabricated products have, in fact, the characteristics stated.

Quality assurance certification is intended to complete the initial declaration or certification of conformity.

As proof that all the necessary measures have been taken for assuring the quality of production, the manufacturer obtains certification of the quality control system which monitors the fabrication of the product concerned. These certificates are issued by organizations specializing in quality control, and are based on the international standard ISO 9001: 2000.

These standards define three model systems of quality assurance control corresponding to different situations rather than to different levels of quality:

- Model 3 defines assurance of quality by inspection and checking of final products
- Model 2 includes, in addition to checking of the final product, verification of the manufacturing process. For example, this method is applied, to the manufacturer of fuses where performance characteristics cannot be checked without destroying the fuse
- Model 1 corresponds to model 2, but with the additional requirement that the quality of the design process must be rigorously scrutinized; for example, where it is not intended to fabricate and test a prototype (case of a custom-built product made to specification).

2.9 Environment

The contribution of the whole electrical installation to sustainable development can be significantly improved through the design of the installation. Actually, it has been shown that an optimised design of the installation, taking into account operation conditions, MV/LV substations location and distribution structure (switchboards, busways, cables), can reduce substantially environmental impacts (raw material depletion, energy depletion, end of life), especially in term of energy efficiency.

Beside its architecture, environmental specification of the electrical component and equipment is a fundamental step for an eco-friendly installation. In particular to ensure proper environmental information and anticipate regulation.

In Europe several Directives concerning electrical equipments have been published, leading the worldwide move to more environment safe products.

a) RoHS Directive (**R**estriction of **H**azardous **S**ubstances): in force since July 2006 and revised on 2012. It aims to eliminate from products six hazardous substances: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) from most of end user electrical products.. Though electrical installations being “large scale fixed installation” are not in the scope, RoHS compliance requirement may be a recommendation for a sustainable installation

b) WEEE Directive (**W**aste of **E**lectrical and **E**lectronic **E**quipment): in force since August 2005 and currently under revision. Its purpose is to improve the end of life treatments for household and non household equipment, under the responsibility of the manufacturers. As for RoHS, electrical installations are not in the scope of this directive. However, End of Life Product information is recommended to optimise recycling process and cost.

c) Energy Related Product, also called Ecodesign. Apart for some equipments like lighting or motors for which implementing measures are compulsory, there are no legal requirements that directly apply to installation. However, trend is to provide electrical equipments with their Environmental Product Declarattion, as it is becoming for Construction Products, to anticipate Building Market coming requirements.

d) REACh: (**R**egistration **E**valuation **A**uthorisation of **C**hemicals). In force since 2007, it aims to control chemical use and restrict application when necessary to reduce hazards to people and environment. With regards to Energy Efficiency and installations, it implies any supplier shall, upon request, communicate to its customer the hazardous substances content in its product (so called SVHC, Substances of Very High Concern). Then, an installer should ensure that its suppliers have the appropriate information available

In other parts of the world new legislations will follow the same objectives.

3 Installed power loads - Characteristics

An examination of the actual apparent-power demands of different loads: a necessary preliminary step in the design of a LV installation

The examination of actual values of apparent-power required by each load enables the establishment of:

- A declared power demand which determines the contract for the supply of energy
- The rating of the MV/LV transformer, where applicable (allowing for expected increased load)
- Levels of load current at each distribution board.

The nominal power in kW (Pn) of a motor indicates its rated equivalent mechanical power output.
The apparent power in kVA (Pa) supplied to the motor is a function of the output, the motor efficiency and the power factor.

$$Pa = \frac{Pn}{\eta \cos\varphi}$$

3.1 Induction motors

Current demand

The rated current In supplied to the motor is given by the following formulae:

- 3-phase motor: In = Pn x 1000 / ($\sqrt{3}$ x U x η x cos φ)
- 1-phase motor: In = Pn x 1000 / (U x η x cos φ)

where

In: rated current (in amps)

Pn: nominal power (in kW)

U: voltage between phases for 3-phase motors and voltage between the terminals for single-phase motors (in volts). A single-phase motor may be connected phase-to-neutral or phase-to-phase.

η: per-unit efficiency, i.e. output kW / input kW

cos φ: power factor, i.e. kW input / kVA input.

Subtransient current and protection setting

- Subtransient current peak value can be very high; typical value is about 12 to 15 times the rms rated value In. Sometimes this value can reach 25 times In.
- Schneider Electric circuit breakers, contactors and thermal relays are designed to withstand motor starts with very high subtransient current (subtransient peak value can be up to 19 times the rms rated value In).
- If unexpected tripping of the overcurrent protection occurs during starting, this means the starting current exceeds the normal limits. As a result, some maximum switchgear withstands can be reached, life time can be reduced and even some devices can be destroyed. In order to avoid such a situation, oversizing of the switchgear must be considered.
- Schneider Electric switchgears are designed to ensure the protection of motor starters against short-circuits. According to the risk, tables show the combination of circuit breaker, contactor and thermal relay to obtain type 1 or type 2 coordination (see chapter N).

Motor starting current

Although high efficiency motors can be found on the market, in practice their starting currents are roughly the same as some of standard motors.

The use of start-delta starter, static soft start unit or variable speed drive allows to reduce the value of the starting current (Example: 4 In instead of 7.5 In).

See also chapter N §5 "Asyncronous motors" for more information

Compensation of reactive-power (kvar) supplied to induction motors

It is generally advantageous for technical and financial reasons to reduce the current supplied to induction motors. This can be achieved by using capacitors without affecting the power output of the motors.
The application of this principle to the operation of induction motors is generally referred to as “power-factor improvement” or “power-factor correction”.

As discussed in chapter L, the apparent power (kVA) supplied to an induction motor can be significantly reduced by the use of shunt-connected capacitors. Reduction of input kVA means a corresponding reduction of input current (since the voltage remains constant).

Compensation of reactive-power is particularly advised for motors that operate for long periods at reduced power.

As noted above $\cos\varphi = \frac{\text{kW input}}{\text{kVA input}}$ so that a kVA input reduction will increase (i.e. improve) the value of cos φ.

The current supplied to the motor, after power-factor correction, is given by:

$$I = Ia \frac{\cos \varphi}{\cos \varphi'}$$

where cos φ is the power factor before compensation and cos φ' is the power factor after compensation, Ia being the original current.

Figure A4 below shows, in function of motor rated power, standard motor current values for several voltage supplies (IEC 60947-4-1 Annex G)

kW	hp	230 V A	380 - 415 V A	400 V A	440 - 480 V A	500 V A	690 V A
0.18	-	1.0	-	0.6	-	0.48	0.35
0.25	-	1.5	-	0.85	-	0.68	0.49
0.37	-	1.9	-	1.1	-	0.88	0.64
-	1/2	-	1.3	-	1.1	-	-
0.55	-	2.6	-	1.5	-	1.2	0.87
-	3/4	-	1.8	-	1.6	-	-
-	1	-	2.3	-	2.1	-	-
0.75	-	3.3	-	1.9	-	1.5	1.1
1.1	-	4.7	-	2.7	-	2.2	1.6
-	1-1/2	-	3.3	-	3.0	-	-
-	2	-	4.3	-	3.4	-	-
1.5	-	6.3	-	3.6	-	2.9	2.1
2.2	-	8.5	-	4.9	-	3.9	2.8
-	3	-	6.1	-	4.8	-	-
3.0	-	11.3	-	6.5	-	5.2	3.8
4	-	15	9.7	8.5	7.6	6.8	4.9
-	5	-	9.7	-	7.6	-	-
5.5	-	20	-	11.5	-	9.2	6.7
-	7-1/2	-	14.0	-	11.0	-	-
-	10	-	18.0	-	14.0	-	-
7.5	-	27	-	15.5	-	12.4	8.9
11	-	38.0	-	22.0	-	17.6	12.8
-	15	-	27.0	-	21.0	-	-
-	20	-	34.0	-	27.0	-	-
15	-	51	-	29	-	23	17
18.5	-	61	-	35	-	28	21
-	25	-	44	-	34	-	
22	-	72	-	41	-	33	24
-	30	-	51	-	40	-	-
-	40	-	66	-	52	-	-
30	-	96	-	55	-	44	32
37	-	115	-	66	-	53	39
-	50	-	83	-	65	-	-
-	60	-	103	-	77	-	-
45	-	140	-	80	-	64	47
55	-	169	-	97	-	78	57
-	75	-	128	-	96	-	-
-	100	-	165	-	124	-	-
75	-	230	-	132	-	106	77
90	-	278	-	160	-	128	93
-	125	-	208	-	156	-	-
110	-	340	-	195		156	113
-	150	-	240	-	180	-	-
132	-	400	-	230	-	184	134
-	200	-	320	-	240	-	-
150	-	-	-	-	-	-	-
160	-	487	-	280	-	224	162
185	-	-	-	-	-	-	-
-	250	-	403	-	302	-	-
200	-	609	-	350	-	280	203
220	-	-	-	-	-	-	-
-	300	-	482	-	361	-	-
250	-	748	-	430	-	344	250
280	-	-	-	-	-	-	-
-	350	-	560	-	414	-	-
-	400	-	636	-	474	-	-
300	-	-	-	-	-	-	-

Fig. A4: Rated operational power and currents (continued on next page)

kW	hp	230 V A	380 - 415 V A	400 V A	440 - 480 V A	500 V A	690 V A
315	-	940	-	540	-	432	313
-	450	-	-	-	515	-	-
335	-	-	-	-	-	-	-
355	-	1061	-	610	-	488	354
-	500	-	786	-	590	-	-
375	-	-	-	-	-	-	-
400	-	1200	-	690	-	552	400
425	-	-	-	-	-	-	-
450	-	-	-	-	-	-	-
475	-	-	-	-	-	-	-
500	-	1478	-	850	-	680	493
530	-	-	-	-	-	-	-
560	-	1652	-	950	-	760	551
600	-	-	-	-	-	-	-
630	-	1844	-	1060	-	848	615
670	-	-	-	-	-	-	-
710	-	2070	-	1190	-	952	690
750	-	-	-	-	-	-	-
800	-	2340	-	1346	-	1076	780
850	-	-	-	-	-	-	-
900	-	2640	-	1518	-	1214	880
950	-	-	-	-	-	-	-
1000	-	2910	-	1673	-	1339	970

***Fig. A4**: Rated operational power and currents (concluded)*

3.2 Resistive-type heating appliances and incandescent lamps (conventional or halogen)

See also chapter N §4 "Lighting circuits"

The current demand of a heating appliance or an incandescent lamp is easily obtained from the nominal power Pn quoted by the manufacturer (i.e. cos φ = 1) (see **Fig. A5**).

Nominal power (kW)	Current demand (A)			
	1-phase 127 V	1-phase 230 V	3-phase 230 V	3-phase 400 V
0.1	0.79	0.43	0.25	0.14
0.2	1.58	0.87	0.50	0.29
0.5	3.94	2.17	1.26	0.72
1	7.9	4.35	2.51	1.44
1.5	11.8	6.52	3.77	2.17
2	15.8	8.70	5.02	2.89
2.5	19.7	10.9	6.28	3.61
3	23.6	13	7.53	4.33
3.5	27.6	15.2	8.72	5.05
4	31.5	17.4	10	5.77
4.5	35.4	19.6	11.3	6.5
5	39.4	21.7	12.6	7.22
6	47.2	26.1	15.1	8.66
7	55.1	30.4	17.6	10.1
8	63	34.8	20.1	11.5
9	71	39.1	22.6	13
10	79	43.5	25.1	14.4

***Fig. A5**: Current demands of resistive heating and incandescent lighting (conventional or halogen) appliances*

The currents are given by:

- 3-phase case: $Ia = \frac{Pn}{\sqrt{3}\,U}$ (1)
- 1-phase case: $Ia = \frac{Pn}{U}$ (1)

where U is the voltage between the terminals of the equipment.

For an incandescent lamp, the use of halogen gas allows a more concentrated light source. The light output is increased and the lifetime of the lamp is doubled.

Note: At the instant of switching on, the cold filament gives rise to a very brief but intense peak of current.

3.3 Fluorescent lamps

See also chapter N §4 "Lighting circuits"

Fluorescent lamps and related equipment

The power Pn (watts) indicated on the tube of a fluorescent lamp does not include the power dissipated in the ballast.

The current is given by:

$$Ia = \frac{P_{ballast} + Pn}{U \cos \varphi}$$

Where U = the voltage applied to the lamp, complete with its related equipment.
If no power-loss value is indicated for the ballast, a figure of 25 % of Pn may be used.

Standard tubular fluorescent lamps

With (unless otherwise indicated):

- cos φ = 0.6 with no power factor (PF) correction(2) capacitor
- cos φ = 0.86 with PF correction(2) (single or twin tubes)
- cos φ = 0.96 for electronic ballast.

If no power-loss value is indicated for the ballast, a figure of 25 % of Pn may be used.
Figure A6 gives these values for different arrangements of ballast.

Arrangement of lamps, starters and ballasts	Tube power (W) (3)	Current (A) at 230 V			Tube length (cm)
		Magnetic ballast		Electronic ballast	
		Without PF correction capacitor	With PF correction capacitor		
Single tube	18	0.20	0.14	0.10	60
	36	0.33	0.23	0.18	120
	58	0.50	0.36	0.28	150
Twin tubes	2 x 18		0.28	0.18	60
	2 x 36		0.46	0.35	120
	2 x 58		0.72	0.52	150

(3) Power in watts marked on tube

Fig. A6: Current demands and power consumption of commonly-dimensioned fluorescent lighting tubes (at 230 V-50 Hz)

Compact fluorescent lamps

Compact fluorescent lamps have the same characteristics of economy and long life as classical tubes. They are commonly used in public places which are permanently illuminated (for example: corridors, hallways, bars, etc.) and can be mounted in situations otherwise illuminated by incandescent lamps (see **Fig. A7** next page).

(1) Ia in amps; U in volts. Pn is in watts. If Pn is in kW, then multiply the equation by 1000

(2) "Power-factor correction" is often referred to as "compensation" in discharge-lighting-tube terminology.
Cos φ is approximately 0.95 (the zero values of V and I are almost in phase) but the power factor is 0.5 due to the impulsive form of the current, the peak of which occurs "late" in each half cycle

Type of lamp	Lamp power (W)	Current at 230 V (A)
Separated ballast lamp	10	0.080
	18	0.110
	26	0.150
Integrated ballast lamp	8	0.075
	11	0.095
	16	0.125
	21	0.170

Fig. A7: Current demands and power consumption of compact fluorescent lamps (at 230 V-50 Hz)

The power in watts indicated on the tube of a discharge lamp does not include the power dissipated in the ballast.

3.4 Discharge lamps

See also chapter N §4 "Lighting circuits"

Figure A8a gives the current taken by a complete unit, including all associated ancillary equipment.

These lamps depend on the luminous electrical discharge through a gas or vapour of a metallic compound, which is contained in a hermetically-sealed transparent envelope at a pre-determined pressure. These lamps have a long start-up time, during which the current Ia is greater than the nominal current In. Power and current demands are given for different types of lamp (typical average values which may differ slightly from one manufacturer to another).

Type of lamp (W)	Power demand (W) at 230 V	Power demand (W) at 400 V	Current In(A) PF not corrected 230 V	Current In(A) PF not corrected 400 V	Current In(A) PF corrected 230 V	Current In(A) PF corrected 400 V	Starting x In	Starting Period (mins)	Luminous efficiency (lumens per watt)	Average timelife of lamp (h)	Utilization
High-pressure sodium vapour lamps											
50	60		0.76		0.3		1.4 to 1.6	4 to 6	80 to 120	9000	■ Lighting of large halls ■ Outdoor spaces ■ Public lighting
70	80		1		0.45						
100	115		1.2		0.65						
150	168		1.8		0.85						
250	274		3		1.4						
400	431		4.4		2.2						
1000	1055		10.45		4.9						
Low-pressure sodium vapour lamps											
26	34.5		0.45		0.17		1.1 to 1.3	7 to 15	100 to 200	8000 to 12000	■ Lighting of autoroutes ■ Security lighting, station ■ Platform, storage areas
36	46.5				0.22						
66	80.5				0.39						
91	105.5				0.49						
131	154				0.69						
Mercury vapour + metal halide (also called metal-iodide)											
70	80.5		1		0.40		1.7	3 to 5	70 to 90	6000	■ Lighting of very large areas by projectors (for example: sports stadiums, etc.)
150	172		1.80		0.88					6000	
250	276		2.10		1.35					6000	
400	425		3.40		2.15					6000	
1000	1046		8.25		5.30					6000	
2000	2092	2052	16.50	8.60	10.50	6				2000	
Mercury vapour + fluorescent substance (fluorescent bulb)											
50	57		0.6		0.30		1.7 to 2	3 to 6	40 to 60	8000 to 12000	■ Workshops with very high ceilings (halls, hangars) ■ Outdoor lighting ■ Low light output(1)
80	90		0.8		0.45						
125	141		1.15		0.70						
250	268		2.15		1.35						
400	421		3.25		2.15						
700	731		5.4		3.85						
1000	1046		8.25		5.30						
2000	2140	2080	15		11	6.1					

(1) Replaced by sodium vapour lamps.

Note: these lamps are sensitive to voltage dips. They extinguish if the voltage falls to less than 50 % of their nominal voltage, and will not re-ignite before cooling for approximately 4 minutes.

Note: Sodium vapour low-pressure lamps have a light-output efficiency which is superior to that of all other sources. However, use of these lamps is restricted by the fact that the yellow-orange colour emitted makes colour recognition practically impossible.

Fig. A8a: Current demands of discharge lamps

3.5 LED lamps & fixtures

See also chapter N §4 "Lighting circuits"

A lamp or luminaire with LED technology is powered by a driver:
- can be integrated into the bulb (tube or lamp for retrofit) : in this case refer to the power indicated on the lamp
- if separated : in that case it is necessary to take into account the power dissipated in the driver and the power indicated for one or several associated LED modules.

This technology has a very short start-up time. On the other hand, the inrush current at the powering is generally much higher than for fluorescent lamp with electronic ballast.

Note: The power in Watts indicated on the LED module with a separated driver doesn't include the power dissipated in the driver.

Power demand (W) at 230 V	Power factor	Starting			Luminous efficiency (lumens per watt)	Average timelife	Utilization
		Inrush current Ip/In	Inrush current time (microsec)	Full Time to start			
3 to 400 W	> 0.9	Up to 250	< 250 microsec	< 0.5 to 1 sec	100 to 140	20000 to 50000	■ All lighting applications in all domains (housing, commercial and industrial building, infrastructure)

Fig. A8b: Main characteristics of LED lamps & fixtures

4 Power loading of an installation

In order to design an installation, the actual maximum load demand likely to be imposed on the power-supply system must be assessed.

To base the design simply on the arithmetic sum of all the loads existing in the installation would be extravagantly uneconomical, and bad engineering practice.

The aim of this chapter is to show how some factors taking into account the diversity (non simultaneous operation of all appliances of a given group) and utilization (e.g. an electric motor is not generally operated at its full-load capability, etc.) of all existing and projected loads can be assessed. The values given are based on experience and on records taken from actual installations. In addition to providing basic installation-design data on individual circuits, the results will provide a global value for the installation, from which the requirements of a supply system (distribution network, MV/LV transformer, or generating set) can be specified.

4.1 Installed power (kW)

The installed power is the sum of the nominal powers of all power consuming devices in the installation.
This is not the power to be actually supplied in practice.

Most electrical appliances and equipments are marked to indicate their nominal power rating (Pn).
The installed power is the sum of the nominal powers of all power-consuming devices in the installation. This is not the power to be actually supplied in practice. This is the case for electric motors, where the power rating refers to the output power at its driving shaft. The input power consumption will evidently be greater.

Fluorescent and discharge lamps associated with stabilizing ballasts, are other cases in which the nominal power indicated on the lamp is less than the power consumed by the lamp and its ballast.

Methods of assessing the actual power consumption of motors and lighting appliances are given in Section 3 of this Chapter.

The power demand (kW) is necessary to choose the rated power of a generating set or battery, and where the requirements of a prime mover have to be considered.

For a power supply from a LV public-supply network, or through a MV/LV transformer, the significant quantity is the apparent power in kVA.

4.2 Installed apparent power (kVA)

The installed apparent power is commonly assumed to be the arithmetical sum of the kVA of individual loads. The maximum estimated kVA to be supplied however is not equal to the total installed kVA.

The installed apparent power is commonly assumed to be the arithmetical sum of the kVA of individual loads. The maximum estimated kVA to be supplied however is not equal to the total installed kVA.

The apparent-power demand of a load (which might be a single appliance) is obtained from its nominal power rating (corrected if necessary, as noted above for motors, etc.) and the application of the following coefficients:

η = the per-unit efficiency = output kW / input kW

cos φ = the power factor = kW / kVA

The apparent-power kVA demand of the load

Pa = Pn /(η x cos φ)

From this value, the full-load current Ia (A)(1) taken by the load will be:

- $Ia = \frac{Pa \times 10^3}{V}$

for single phase-to-neutral connected load

- $Ia = \frac{Pa \times 10^3}{\sqrt{3} \times U}$

for three-phase balanced load where:

V = phase-to-neutral voltage (volts)

U = phase-to-phase voltage (volts)

It may be noted that, strictly speaking, the total kVA of apparent power is not the arithmetical sum of the calculated kVA ratings of individual loads (unless all loads are at the same power factor).

It is common practice however, to make a simple arithmetical summation, the result of which will give a kVA value that exceeds the true value by an acceptable "design margin".

(1) For greater precision, account must be taken of the factor of maximum utilization as explained below in 4.3

When some or all of the load characteristics are not known, the values shown in **Figure A9** may be used to give a very approximate estimate of VA demands (individual loads are generally too small to be expressed in kVA or kW).
The estimates for lighting loads are based on floor areas of 500 m².

Fluorescent lighting (corrected to cos φ = 0.86)		
Type of application	**Estimated (VA/m²) fluorescent tube with industrial reflector(1)**	**Average lighting level (lux = lm/m²)**
Roads and highways storage areas, intermittent work	7	150
Heavy-duty works: fabrication and assembly of very large work pieces	14	300
Day-to-day work: office work	24	500
Fine work: drawing offices high-precision assembly workshops	41	800
Power circuits		
Type of application	**Estimated (VA/m²)**	
Pumping station compressed air	3 to 6	
Ventilation of premises	23	
Electrical convection heaters:		
private houses	115 to 146	
flats and apartments	90	
Offices	25	
Dispatching workshop	50	
Assembly workshop	70	
Machine shop	300	
Painting workshop	350	
Heat-treatment plant	700	

(1) example: 65 W tube (ballast not included), flux 5,100 lumens (lm), luminous efficiency of the tube = 78.5 lm / W.

Fig. A9: Estimation of installed apparent power

4.3 Estimation of actual maximum kVA demand

All individual loads are not necessarily operating at full rated nominal power nor necessarily at the same time. Factors ku and ks allow the determination of the maximum power and apparent-power demands actually required to dimension the installation.

Factor of maximum utilization (ku)

In normal operating conditions the power consumption of a load is sometimes less than that indicated as its nominal power rating, a fairly common occurrence that justifies the application of an utilization factor (ku) in the estimation of realistic values.

This factor must be applied to each individual load, with particular attention to electric motors, which are very rarely operated at full load.

In an industrial installation this factor may be estimated on an average at 0.75 for motors.

For incandescent-lighting loads, the factor always equals 1.

For socket-outlet circuits, the factors depend entirely on the type of appliances being supplied from the sockets concerned.

For Electric Vehicle the utilization factor will be systematically estimated to 1, as it takes a long time to load completely the batteries (several hours) and a dedicated circuit feeding the charging station or wall box will be required by standards.

Diversity factor - Coincidence factor (ks)

It is a matter of common experience that the simultaneous operation of all installed loads of a given installation never occurs in practice, i.e. there is always some degree of diversity and this fact is taken into account for estimating purposes by the use
of a factor (ks).
This factor is defined in IEC60050 - International Electrotechnical Vocabulary, as follows:

- **Coincidence factor:** the ratio, expressed as a numerical value or as a percentage, of the simultaneous maximum demand of a group of electrical appliances or consumers within a specified period, to the sum of their individual maximum demands within the same period. As per this definition, the value is always ⩽ 1 and can be expressed as a percentage
- **Diversity factor:** the reciprocal of the coincidence factor. It means it will always be ⩾ 1.

The determination of ks factors is the responsibility of the designer, since it requires a detailed knowledge of the installation and the conditions in which the individual circuits are to be exploited. For this reason, it is not possible to give precise values for general application.

Note: In practice, the most commonly used term is the diversity factor, but it is used in replacement of the coincidence factor, thus will be always <= 1. The term "simultaneity factor" is another alternative that is sometimes used.

The factor ks is applied to each group of loads (e.g. being supplied from a distribution or sub-distribution board).

The following tables are coming from local standards or guides, not from international standards. They should only be used as examples of determination of such factors.

Diversity factor for an apartment block

Some typical values for this case are given in **Figure A10**, and are applicable to domestic consumers without electrical heating, and supplied at 230/400 V (3-phase 4-wires). In the case of consumers using electrical heat-storage units for space heating, a factor of 0.8 is recommended, regardless of the number of consumers.

Number of downstream consumers	Diversity factor (ks)
2 to 4	1
5 to 9	0.78
10 to 14	0.63
15 to 19	0.53
20 to 24	0.49
25 to 29	0.46
30 to 34	0.44
35 to 39	0.42
40 to 49	0.41
50 and more	0.38

Fig. A10: Example of diversity factors for an apartment block as defined in French standard NFC14-100, and applicable for apartments without electrical heating

Example (see **Fig. A11**):

5 storeys apartment building with 25 consumers, each having 6 kVA of installed load.

The total installed load for the building is: 36 + 24 + 30 + 36 + 24 = 150 kVA

The apparent-power supply required for the building is: 150 x 0.46 = 69 kVA

From **Fig. A11**, it is possible to determine the magnitude of currents in different sections of the common main feeder supplying all floors. For vertical rising mains fed at ground level, the cross-sectional area of the conductors can evidently be progressively reduced from the lower floors towards the upper floors.

These changes of conductor size are conventionally spaced by at least 3-floor intervals.

In the example, the current entering the rising main at ground level is:

$$\frac{150 \times 0.46 \times 10^3}{400\sqrt{3}} = 100 \text{ A}$$

the current entering the third floor is:

$$\frac{(36 + 24) \times 0.63 \times 10^3}{400\sqrt{3}} = 55 \text{ A}$$

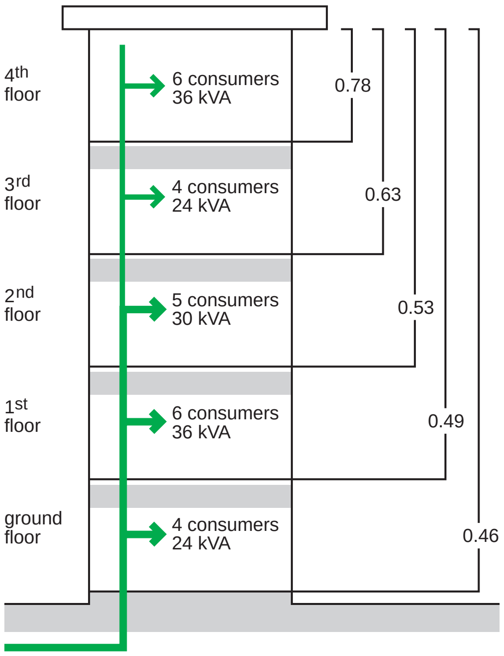

Fig. A11: Application of the diversity factor (ks) to an apartment block of 5 storeys

Rated Diversity Factor for distribution switchboards

The standards IEC61439-1 and 2 define in a similar way the Rated Diversity Factor for distribution switchboards (in this case, always ≤ 1)

IEC61439-2 also states that, in the absence of an agreement between the assembly manufacturer (panel builder) and user concerning the actual load currents (diversity factors), the assumed loading of the outgoing circuits of the assembly or group of outgoing circuits may be based on the values in **Fig. A12**.

If the circuits are mainly for lighting loads, it is prudent to adopt ks values close to unity.

Type of load	Assumed loading factor
Distribution - 2 and 3 circuits	0.9
Distribution - 4 and 5 circuits	0.8
Distribution - 6 to 9 circuits	0.7
Distribution - 10 or more circuits	0.6
Electric actuator	0.2
Motors ≤ 100 kW	0.8
Motors > 100 kW	1.0

Fig. A12: Rated diversity factor for distribution boards (cf IEC61439-2 table 101)

Diversity factor according to circuit function

ks factors which may be used for circuits supplying commonly-occurring loads, are shown in **Figure A13**. It is provided in French practical guide UTE C 15-105.

Circuit function		Diversity factor (ks)
Lighting		1
Heating and air conditioning		1
Socket-outlets		0.1 to 0.2 (1)
Lifts and catering hoist (2)	■ For the most powerful motor	1
	■ For the second most powerful motor	0.75
	■ For all motors	0.60

(1) In certain cases, notably in industrial installations, this factor can be higher.

(2) The current to take into consideration is equal to the nominal current of the motor, increased by a third of its starting current.

Fig. A13: Diversity factor according to circuit function (see UTE C 15-105 table AC)

4.4 Example of application of factors ku and ks

An example in the estimation of actual maximum kVA demands at all levels of an installation, from each load position to the point of supply is given **Fig. A14**.

In this example, the total installed apparent power is 126.6 kVA, which corresponds to an actual (estimated) maximum value at the LV terminals of the MV/LV transformer of 65 kVA only.

Note: in order to select cable sizes for the distribution circuits of an installation, the current I (in amps) through a circuit is determined from the equation:

$$I = \frac{kVA \times 10^3}{U\sqrt{3}}$$

where kVA is the actual maximum 3-phase apparent-power value shown on the diagram for the circuit concerned, and U is the phase to- phase voltage (in volts).

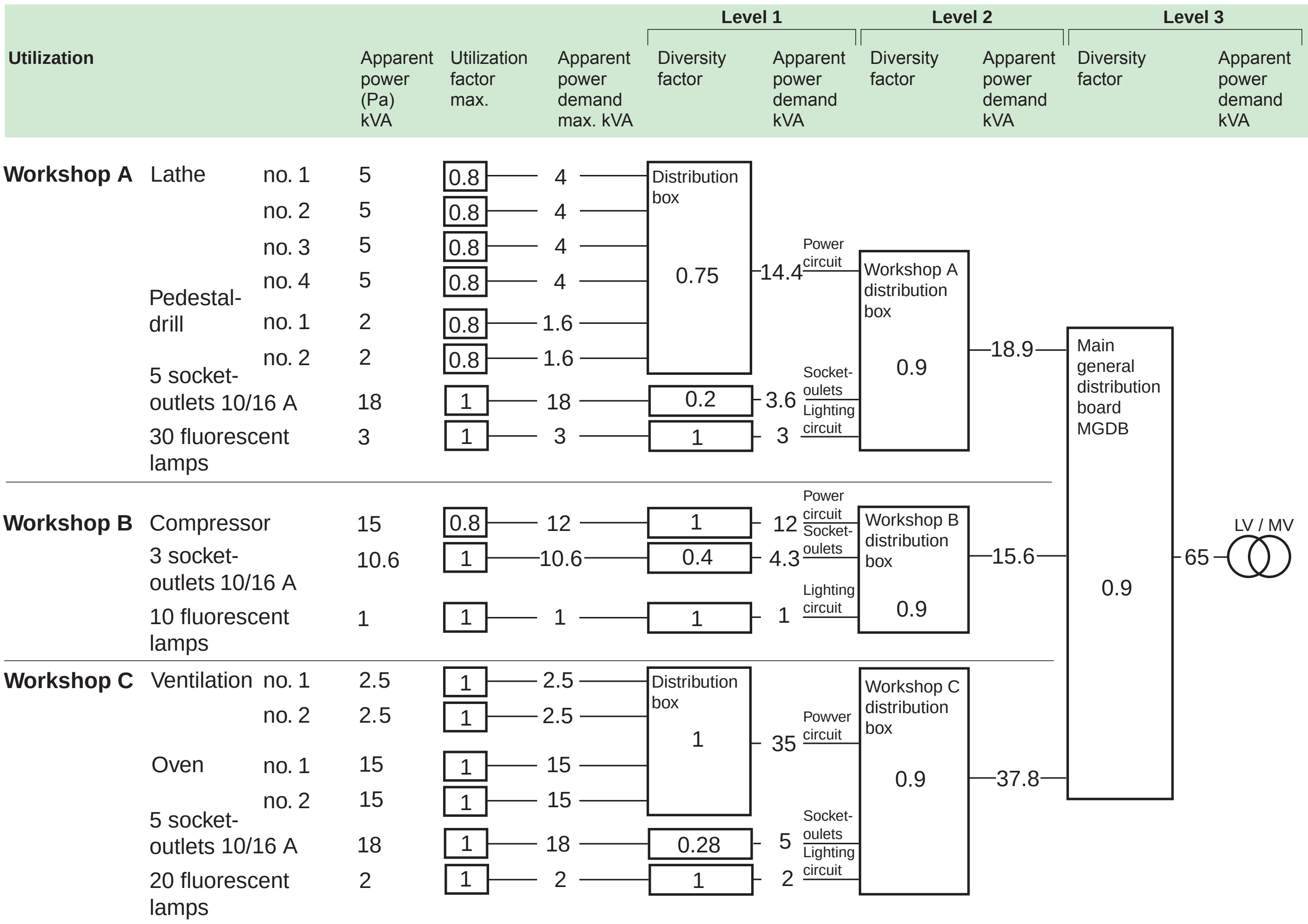

Fig A14: An example in estimating the maximum predicted loading of an installation (the factor values used are for demonstration purposes only)

4.5 Choice of transformer rating

When an installation is to be supplied directly from a MV/LV transformer and the maximum apparent-power loading of the installation has been determined, a suitable rating for the transformer can be decided, taking into account the following considerations (see **Fig. A15**):

- The possibility of improving the power factor of the installation (see chapter L)
- Anticipated extensions to the installation
- Installation constraints (e.g. temperature)
- Standard transformer ratings.

The nominal full-load current In on the LV side of a 3-phase transformer is given by:

$$In = \frac{Pa \times 10^3}{U\sqrt{3}}$$

where

- Pa = kVA rating of the transformer
- U = phase-to-phase voltage at no-load in volts (237 V or 410 V)
- In is in amperes.

For a single-phase transformer:

$$In = \frac{Pa \times 10^3}{V}$$

where

- V = voltage between LV terminals at no-load (in volts)

Simplified equation for 400 V (3-phase load)

- In = kVA x 1.4

The IEC standard for power transformers is IEC 60076.

Apparent power	In (A)	
kVA	237 V	410 V
100	244	141
160	390	225
250	609	352
315	767	444
400	974	563
500	1218	704
630	1535	887
800	1949	1127
1000	2436	1408
1250	3045	1760
1600	3898	2253
2000	4872	2816
2500	6090	3520
3150	7673	4436

Fig. A15: Standard apparent powers for MV/LV transformers and related nominal output currents

4.6 Choice of power-supply sources

The importance of maintaining a continuous supply raises the question of the use of standby-power plant. The choice and characteristics of these alternative sources are part of the architecture selection, as described in chapter D.

For the main source of supply the choice is generally between a connection to the MV or the LV network of the power-supply utility. In some cases main source of supply can be rotating generators in the case of remote installations with difficult access to the local Utility public grid (MV or LV) or where the reliability of the public grid does not have the minimum level of reliability expected.

In practice, connection to a MV source may be necessary where the load exceeds (or is planned eventually to exceed) a certain level - generally of the order of 250 kVA, or if the quality of service required is greater than that normally available from a LV network.

Moreover, if the installation is likely to cause disturbance to neighbouring consumers, when connected to a LV network, the supply authorities may propose a MV service.

Supplies at MV can have certain advantages: in fact, a MV consumer:

- Is not disturbed by other consumers, which could be the case at LV
- Is free to choose any type of LV earthing system
- Has a wider choice of economic tariffs
- Can accept very large increases in load

It should be noted, however, that:

- The consumer is the owner of the MV/LV substation and, in some countries, he must build equip and maintain it at his own expense. The power utility can, in certain circumstances, participate in the investment, at the level of the MV line for example
- A part of the connection costs can, for instance, often be recovered if a second consumer is connected to the MV line within a certain time following the original consumer's own connection
- The consumer has access only to the LV part of the installation, access to the MV part being reserved to the utility personnel (meter reading, operations, etc.). However, in certain countries, the MV protective circuit breaker (or fused load-break switch) can be operated by the consumer
- The type and location of the substation are agreed between the consumer and the utility.

More and more renewable energy sources such as photovoltaic panels are used to supply low-voltage electrical installations. In some case these PV panels are connected in parallel to the Utility grid or these PV panels are used in an autonomous mode without connection to the public grid. Conversion from d.c. to a.c. is then necessary as rated voltage of these PV panels are higher and higher (few hundreds volts) and also because PV panels produce d.c. currents.

See also chapter P "Photovoltaic installations"

Chapter B
Connection to the MV utility distribution network

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1 Power supply at medium voltage

The term "medium voltage" is commonly used for distribution systems with voltages above 1 kV and generally applied up to and including 52 kV(1). For technical and economic reasons, the service voltage of medium voltage distribution networks rarely exceeds 35 kV.

In this chapter, networks which operate at 1000 V or less are referred to as low voltage (LV) networks.

The connection of an electrical installation to a MV utility distribution network is always realized by means of a dedicated MV substation usually designed "Main substation". Depending on its size and specific criteria mainly related to the loads (Rated voltage, number, power, location, etc…), the installation may include additional substations designed "Secondary substations". The locations of these substations are carefully selected in order to optimize the budget dedicated to MV and LV power cables. They are supplied from the main substation through the internal MV distribution.

Generally, most of the loads are supplied in low voltage by means of MV/LV step down transformers. Large loads such as asynchronous motors above around 1MW are supplied in MV. Only LV loads are considered in this electrical guide.

MV/LV step down power transformers are indifferently located either in the main substation or in the secondary substations. Small installations may only include a single MV/LV transformer installed in the main substation in most of the cases.

A main substation includes five basic functions:
Function 1: Connection to the MV utility network
Function 2: General protection of the installation
Function 3: Supply and protection of MV/LV power transformers located in the substation
Function 4: Supply and protection of the internal MV distribution
Function 5: Metering.

For the installations including a single MV/LV power transformer the general protection and the protection of the transformer are merged.

The metering can be performed either at MV level or at LV level. It is authorized at LV level for any installation including a single MV/LV transformer, provided that the rated power of the transformer remains below the limit fixed by the local utility supplying the installation.

In addition to the functional requirements the construction of both main and secondary substations shall comply with the local standards and rules dedicated to the protection of persons. IEC recommendations should also be taken into consideration in all circumstances.

1.1 Main requirements for power supply at Medium Voltage and typical architectures

The characteristics of electrical equipment (switchgears, transformers, etc…) installed in the substations are fixed by the rated values of both voltage and current specified for the distribution network supplying the installation:
- Ur, rated voltage, rms value, kV
- Ud, rated power frequency withstand voltage, rms value, kV during 1mn
- Up: rated lightning impulse withstand voltage, peak value, kV
- Un, service voltage, rms value, kV

As the rated voltage Ur indicates the maximum value of the "highest system voltage" of networks for which the equipment may be used, the service voltage Un really existing in the network, including its possible variations shall remain below the rated voltage.
- Rated normal current Ir, rms value, A
- Rated short-time withstand current Ik, rms value, kA
- Rated peak withstand current Ip, peak value, kA.

Considering the previous requirements and basic usages, four typical architectures can be defined for an electrical installation connected to a MV utility distribution network:
Fig. B1: single MV/LV power transformer with metering at LV level
Fig. B2: single MV/LV power transformer with metering at MV level
Fig. B3: several MV/LV transformers, all located in the main substation
Fig. B4: several secondary substations supplied by an internal MV distribution. Most of MV/LV transformers are located in secondary substations. Some of them when required are installed in the main substation

(1) According to the IEC there is no clear boundary between medium and high voltage. Local and historical factors play a part, and limits are usually between 30 and 100 kV (see IEV 601-01-28). The publication IEC 62271-1 *"High-voltage switchgear and controlgear; common specifications"* *incorporates a note in its scope: "For the use of this standard, high voltage (see IEV 601-01-27) is the rated voltage above 1000 V. However, the term medium voltage (see IEV 601-01-28) is commonly used for distribution systems with voltages above 1 kV and generally applied up to and including 52 kV.".*

The functional and safety requirements defined above are detailed in this chapter, in the following sub-clauses:

- **1.2 to 1.4:** Voltages and currents according to IEC Standards, different types of MV power supply, practical issues concerning MV distribution networks
- **2.1 to 2.2:** Procedure for the establishment of a new substation
- **3.1 to 3.4:** Protection against electrical hazards, faults and mis-operations
- **4.1 to 4.2:** Consumer substation with LV metering
- **5.1 to 5.2:** Consumer substation with MV metering
- **6.1 to 6.4:** Choose and use MV equipment and MV/LV transformers
- **7.1 to 7.3:** Substation including generators and parallel operation of transformers
- **8.1 to 8.3:** Types and constitution of MV/LV distribution substations.

The methodology of selection of an architecture for a MV/LV electrical installation is detailed in chapter D.

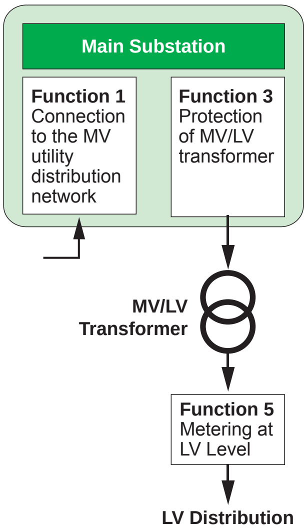


Fig. B1: Installation including a single MV/LV power transformer with metering at LV level

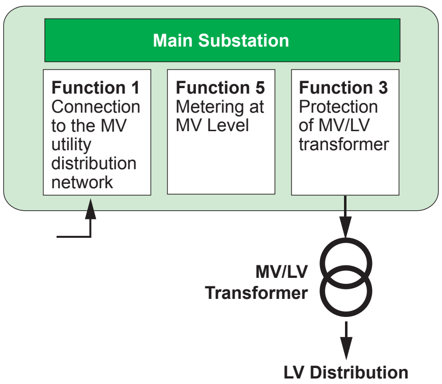


Fig. B2: Installation including a single MV/LV power transformer with metering at MV level

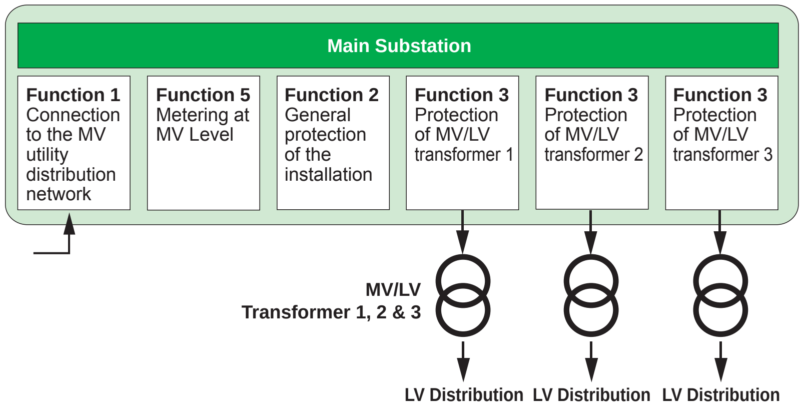


Fig. B3: Installation including several MV/LV transformers, all located in the main substation

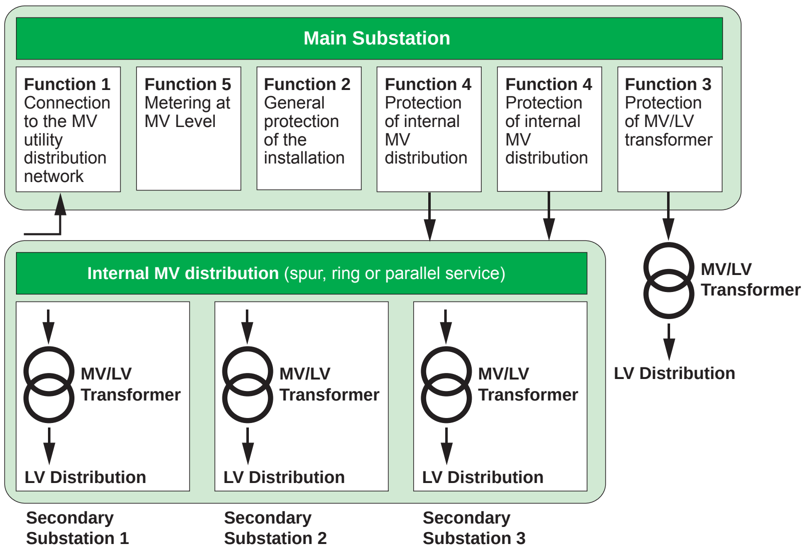


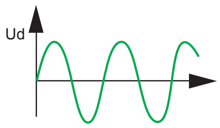
Fig. B4: Installation including several secondary substations supplied by an internal MV distribution

1.2 Medium voltages and current values according to IEC Standards

1.2.1 Rated voltage values according to IEC 60071-1 (Insulation co-ordination – Part 1: Definitions, principles and rules) (see **Fig. B5**)

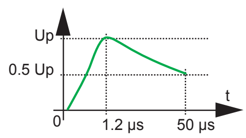
- Ur, rated voltage, rms value, kV: this is the maximum rms value of voltage that the equipment can withstand permanently. 24 kV rms for example.
- Ud, rated power frequency withstand voltage, rms value, kV during 1 mn: defines the level of rms over-voltages that the equipment may withstand during 1 minute. 50 kV rms for example.
- Up: rated lightning impulse withstand voltage, peak value, kV: define the level of lightning over-voltages that the equipment may withstand. 125 kV peak for example.
- The service voltage, Un rms value, kV: is the voltage at which the MV utility distribution network is operated. For example, some networks are operated at Un 20 kV. In this case, switchgear of at least 24 kV rated voltage shall be installed.

IEC standardised voltages



Rated power frequency withstand voltage
50 Hz 1 mn

Rated voltage



Rated lightning withstand voltage

Ud	Ur	Up
20	7.2	60
28	12	75
38	17.5	95
50	24	125
70	36	170

Fig. B5: Example of standard values Ur, Ud, Up (kV)

1.2.2 Rated current values according to IEC 62271-1 (High-voltage switchgear and controlgear - Part 1: Common specifications)

- Rated normal current Ir, rms value, A: this is the rms value of current that equipment may withstand permanently, without exceeding the temperature rise allowed in the standards. 630 A rms for example.
- Rated short-time withstand current Ik, rms value, kA: this is the rms value of the short circuit current that the equipment can carry during a specific time. It is defined in kA for generally 1 s, and sometimes 3 s. It is used to define the thermal withstand of the equipment 12 kA rms 1s for example.
- Rated peak withstand current Ip, peak value, kA: this is the peak value of the short circuit current that the equipment may withstand. It is used to define the electro-dynamic withstand of the equipment, 30 kA peak for example.

1.3 Different types of MV power supply

The following methods may be used for the connection of an electrical installation to a MV utility distribution network.

1.3.1 Connection to an MV radial network: Single-line service

The substation is supplied by a tee-off from the MV radial network (overhead line or underground cable), also known as a spur network.
This method provides only one supply for loads (see **Fig. B6,** A and B). It is widely used for installations including a single MV/LV transformer with LV metering. It can also be used without any restriction for installations with MV metering including either several MV/LV transformers or even an internal MV distribution netwok.
The connection is made by means of a single load break switch associated to a earthing switch dedicated to overhead line or underground cable grounding.
This principle can be the first step of the two other methods of connection (ring main and dual parallel feeders), the upgrading of the substation being generally performed during an extension of the installation or required by the adjunction of loads asking a higher level of supply continuity.

Generally, the pole-mounted transformers in rural areas are connected to the over-head lines according to this principle without load break switch nor fuses. Protection of the line and associated switching devices are located in the remote substations supplying the over-head distribution network.

1.3.2 Connection to an MV loop: Ring-main service

The substation is connected to a loop (see **Fig. B6,** C) of the medium voltage distribution network. The line current passes through the substation which gives the possibility to supply the substation by two different ways.
With this arrangement, the user benefits of a reliable power supply based on two redundant MV feeders.
The connection is made by means of two independent load break switches, each associated to an earthing switch for underground cables earthing.
This method is mainly used for the underground MV distribution networks found in urban areas.

1.3.3 Connection to two dual MV cables: Parallel feeders service

Two parallel underground cables are used to supply the substation. Each cable is connected to the substation by means of a load-break switch. (see **Fig. B6,** D).
As mentioned for single and ring main service cable grounding is performed by means of earthing switches associated to the load break switches.
The two load break switches are interlocked, meaning that only one load break switch is closed at a time.
This principle gives the possibility to supply the substation by two independent sources giving a full redundancy.
In the event of the loss of supply, the load-break switch supplying the installation before the loss of supply must be open and the second must be closed.
This sequence can be performed either manually or automatically.
This method is used to supply very sensitive installation such as hospitals for example. It is also often used for densely-populated urban areas supplied by underground cables.

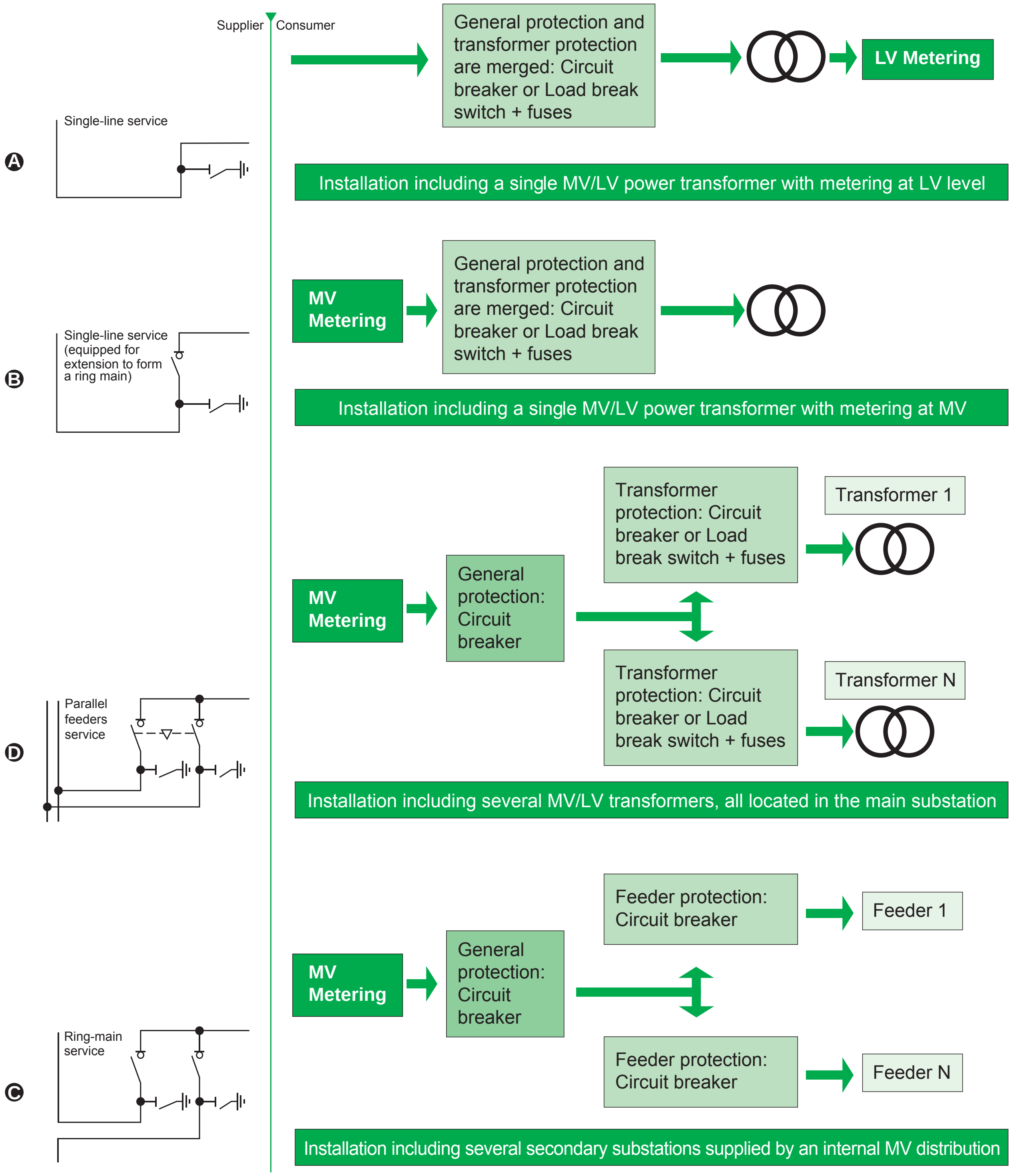


Fig. B6: *A: Single line service. B: Single line service with provision for extension to ring main or parallel feeder service. C: Ring main service. D: parallel feeder service*

1.4 Some practical issues concerning MV distribution networks

1.4.1 Overhead networks

Weather conditions such as wind may bring overhead wires into contact and cause phase to phase short-circuits.
Over voltages due to lightning strokes may generate flash-over across ceramic or glass insulators and cause phase to earth faults
Temporary contacts of vegetation such as trees with live overhead conductors may also generate phase to earth faults.
Most of these faults are temporary. They disappear naturally with the interruption of the voltage. This means that the supply can be restored after a short delay following the tripping. This delay is usually named "dead time".
Hence the sequence of fault clearing and voltage restoration in an overhead network is as follows:

- Fault detection by phase to phase or phase to earth protection
- Circuit breaker opening, the faulty over-head line is de-energized
- Dead time
- Circuit breaker reclosing. Following the reclosing two situations are possible:
  - The fault has been cleared by the interruption of the voltage, the reclosing is successful
  - The line is still faulty, a new tripping is initiated followed again by a reclosing sequence.
- Several sequences of tripping-reclosing may be activated depending on the rules of operation of the network adopted by the utility
- If after the execution of the preselected number of reclosing sequences the fault is still present, the circuit breaker is automatically locked and consequently the faulty part of the network remains out of service until the fault is localized and eliminated.

As such, it is possible to improve significantly the service continuity of overhead networks by using automatic reclosing facilities. Generally a reclosing circuit breaker is associated to each overhead line.

1.4.2 Underground networks

The use of centralised remote control and monitoring based on SCADA (Supervisory Control And Data Acquisition) systems and recent developments in digital communication technology is increasingly common in countries where the complexity associated with highly interconnected networks justifies the investment required.

Cable Faults on underground MV cables may have several causes such as:

- Poor quality of cable laying, absence of mechanical protection
- Bad quality of cable terminations confection
- Damages caused by excavators or tools such as pneumatic drills
- Over voltages generated by lightning strokes occurring on overhead line connected to underground cables. The over voltages can be amplified at the levels of the junctions between overhead lines and underground cables causing the destruction

of the cable terminations. Lightning arresters, are often installed at these locations to limit the risks of damages.
The experience shows that the rate of fault occurring on underground cables is lower than the one registered for overhead lines. But faults on underground cables are invariably permanent and take longer time to locate and repair.
A loop architecture (see **Fig. B10**) correctly instrumented with fault detectors and motorized load break switches allow within a short period of time to identify a faulty cable, to disconnect it and to restore the supply to the whole substations included in the loop.

These procedures of faults detection, cables disconnection and supply restoration can be automatically performed in less than one minute by dedicated functions commonly integrated in remote control and monitoring systems of MV networks.

Fig. B7: *Supervisory Control And Data Acquisition System SCADA*

1.4.3 Remote control and monitoring for MV networks (see **Fig. B7**)

Remote control and monitoring of MV feeders make it possible to reduce loss of supply resulting from cable faults by supporting fast and effective loop reconfiguration.
This facility relies on motorized switches associated with fault detectors on a number of substations in the loop and controlled by remote control units.
All stations containing this equipment can have their supply restored remotely, whereas other stations will require additional manual operations.

1.4.4 Values of earth fault currents in MV networks

(see **Fig. B8** and **Fig. B9**)

The values of earth fault currents in MV distribution networks depend on the MV neutral earthing system. These values must be limited to reduce their effects, mainly:

- Damages to equipment
- Temporary over voltages
- Transient over voltages
- Touch and step voltages.

The neutral of an MV network can be earthed by five different methods, according to type (resistive, inductive) and the value (zero to infinity) of the impedance Z_n connected between the neutral and the earth:

- $Z_n = \infty$ isolated neutral, no intentional neutral earthing connection
- Z_n is related to a resistance with a fairly high value,
- Z_n is related to a reactance, with a generally low value,
- Z_n is related to a compensation reactance, designed to compensate the capacitance of the network
- $Z_n = 0$: the neutral is solidly earthed.

	Methods of Neutral Earthing				
	Isolated	**Resistance**	**Reactance**	**Compensated**	**Solid**
Damages	Very low	Low	Low	Very low	Very high
Temporary over voltages	High	Medium	Medium	Medium	Low
Transient over voltages	High	Low	High	High	Low
Touch and step voltages	Very low	Low	Low	Low	High

***Fig. B8**: Effects of the phase to earth fault current*

The fault current I_{K1} is the sum of two components:
- *The neutral current through the impedance Z_n*
- *The capacitive current through the phase to earth capacitors.*

When Z_n is a reactance these two currents are opposite, which means that the reactance compensate the capacitive current. If the compensation is perfect, the fault current value is zero.

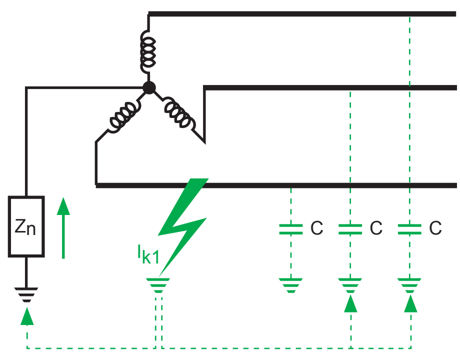


***Fig. B9**: Circulation of the phase to earth fault current*

1.4.5 Medium voltage loop (see **Fig. B10**)

A medium voltage loop is generally supplied from two separate primary substations. It supplies secondary MV/LV substations dedicated to the LV public distribution and private electrical installations.

The MV/LV secondary substations and those dedicated to the connection of private electrical installations are connected in series by means of underground cables. Two load break switches are used for the connection of each secondary substation. The loop is normally open, all the load break switches are closed except one.

In case of fault between A and B, the breaker C trips clearing the fault. The two substations S1 and S2 are de-energized. The restoration of the supply to all substations is then realized as follow:

1 - Isolation of the faulty cable by opening load break switches A and B
2 - Closing open point D
3 - Reclosing circuit breaker C. The open point is now between S1 and S2.

This sequence of faulty cable disconnection followed by the restoration of the supply can be executed either manually by the operators of the MV network or automatically by means of dedicated functions integrated in remote control and monitoring systems of MV networks.

Manual operations are generally long whereas automatic supply restoration can be executed within less than one minute by the remote control system. These automatism now available in any control system require a suitable instrumentation of the loop:

- Fault detectors at both ends of the underground cables
- Motorized load break switches
- Remote Terminal Unit (RTU) in each secondary substation. The RTU performes:
  - The monitoring of the fault detectors and load break switches
  - Local automatism
  - The command of load break switches
  - The communication with the remote control and monitoring center
- DC auxiliary supply in every substation.

As described above, most of the loops are historically equipped with load break switches and protected at each end only by circuit breakers located in the HV/ MV primary substations. In case of fault, all the customers supplied by a faulty feeder are disconnected. But in fact the customers upstream from the fault could have not been disconnected.

The addition of circuit breakers, adequately located and associated with appropriate protection relays may reduce the number of customers disconnected in case of fault.

As an example, a loop including two additional circuit breakers is divided in four independent sections. Assume the open point located between the two additional circuit breakers. In case of fault in the section delimited by these two circuit breakers only a part of the secondary substations of the section will be disconnected, all the other remaining energized.

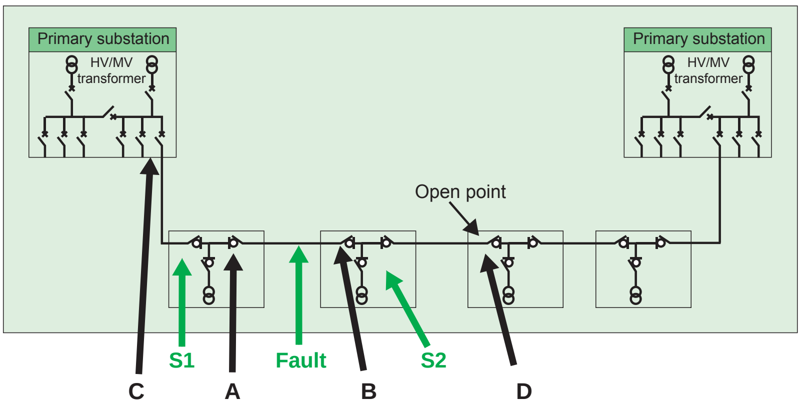


Fig. B10: Open loop configuration and operation

2 Procedure for the establishment of a new substation

Large consumers of electricity are always fed by a medium voltage supply.

On LV systems operating at 120/208 V (3-phases 4-wires), a load of 50 kVA may be considered as "large", while on a 230/400 V (3-phases 4-wires) system this limit is generally above 100 kVA. These two systems of LV distribution are widely used in most of the parts of the world. See chapter A §2.1 "Definition of voltage ranges".

The IEC recommends a "world" standard low voltage system of 230/400 V for 3-phases 4-wires. This is a compromise which will allow the existing systems operated at either 220/380 V or 240/415 V, or close to these values, to comply simply with the proposed standard by just adjusting the off load tap changers of the MV/LV distribution transformers.

The choice of the most appropriate level of supply of a new electrical installation is under the responsibility of the utility operating the network to which the installation is supposed to be connected.
The decision is mainly based on two criteria:
■ The distance to the primary substation that will feed the installation
■ The total power required by the installation.
Other criteria such as the rate of availability of the electricity supply are also taken into account.

There are two possibilities for the construction of a substation dedicated to the supply of a new electrical installation:
1 - The utility builds the substation according to its own specifications, close to the consumer's premises. The MV/LV transformer(s) however, remain located inside the installation, close to the loads.
Depending on local rules the MV/LV transformer(s) may belong or not to the utility, they may be installed or not by the owner of the installation, the utility has or not unrestricted access to their locations
2 - The owner of the electrical installation builds and equips the substation inside his premises.
In most of the cases the utility must at least have unrestricted access to the metering and to the part of the substation ensuring the connection of the installation to the MV utility network. The utility may require a separate room for the equipment dedicated to these two functions.

The following chapters only refer to the construction of the substation by the owner of the electrical installation.

2.1 Preliminary information

In most of the cases the project of the construction of a new substation must be submitted before any further detailed studies to the approval of the utility operating the MV network that will feed the substation. The list of information to provide for this approval may be the result of preliminary discussions with the utility. Among all information, the following are generally required:

2.1.1 Maximum anticipated power (kVA) demand

The method of evaluation of this parameter is detailed in Chapter A, it must take into account the future additional loads. According to chapter A, two factors associated to the loads are used in the proposed method:
■ The factor of maximum utilization (ku)
■ The diversity factor (ks).

2.1.2 Layout and arrangement drawings of the proposed substation

The following information may be required:
■ Situation of the substation with regard to traffic lane
■ Location of the substation inside the installation
■ Dispositions foreseen for the unrestricted access of the utility operating staff
■ Arrangement drawings showing clearly the location of the electrical equipment (MV Switchboard, transformers, Metering panel,…)
■ Routing of MV cables
■ Single line diagram and type of protections against phase to phase and phase to earth faults
■ Main characteristics of electrical equipment
■ Solution foreseen for the compensation of the reactive energy
■ Principle of the earthing system
■ Presence in the installation of a power generator operated in parallel with the MV network
■ Etc.

2.1.3 Degree of supply continuity required

The consumer must estimate the consequences of a failure of supply in terms of:
- Safety of the persons
- Impact on the environment
- Safety of the installation
- Loss of production.

He shall indicate to the utility the acceptable frequency of the interruptions of the electricity and their durations.

2.2 Information and requirements provided by the utility

Based on the information provided by the consumer, the utility must provide his proposition, his commitment and his own requirements concerning the connection of the substation:
- Level of voltage
- Supply by overhead line
- Supply by underground cables
- Single-line service, ring type supply, parallel feeders, etc.
- Rated values concerning the voltage
- Rated value concerning the current
- Details concerning the applicable tariff and the billing of the electrical energy
- Comments on drawings and information provided by the consumer
- Specific requirements applicable to the substation.

The detailed studies of the substation must take into account all these parameters and requirements.

2.3 Commissioning, testing, energizing

When required by the local authority, commissioning tests and checking must be successfully completed to get the authorization to energize a new installation.
The following tests and checking are generally mandatory and applicable to the whole installation:
- Verification that the main substation complies with all the requirements expressed by the utility
- Measurement of earth-electrodes resistances
- Electrical continuity of all equipotential and bonding conductors
- Inspection and functional testing of all MV components
- Dielectric test of switchgears and transformers
- Inspection and testing of the LV parts of the installation
- Mechanical and electrical interlocks checking
- Protective-relays checking
- Other additional tests and checking mat be required.

As soon as the conformity official document is issued, the utility proceeds with the energizing of the installation.

3 Protection against electrical hazards, faults and mis-operations in electrical installations

The subject of protection in the industry and electrical installations is vast. It covers many aspects:
- Protection of the persons and animals against electrical shocks
- Protection of the equipment and components against the stresses generated by short-circuits, lightning surges, power-system instability, and other electrical perturbations
- Protection of the property and equipment against damages and destructions
- Protection against the production losses
- Protection of the workers, the surrounding population and the environment against fire, explosions, toxic gases, etc.
- Protection of the operators and of the electrical equipment from the consequences of incorrect operations. This means that the switching devices (Load break switches, disconnectors, earthing switches) must be operated in the right order. Suitable Interlocking ensures strict compliance with the correct operating sequences.

Four aspects of the protection are detailed in the scope of this guide:
- Protection against electrical shocks
- Protection of the transformers against external constraints and internal faults
- Improvement of MV/LV transformer protection with circuit breaker associated to self powered relay
- Protection of the operators against the consequences of incorrect operations by appropriate interlocks.

3.1 General principle of protection against electrical shocks in electrical installations

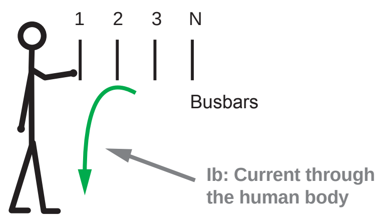


Fig. B11: Direct contact

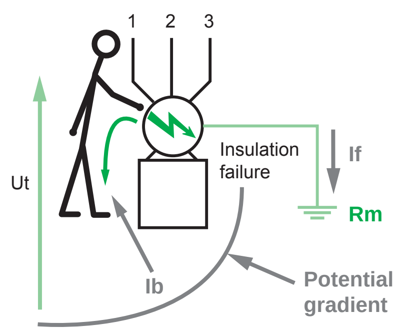


Fig B12: Indirect contact

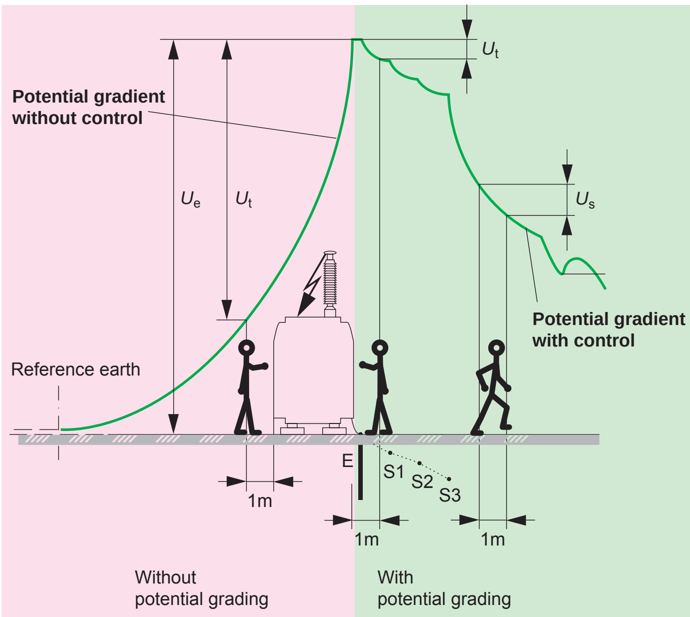
Protective measures against electric shocks are based on two well known dangers:
- **Direct contact:** contact with an active conductor, i.e. which is live with respect to the earth in normal circumstances. (see **Fig. B11**).
- **Indirect contact:** contact with a conductive part of an apparatus which is normally dead and earthed, but which has become live due to an internal insulation failure. (see **Fig. B12**).

Touching the part with hand would cause a current to pass through the hand and both feet of the exposed person. The value of the current passing through the human body depends on:
- The level of the touch voltage generated by the fault current injected in the earth electrode (see **Fig. B12**)
- The resistance of the human body
- The value of additional resistances like shoes.

■ Touch voltage: Ut ■ Ut ⩽ Ue	■ Earth potential rise: Ue ■ Ue = Rm x If	■ Ib: Current through the human body ■ Ib = Ut/Rb ■ Rb: Resistance of the human body	■ If: Earth Fault current ■ Rm: Resistance of the earth electrode

■ The touch voltage Ut is lower than the earth potential rise Ue. Ut depends on the potential gradient on the surface of the ground.

In **Figure B13,** the green curve shows the variation of the earth surface potential along the ground: it is the highest at the point where the fault current enters the ground, and declines with the distance. Therefore, the value of the touch voltage Ut is generally lower than the earth potential rise Ue.
On the left side, it shows the earth potential evolution without potential grading earth electrodes. On the right side, it describes how buried potential grading earth electrodes made of naked copper (S1,S2, Sn..) contribute to the reduction of the contact voltages (Ut, Us).
A third type of shock hazard is also shown in **Figure B13**, the "step- voltage" hazard (Us): the shock current enters by one foot and leaves by the other. This hazard exists in the proximity of MV and LV earth electrodes which are passing earth-fault currents. It is due to the potential gradients on the surface of the ground. Animals with a relatively long front-to-hind legs span are particularly sensitive to step-voltage hazards.
It clearly appears that the higher is the potential gradient without control (Ue), the higher are the levels of both touch voltage (Ut) and step voltage (Us).
Any presence of bonding conductors between all the metallic parts embedding concrete reinforcement contributes significantly to the reduction of contact voltages (touch, step).
In addition, surrounding the MV installation with any equipotential loop of buried naked copper contributes to a wider equipotential area.



■ Ue: Earth potential rise. ■ Ut: Prospective touch voltage. ■ Us: Prospective step voltage.
■ E: Earth electrode. ■ S1,S2,S3: Potential grading earth electrodes (e.g. ring earth electrodes), connected to the earth electrode E

Fig B13: Potential gradient control - EN50522 - Earthing of power installations exceeding 1 kV a.c.

3.1.1 Direct-contact protection or basic protection

There are four main principles of protection against direct contact hazards:

■ By containing all live parts in housings made of insulating material or in metallic earthed cubicles.
For MV switchgear, the IEC standard 62271-200 (Prefabricated Metal Enclosed switchgear and controlgear for voltages up to 52 kV) specifies a minimum **P**rotection **I**ndex (IP coding) of IP2X to ensures the direct-contact protection. Furthermore, the metallic cubicles has to demonstrate an electrical continuity between all inside and outside metallic parts.

■ By placing live parts out of reach. This principle is used in **A**ir **I**nsulated **S**ubstations "AIS" (see **Fig. B14**)

■ By installations of barriers also used in AIS substations (see **Fig. B15**)

■ By insulation. The best example of protection by insulation is the electrical LV and HV cables.

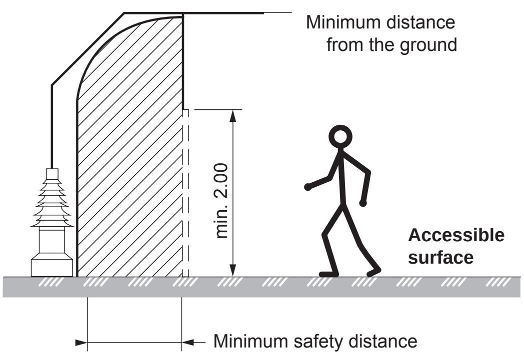


Fig. B15: Protection by installation of barriers. The safety distances are fixed by IEC 61936

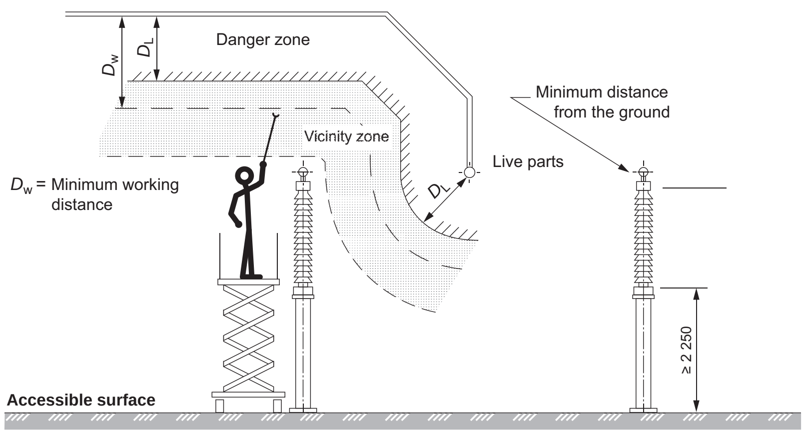


Fig. B14: Protection by placing live parts out of reach. The safety distances are fixed by IEC 61936

3.1.2 Indirect-contact protection or fault protection

As described above, a person touching the metal enclosure or the frame of an electrical apparatus affected by an internal failure of insulation is subject to an indirect contact.
Extensive studies have demonstrated that a current lower than 30 mA passing through the human body can be considered as not dangerous. It correspond to a touch voltage of about 50 V.
This means that the operation of installations may continue in presence of any phase to earth fault if the touch voltages can be maintained below 50 V. In all other situations where the expected touch voltages are above 50 V the interruption of the supply is mandatory. The higher the expected touch voltages are, the lower the interruption time must be. The maximum admissible interruption times, function of the expected touch voltages are specified by the IEC 60364 and IEC 61936 for LV and HV systems respectively.

Case of fault on L.V. system

Only the isolated neutral system (IT) allows to maintain touch voltages below 50 V and does not require the interruption of the supply in presence of phase to earth faults. Other two neutral systems (TT and TN) are always subjected to expected touch voltages above 50 V. In these cases the interruption of the voltage is mandatory. It is ensured within the time specified by the IEC 60364, either by the circuit breakers or the fuses protecting the electrical circuits. For more information concerning indirect contact in LV system, refer to chapter F.

Indirect-contact hazard in the case of a MV fault

In MV electrical systems, the expected touch voltages may reach values requiring interruption of the supply within much shorter times than the quickest opening time of the breakers. The principle of protection used for the LV systems cannot be applied as such for MV systems.
One possible solution for the protection of the persons it to create equipotential systems by means of bonding conductors interconnecting all the metallic parts of the installation: enclosures of switchgears, frames of electrical machines, steel structures, metallic floor pipes, etc. This disposition allows to maintain the touch voltages below the dangerous limit.

A more sophisticated approach concerning the protection of persons against indirect contact in MV and HV installations is developed in IEC 61936 and EN 50522. The method developed in these standards authorizes higher touch voltage limits justified by higher values of the human body resistance and additional resistances such as shoes and layer of crushed rock.

3.2 Protection of transformer and circuits

The electrical equipment and circuits in a substation must be protected in order to limit the damages due to abnormal currents and over voltages.
All equipment installed in a power electrical system have standardized ratings for short-time withstand current and short duration power frequency voltage.
The role of the protections is to ensure that these withstand limits can never be exceeded, therefore clearing the faults as fast as possible.
In addition to this first requirement a system of protection must be selective.
Selectivity or discrimination means that any fault must be cleared by the device of current interruption (circuit breaker or fuses) being the nearest to the fault, even if the fault is detected by other protections associated with other interruption devices.
As an example for a short circuit occurring on the secondary side of a power transformer, only the circuit breaker installed on the secondary must trip. The circuit breaker installed on the primary side must remain closed. For a transformer protected with MV fuses, the fuses must not blow.
They are typically two main devices able to interrupt fault currents, circuit breakers and fuses :

- The circuit breakers must be associated with a protection relay having three main functions:
  - Measurement of the currents
  - Detection of the faults
  - Emission of a tripping order to the breaker
- The fuses blow under certain fault conditions.

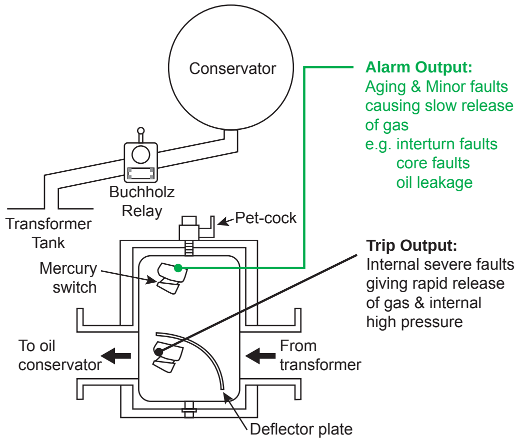


Fig. B16a: Breathing transformer protected by buchholz

Fig. B16b: Transformer with conservator

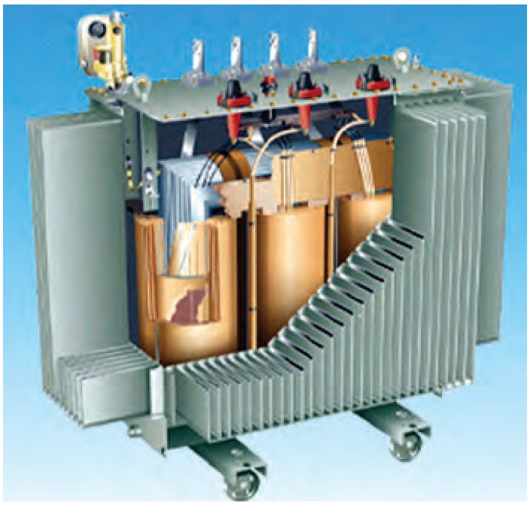


Fig. B17: Integral filled transformer

3.2.1 Transformer protection

Stresses generated by the supply

Two types of over voltages may stress and even destroy a transformer:

- The lightning over voltages due to lightning stroke falling on or near an overhead line supplying the installation where the transformer is installed
- The switching over voltages generated by the opening of a circuit breaker or a load break switch for instance.

Depending of the application, protection against these two types of voltage surges may be necessary and are often ensured by means of Z_nO surge arrestors preferably connected on the MV bushing of the transformer.

Stresses due to the load

A transformer overload is always due to an increase of the apparent power demand (kVA) of the installation. This increase of the demand can be the consequence of either a progressive adjunction of loads or an extension of the installation itself.
The effect of any overload is an increase of the temperature of oil and windings of the transformer with a reduction of its life time.

The protection of a transformer against the overloads is performed by a dedicated protection usually called thermal overload relay. This type of protection simulates the temperature of the transformer's windings. The simulation is based on the measure of the current and on the thermal time constant of the transformer. Some relays are able to take into account the effect of harmonics of the current due to non-linear loads such as rectifiers, computers, variable speed drives etc. This type of relay is also able to evaluate the remaining time before the emission of the tripping order and the time delay before re-energizing the transformer.
In addition, oil-filled transformers are equipped with thermostats controlling the temperature of the oil.
Dry-type transformers use heat sensors embedded in the hottest part of the windings insulation.
Each of these devices (thermal relay, thermostat, heat sensors) generally provides two levels of detection:

- A low level used to generate an alarm to advise the maintenance staff,
- A high level to de-energize the transformer.

Internal faults in oil filled transformers

In oil filled transformers, internal faults may be classified as follow:

- Faults generating production of gases, mainly:
  - Micro arcs resulting from incipient faults in the winding insulation
  - Slow degradation of insulation materials
  - Inter turns short circuit
- Faults generating internal over pressures with simultaneously high level of line over currents:
  - Phase to earth short circuit
  - Phase to Phase short circuit.

These faults may be the consequence of external lightning or switching over voltage.
Depending on the type of the transformer, there are two kinds of devices able to detect internal faults affecting an oil filled transformer.

- The Buchholz dedicated to the transformers equipped with an air breathing conservator (see **Fig. B16a**)

The buchholz is installed on the pipe connecting the tank of he transformer to the conservator (see **Fig. B16b**). It traps the slow emissions of gasses and detect the flow back of oil due to the internal over pressures

- The DGPT (Detection of Gas, Pressure and Temperature) for the integral filled transformers (see **Fig. B17**, **Fig. B18a** and **Fig. B18b**). This type of transformer is manufactured up to around10 MVA. The DGPT as the buchholz detects the emissions of gasses and the internal over pressures. In addition it monitors the temperature of the oil.

Concerning the monitoring of gas and temperature the buchholz and the DGPT provide two levels of detection:

- A low level used to generate an alarm to advise the maintenance staff,
- A high level to trip the switching device installed on the primary side of the transformer (circuit breaker or load break switch associated with fuses).

In addition, both the buchholz and the DGPT are suitable for oil leakages detection.

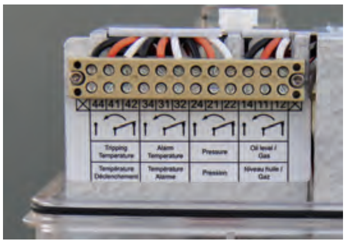


Fig. B18a: Contacts of the transformer protection relay DGPT (cover removed)

Fig. B18b: Transformer protection relay DGPT

Fig. B19: Dry type transformer

Fig. B20: Thermal relay for protection of dry type transformer (Ziehl)

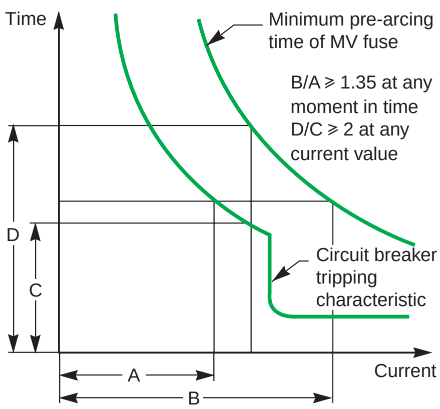


Fig. B21: Discrimination between MV fuse operation and LV circuit breaker tripping, for transformer protection

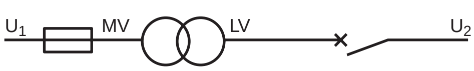


Fig. B22: MV fuse and LV circuit breaker configuration

Overloads and internal faults in dry type transformers
(see **Fig. B19** and **Fig. B20**)

The dry type transformers are protected against over-heating due to possible downstream overloads by a dedicated relay monitoring thermal sensors embedded in the windings of the transformer (see **Fig. B20**).

The internal faults, mainly inter turns and phase to earth short circuits occurring inside a dry type transformers are cleared either by the circuit breaker or the fuses installed on the primary side of the transformer. The tripping of the circuit breakers when used is ordered by the phase to phase and phase to earth over current protections.

Inter turns faults need a dedicated attention:
■ They generally generate moderate line over currents. As an example when 5 % of a HV winding are short circuited the line current of the transformer does not exceed 2 In, for a short circuit affecting 10 % of the winding the line current is limited around 3 In.
■ Fuses are not appropriate to clear properly such currents
■ Dry type transformers are not equipped with additional protection devices such as DGPT dedicated to internal faults detection.
Hence, internal faults generating low level of line over current may not be safely cleared by fuses. Protection by means of over current relay with adequate characteristic and settings is preferred (Schneider Electric VIP relay range for example).

Discrimination between the protective devices upstream and downstream of the transformer

It is a common practice to ensure the discrimination between the MV circuit breaker or fuses installed on the primary side of a transformer and the LV circuit breaker.

The characteristics of the protection ordering the tripping or the MV circuit breaker or the operating curves of the fuses when used must be such as in case of downstream fault the LV circuit breaker only trips. The MV circuit breaker must remain closed or the fuse must not blow.

The tripping curves of MV fuses, MV protection and LV circuit breakers are given by graphs giving the operating time as a function of the current.
The curves are in general inverse-time type. LV circuit breakers have an abrupt discontinuity which defines the limit of the instantaneous action.
Typical curves are shown in **Fig. B21**.

Discrimination between LV circuit breaker and MV fuses (see **Fig. B21** and **Fig. B22**)

■ All parts of the MV fuse curve must be above and to the right of the LV CB curve.
■ In order to leave the fuses unaffected (i.e. undamaged), the two following conditions must be satisfied:
□ All parts of the minimum pre-arcing fuse curve must be shifted to the right of the LV CB curve by a factor of 1.35 or more.
- Example: where, at time T, the CB curve passes through a point corresponding to 100 A, the fuse curve at the same time T must pass through a point corresponding to 135 A, or more, and so on.
□ All parts of the fuse curve must be above the CB curve by a factor of 2 or more
- Example: where, at a current level I the CB curve passes through a point corresponding to 1.5 seconds, the fuse curve at the same current level I must pass through a point corresponding to 3 seconds, or more, etc.
The factors 1.35 and 2 are based on the maximum manufacturing tolerances given for MV fuses and LV circuit breakers.
In order to compare the two curves, the MV currents must be converted to the equivalent LV currents, or vice-versa.

Discrimination between LV circuit breaker and MV circuit breaker

■ All parts of the minimum MV circuit breaker curve must be shifted to the right of the LV CB curve by a factor of 1.35 or more:
- Example: where, at time T, the LV CB curve passes through a point corresponding to 100 A, the MV CB curve at the same time T must pass through a point corresponding to 135 A, or more, and so on.
■ All parts of the MV CB curve must be above the LV CB curve. The time difference between the two curves must be 0.3 s at least for any value of the current.
The factors 1.35 and 0.3 s are based on the maximum manufacturing tolerances given for MV current transformers, MV protection relay and LV circuit breakers.

Fig. B23: Schneider Electric VIP 30 self powered relay for basic transformer protection

Fig. B24: Schneider Electric VIP 300 self powered IDMT (Inverse Definite Minimum Time) overcurrent and earth-fault relay

3.3 MV/LV transformer protection with circuit breaker

MV/LV transformer protection with circuit-breaker is usually used in large Commercial, Industrial and Building applications and especially when the transformer power exceeds 800 kVA. In these applications, switchboards made of modular units provide high flexibility.

The protection chain of each unit may include self powered relays (see **Fig. B23** and **Fig. B24**) bringing a high level of safety and optimized CTs (See **Fig. B25**).

This solution provides interesting benefits concerning:

- The maintenance
- The improvement of protection of the transformer
- The improvement of the discrimination with the LV installation
- The insensitivity to the inrush currents
- The detection of low earth fault currents.

Fig. B25: Schneider Electric SM6 and Premset switchboards including MV/LV transformer protection with circuit breaker associated to self powered relay

3.3.1 Maintenance

Modern protective relays are now almost maintenance free, as they include self testing features. However it remains necessary to check the protection chain at commissioning stage and periodically (every 5 or 10 years).

3.3.2 Protection performance

Circuit breakers combined with electronic protection relays bring many protection selectivity benefits, including:

- coordination with upstream and downstream devices;
- discrimination of inrush currents;
- detection of low level of phase to phase and phase to earth fault currents.

3.3.3 Discrimination with LV installation

In cases where the LV installation includes an incoming LV Air circuit breaker, discrimination with the MV circuit-breaker is easy, as it is possible to choose the right curve in the electronic relay to ensure discrimination between MV and LV protection.

3.3.4 Inrush current

Transformer energizing produces very high transient inrush current that can reach peak values, up to about ten times the peak rated current for step-down transformer, and 25 times for step-up transformer. This is a natural phenomenon and the protection should not operate. The circuit breaker allows high flexibility to avoid tripping current while still maintaining a good level of protection due to the electronic relay time/current characteristic.

3.3.5 Low magnitude phase fault current

A MV/LV transformer has usually a very low failure rate. Most of the faults are interturn faults or phase to earth faults. Phase-to-phase faults between MV bushing are of more seldom occurrences (see **Fig. B26**).

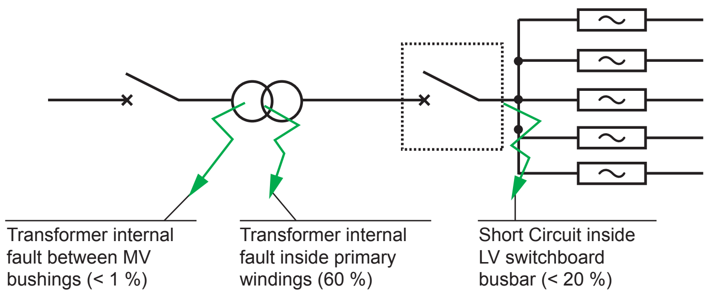


Fig. B26: Localization of a fault

Most common faults are short-circuit inside a turn of the MV winding where the fault level is of low magnitude (1 to 6 times the rated current) (see **Fig. B26**).
In case of circuit breaker, as soon as the fault reaches the setting, the relay will detect it and trip safely the circuit breaker, disconnecting the MV/LV transformer circuit.

3.3.6 High magnitude fault currents

In the rare event of a short-circuit between MV bushings, the protection must act quickly. In that case the circuit breaker is slower than the MV fuse that has current limiting capabilities. However, the circuit breaker will clear the fault in less than 100 ms, and this is effective enough to avoid any serious damages.

3.3.7 Low level MV earth-faults

In case of either high impedance earth fault on MV winding or solid earth-faults in impedance earthed neutral system, the earth fault magnitude is below the rated current of the transformer. Modern self powered relays integrate sensitive earth fault protection and then provide effective coverage on these conditions.

3.3.8 Case of public distribution

In public distribution applications, such as MV ring network configurations, utilities look for the simplest repetitive MV/LV substations that are dispersed in a large geographical area. The power of MV/LV transformer is generally limited to 630 kVA or less. Compact and often non extensible 3 function switchgear are specified by the utilities. In these cases, protection of MV/LV transformers by MV fuses offers an optimized solution (see **Fig. B27**).

Fig. B27: Compact 3 function switchgear

3.4 Interlocks and conditioned operations

Mis-operations in electrical installations may expose operating personnel to danger and lead to electrical incidents.
As a measure of protection against incorrect sequences of manoeuvres by operating personnel, mechanical and electrical interlocks are included in the mechanisms and in control circuits of electrical apparatus.
The interlocks may be classified in two categories:

- Functional interlocks incorporated in MV functional units and dedicated to the operation of the apparatus located in the units only. These interlocks are generally realized by means of specific mechanical devices linked with the mechanisms of the apparatus
- Interlocks between MV functional units or between a functional unit and another equipment such as a MV/LV transformer. Most of these interlocks are realized by means of keys transferred from one equipment to another when they are made free. They may be improved by additional electrical interlocks.

3.4.1 Functional interlocks

Some interlocks are mandatory in MV functional units according to IEC 62271-200, dedicated to metal enclosed switchgear, for example to prevent from:

- closing a switch or circuit breaker on a closed earthing switch;
- closing an earthing switch while the associated switching function is closed

Specific additional interlocks may be specified by the users when required by their operational rules, for example:

- Allowing the opening of a MV cable connection compartment only if the earthing switch associated to the remote end of the MV cable is closed.

The access to a MV compartment requires a certain number of operations which shall be carried out in a pre-determined order. To restore the system to its former condition it is necessary to carry out operations in the reverse order.
Dedicated procedures and instructions may also ensure that the operations are performed in the right sequence.
Hence, the accessibility to an MV compartment can be either interlock controlled or based on procedure. A compartment can also be accessible only by means of tools if its access is not necessary for normal operation or maintenance of the switchgear, or "not accessible", access being either forbidden or impossible (see **Fig. B28**).

Type of accessibility to a compartment	Access features	Type of construction
Interlock-controlled	Opening for normal operation and maintenance, e.g. , fuse replacement.	Access is controlled by the construction of the switchgear, i.e. , integrated interlocks prevent impermissible opening.
Procedure-based	Opening for normal operation or maintenance, e.g. , fuse replacement.	Access control via a suitable procedure (work instruction of the operator) combined with a locking device (lock).
Tool-based	Opening not for normal operation and maintenance, e.g. , cable testing.	Access only with tool for opening; special access procedure (instruction of the operator).
Not accessible	Opening not possible not intended for operator; opening can destroy the compartment. This applies generally to the gas-filled compartments of gas-insulated switchgear. Because the switchgear is maintenance-free and climate-independent, access is neither required nor possible.	

Fig. B28: Type of accessibility to a compartment

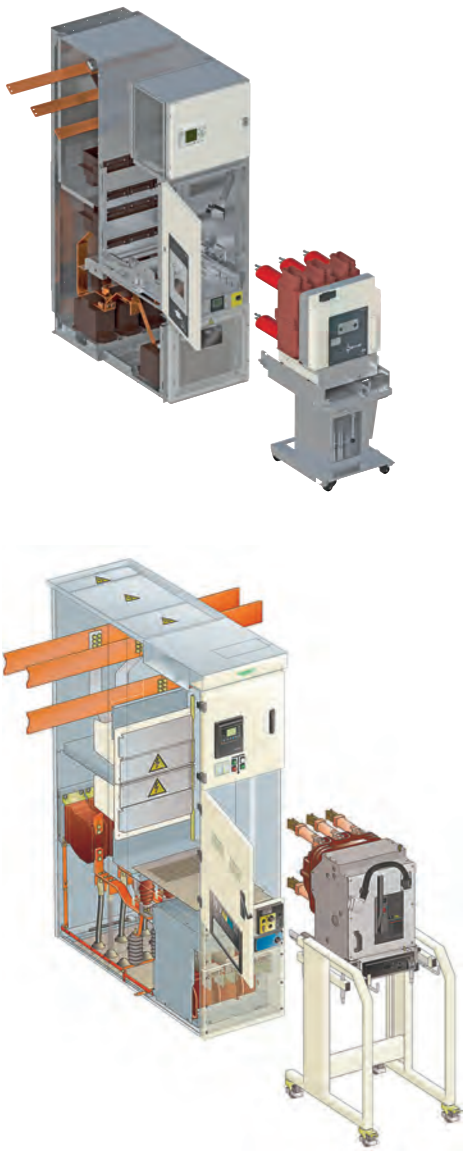


Fig. B29: Example of functional unit architecture with compartments, favoring service continuity

3.4.2 Key interlocking

The interlocks between devices located in separate MV functional units or between a functional unit and access to a MV/LV transformer for example are performed by means of keys.
The principle is based on the possibility of freeing or trapping one or several keys, according to whether or not the required conditions of operation are satisfied.
These conditions ensure the safety of the personnel by the avoidance of incorrect operations.

Note: Concerning the MV/LV substations, the interlocks shall be specified during the design stage. Hence, the apparatuses concerned by the interlocks will be equipped during the manufacturing with the appropriate keys and locking devices.

3.4.3 Service continuity

The notion of **L**oss of **S**ervice **C**ontinuity: "LSC" (see **Fig B29** and **Fig. B30**) defines the conditions of access to any high voltage accessible compartment of a given high voltage functional unit.
IEC 62271-200 defines four categories of Loss of Service Continuity: LSC1, LSC2, LSC2A, LSC2B.
Each category defines which other high voltage compartments and /or other functional units can be kept energized when opening an accessible high-voltage compartment in a given functional unit.

For the single busbar architectures the following definitions are applicable:

- LSC1 functional unit

Functional unit having one or several high-voltage accessible compartments, such that, when any of these accessible high-voltage compartments is open, the busbar and one or several other functional units of the switchgear must be de-energized

- LSC2 functional unit

Functional unit having at least an accessible compartment for the high-voltage connection (called connection compartment), such that, when this compartment is open the busbar can remain energized. All the other functional units of the switchgear can continue to be operated normally.

Note: When LSC2 functional units have accessible compartments other than the connection compartment, further subdivisions into LSC2A and LSC2B are defined.

- LSC2A functional unit

Functional unit having several high-voltage accessible compartments, such that, the busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally

- LSC2B functional unit

Functional unit having several high-voltage accessible compartments, such that, the high-voltage connections compartment and the busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally.

		Applies when
LSC1	When any compartment of the FU is open the busbar and one or several other FUs of the switchgear must be de-energised	One or several compartments in the considered FU are accessible
LSC2	When the cable compartment is open the busbar can remain energized and all the other FUs of the switchgear can be operated normally	Only the connection compartment in the considered FU is accessible
LSC2A	The busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally	Several compartments in the considered FU are accessible
LSC2B	The high-voltage connections compartment and the busbar can remain energized when any other accessible high voltage compartment is open. All the other functional units of the switchgear can continue to be operated normally	Several compartments in the considered FU are accessible

Fig. B30: Loss of Service Continuity definitions

3.4.4 Interlocks in substations

Example of functional interlocks, embedded in single functional units

■ Load break switch closing: the door must be closed and the earthing switch open
■ Earthing switch closing: the door must be closed and associated circuit breaker, switch and/or isolating apparatus open
■ Access to an accessible compartment: the associated circuit breaker, switch and/or isolating apparatus must be open and the earthing switch closed.

Example of functional interlocks involving several functional units or separate equipment (see **Fig. B31**):

Lets consider a MV/LV transformer supplied by a MV functional unit including:
■ A load break switch
■ A set of MV fuses
■ An earthing switch

The transformer is installed in a dedicated cubicle.

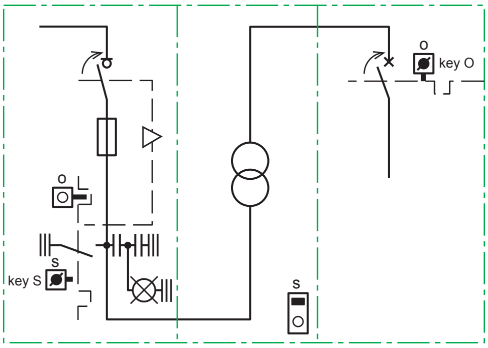
The access to the MV/LV transformer is authorized when the following conditions are satisfied:
■ MV load break switch open
■ MV earthing switch closed and locked in close position
■ LV circuit breaker open and locked in open position
The required sequence of operations to meet these conditions in full safety is the following:

■ **Step 1**: Open the LV CB and lock it open with key "O". Key "O" is then free
■ **Step 2**: Open the MV load break switch. Check that the "voltage presence" indicators are extinguished, unlock earthing switch with key O, key O is now trapped
■ **Step 3**: Close the MV earthing switch and lock it in close position with key S. Key S is now free
■ **Step 4**: Key S allows to open the door of the transformer cubicle. When the door is open, key S is trapped.

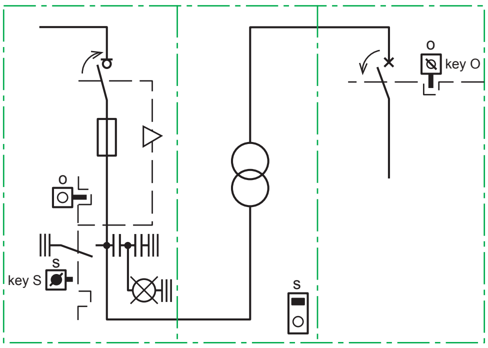
The restoration of the supply to the LV switchboard is performed with the execution of the reverse sequence of operation:

■ **Step 1**: Door of the transformer cubicle closing
■ **Step 2**: MV earthing switch opening
■ **Step 3**: MV load break switch closing
■ **Step 4**: LV circuit breaker closing.

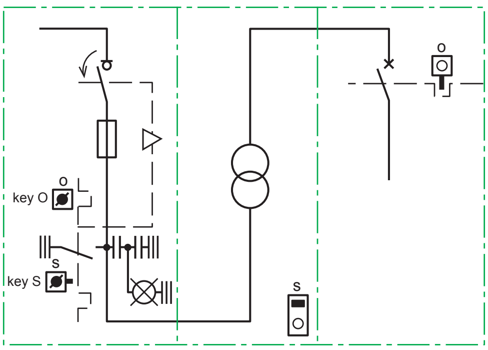
Due to LV production, some national regulations require an earthing system as temporary or permanent device to operate on the transformer under full safety, and the earthing connection shall be integrated within the interlock procedure.



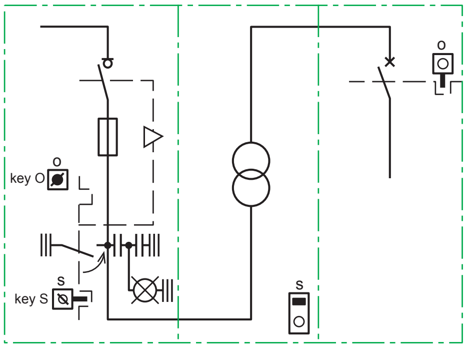
Initial configuration: LV Switchboard energized. MV Load break switch closed. LV circuit breaker closed. Earthing switch open and locked in open position. Key O trapped. Key S trapped.



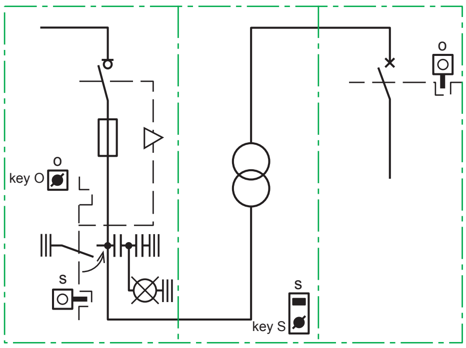
Step 1: Load break switch closed.
LV circuit breaker open and locked. Earthing switch open, locked in open position. Key O free, Key S trapped.



Step 2: Load break switch open,
LV circuit breaker open and locked in open position. Earthing switch unlocked, Key O trapped, Key S trapped.



Step 3: Load break switch open,
LV circuit breaker open and locked in open position.
Earthing switch closed
and locked, Key O trapped, Key S free.



Step 4: Load break switch open,
LV circuit breaker open and locked in open position.
Earthing switch closed and locked, door of transformer cubicle open, Key O trapped, Key S trapped.

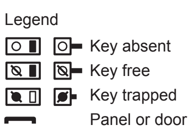


Fig. B31: Example of MV/LV interlocking system

4 The consumer substation with LV metering

4.1 Definition

A consumer substation with LV metering is an electrical installation connected to a utility supply network at a nominal voltage usually between 1 kV - 35 kV, and including generally a single MV/LV transformer not exceeding 1250 kVA. The substation may be installed either in a dedicated room located in a building, or outdoor in a prefabricated housing.

4.2 Functions of a substation with LV metering

4.2.1 Connection to the MV network

Connection to the MV network can be made:
- By a single service cable or overhead line,
- By dual parallel feeders via two mechanically interlocked load-break switches
- Via a ring main unit including two load-break switches.

4.2.2 MV/LV Transformers

Since the ban of PCB in most of the countries, the remaining available insulation technologies for the transformers are:
- Oil-immersed for transformer preferably located outside premises
- Dry-type, cast-resin preferred for transformers located inside premises such as buildings receiving the public.

Local regulations define where the use of cast resin transformers is mandatory.

4.2.3 Metering

Most of the LV metering and billing principles take into account the MV/ LV transformer losses.
The characteristics and the location of the VT's and CT's dedicated to the metering must comply with the utility's requirements.
The metering current transformers are generally installed in the LV terminal box of the power transformer, alternatively they can be installed in a dedicated compartment in the main LV switchboard.
The compartments housing the metering VT's and CT's are generally sealed by the utility.
The meters are mounted on a dedicated panel accessible by the utility at any time.

4.2.4 Local emergency generators

Emergency standby generators are intended to maintain the supply to the essential loads, in the event of failure of the utility power supply.
A substation with LV metering may include one single emergency generator connected at low voltage level on the main LV distribution switchboard.
The generator may be sized either for the supply of the whole installation or for a part only. In this case a load shedding system must be associated to the generator.
The loads requiring an emergency supply may also be grouped on a dedicated LV busbar (see **Fig. B32**).
An **U**ninterruptible **P**ower **S**upply (UPS) may be added when required at LV level to avoid the interruption of the supply during the starting of the emergency generator.

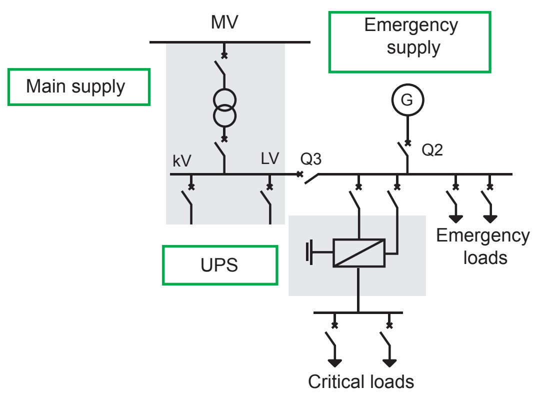


Fig. B32: Emergency generator at LV Level

4.2.5 Capacitors

Capacitors are intended to maintain the power factor of the installation at the contractual value specified by the utility. The capacitor banks are connected on the main LV switchboard and can be fixed or adjustable by means of steps controlled by a regulator.
See chapter L "Power Factor Correction"

4.2.6 LV main switchboard

The MV/LV transformer is connected to a main LV distribution switchboard equipped with a LV general circuit breaker ensuring:
- The general protection of the LV installation
- The general isolation of the LV circuits, according to the rules of protection of the persons working in an electrical installations
- The protection of the MV/LV transformer against overload

To comply with the interlocking requirements defined in 3.3, the circuit breaker must be equipped with padlocking facilities for locking it in open position.

4.2.7 Simplified electrical network diagram

The diagram (**Fig. B33**) shows:
- The different methods to connect a MV/LV substation to the utility supply:
  - Single-line service
  - Single line service with provision for future connection to a ring or to dual parallel feeders
  - Dual parallel feeders
  - Loop or ring-main service
- The protection of the MV/LV transformer, either by a load break switch or by a circuit breaker
- The LV metering
- The main LV switchboard.

4.3 Choice of MV equipment (Refer to section 6)

MV equipment shall comply with applicable IEC standards and local regulations. It shall be selected according to the electrical and environmental constraints to which it is supposed to be subjected.

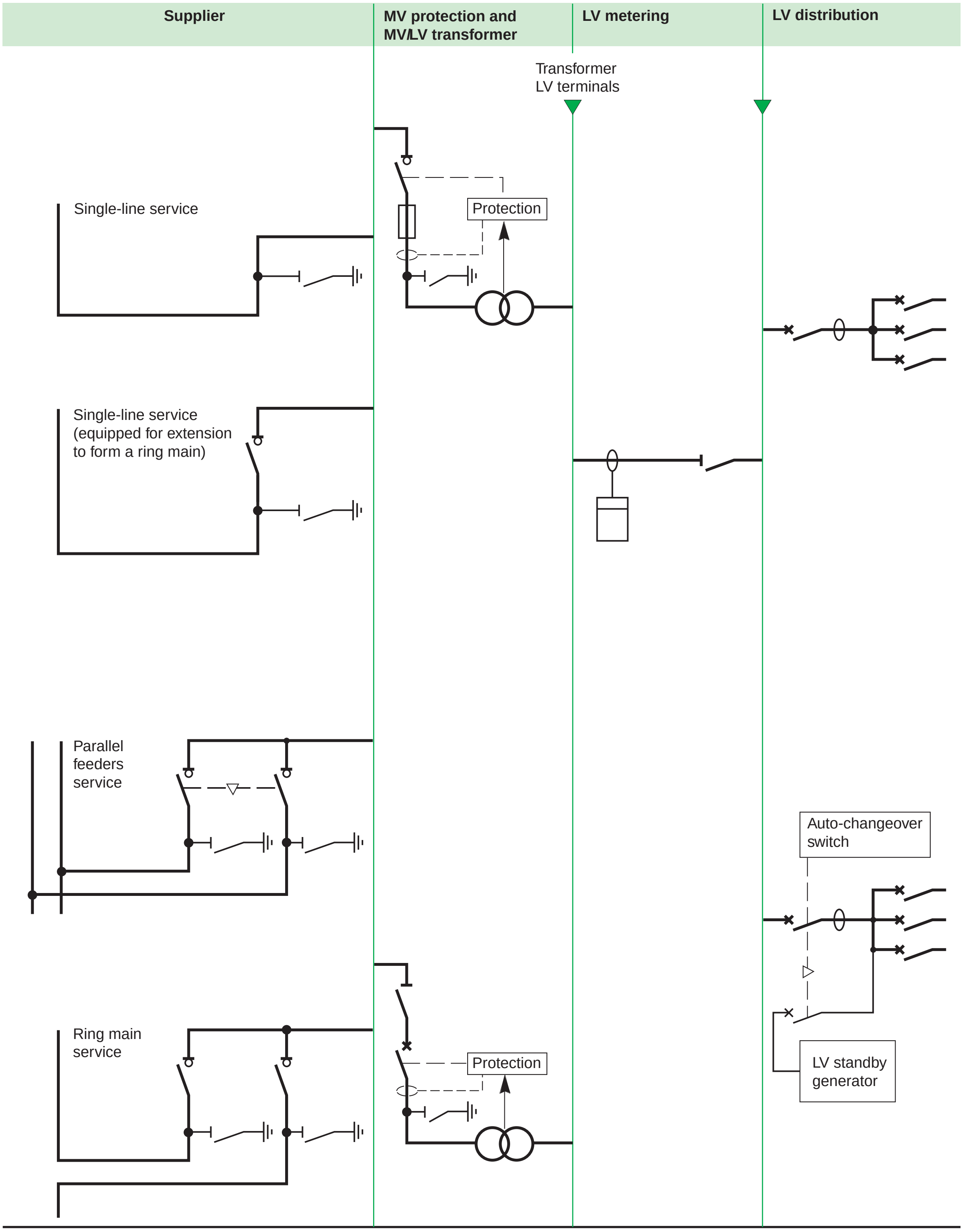


Fig. B33: Consumer substation with LV metering

5 The consumer substation with MV metering

5.1 Definition

A consumer substation with MV metering is an electrical installation connected to a utility supply system at a nominal voltage usually between 1 kV - 35 kV, which for example may supply:

- A single MV/LV transformer exceeding generally 1250 kVA
- Several MV/LV transformers
- One or several MV/LV secondary substations.

The single line diagram and the layout of a substation with MV metering depend on the complexity of the installation and the presence of secondary substations.
For example a substation may:

- Include one single room containing the MV switchboard, the metering panel, the transformer(s) and the low voltage main distribution board(s),
- Supply one or several transformers, each installed in a dedicated room including the corresponding main LV distribution switchboard
- Supply one or several secondary MV/LV substations.

5.2 Functions of the substation with MV metering

5.2.1 Connection to the MV network

Connection to the MV network can be made:

- By a single service cable or overhead line,
- By dual parallel feeders via two mechanically interlocked load-break switches
- Via a ring main unit including two load-break switches.

5.2.2 MV/LV Transformers and internal MV distribution

As mentioned for substation with LV metering, only oil-immersed and dry type cast-resin transformers are allowed with the same rules of installation.
When the installation includes several MV/LV transformers and/or secondary MV/ LV substations an internal MV distribution network is required.
According to the required level of availability, the MV supplies to the transformers and the secondary substations may be made,

- By simple radial feeders connected directly to the transformers or to the secondary substations
- By one or several rings including the secondary MV/LV substations (**Fig. B10**)
- By duplicate feeders supplying the secondary MV/LV substations.

For the two latter solutions the MV switchboard located in each secondary substation includes two load break switch functional units for the connection of the substation to the internal MV distribution and one transformer protection unit, for each transformer installed in the substation.
The level of availability can be increased by using two transformers operating in parallel or arranged in dual configuration with an automatic change over system.
It is not recommended to use MV/LV transformers above 2500 kVA due to:

- The high level of the short circuit current generated on the main LV switchboard.
- The number of LV cable required for the connection of the transformer to the LV switchboard.

5.2.3 Metering

The characteristics and the location of the VT's and CT's dedicated to the metering shall comply with the utility requirements.
The VT's and CT's are generally installed in the MV switchboard. A dedicated functional unit is in most of the cases required for the voltage transformers while the current transformers may be contained in the functional unit housing the circuit breaker ensuring the general protection of the substation.
The panel that contains the meters shall be accessible by the utility at any time.

5.2.4 Local emergency generators

Emergency standby generators are intended to maintain the power supply to the essential loads in the event of failure of the utility power supply.
According to the energy needs an installation may contains one or several emergency generators.
The generators can be connected:

- At MV level to the MV main substation (see **Fig. B34**).The generator(s) may be sized either for the supply of the whole installation or for a part only. In this case a load shedding system must be associated to the generator(s).
- At LV level on one or several LV switchboards requiring an emergency supply. At each location, the loads requiring an emergency supply may be grouped on a dedicated LV busbar supplied by a local generator (see **Fig. B31**).

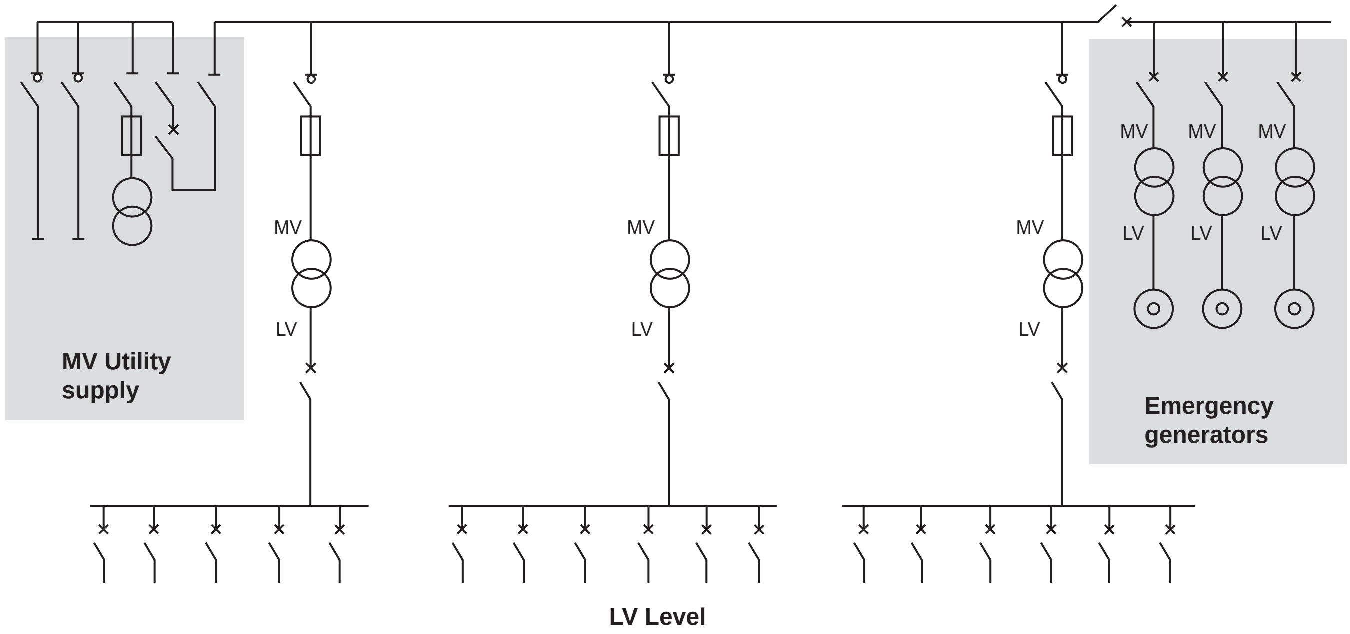


Fig. B34: Connection of emergency generators at MV level

5.2.5 Capacitors

Capacitors are intended to maintain the power factor of the installation at the contractual value specified by the utility. The capacitor banks can be fixed or adjustable by means of steps. They can be connected:
- At MV level to the main MV substation
- At LV level on LV switchboards.

5.2.6 LV main switchboard

Every MV/LV transformer is connected to a main LV switchboard complying with the requirements listed for substation with LV metering (see 4.2.6).

5.2.7 Simplified electrical network diagram

The diagram (**Fig. B35**) shows:
- The different methods to connect a MV/LV substation to the utility supply:
  - Spur network or single-line service
  - Single line service with provision for future connection to a ring or to dual parallel feeders
  - Dual parallel feeders
  - Loop or ring-main service
- General protection at MV level
- MV metering functions
- Protection of MV circuits
- LV distribution switchboard

Compared with a substation with LV metering, a substation with MV metering includes in addition:
- A MV Circuit breaker functional unit for the general protection of the substation
- A MV metering functional unit
- MV Functional units dedicated to the connection and the protection of:
  - MV/LV transformers
  - MV feeders supplying secondary substations
  - MV capacitor banks
  - Emergency generators

The general protection usually includes protection against phase to phase and phase to earth faults. The settings must be coordinated with the protections installed on the feeder of the primary substation supplying the installation.

5.3 Choice of MV equipment (Refer to chapter 6)

MV equipment shall comply with applicable IEC standards and local regulations. It shall be selected according to the electrical and environmental constraints to which it is supposed to be subjected.

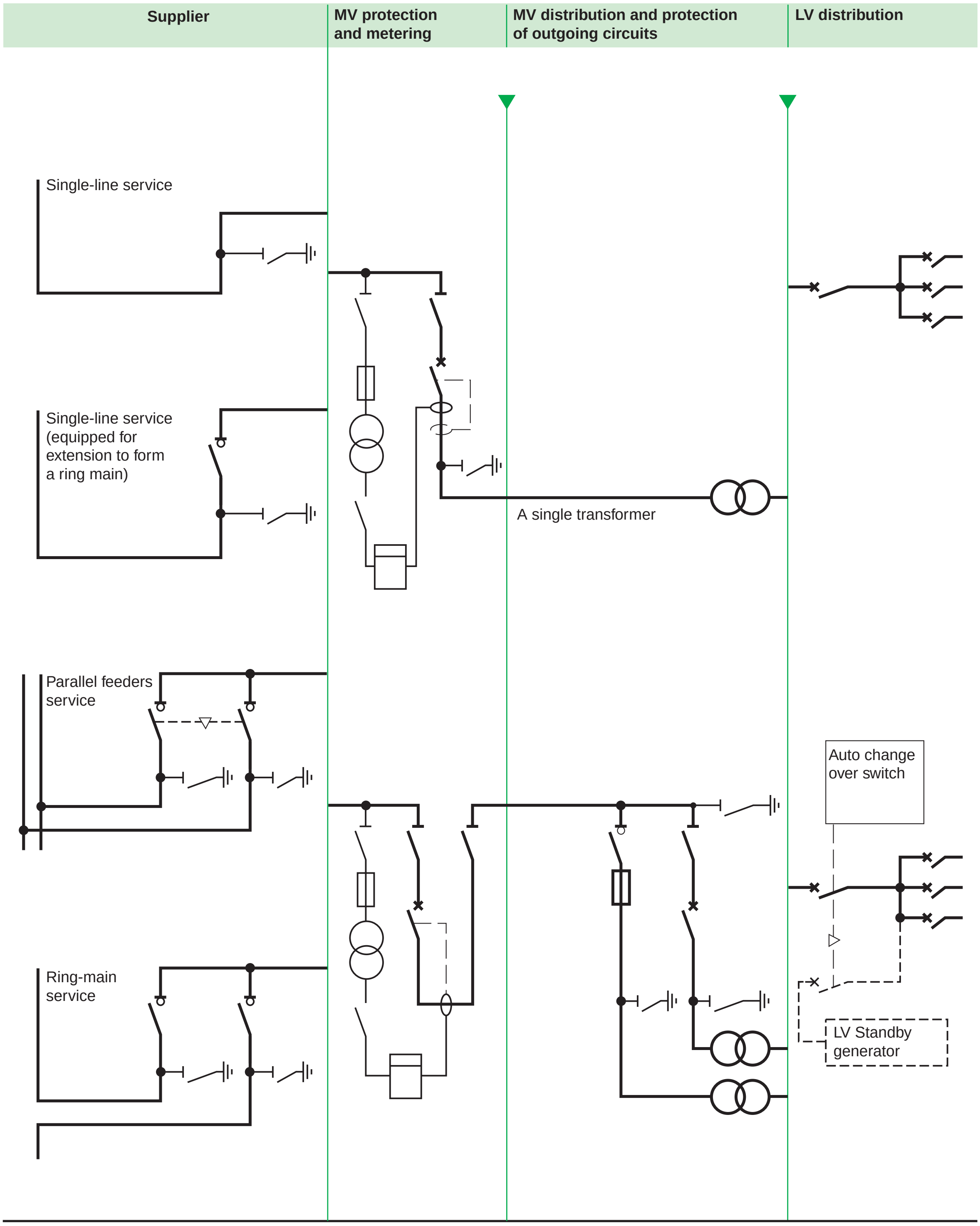


Fig. B35: Consumer substation with MV metering

6 Choice and use of MV equipment and MV/LV transformer

6.1 Choice of MV equipment

The electrical equipment must withstand both electrical and environmental constraints to which it will be submitted during its life time without any mechanical and dielectric degradation reducing its level of performance.

6.1.1 Standards and specifications

Depending on the devices, components and products included in the MV switchgear, different standards have to be considered for compliance, such as:
- IEC 62271-1, 62271-100, 62271-102, 62271-103, 62271-105, 62271-200.

Local regulations may also require compliance with national standards:
- ANSI/IEEE for USA
- EN for European Union
- GOST for Russia
- GB/DL for China.

6.1.2 Types of MV equipment

Substations shall be designed and built according to local standards and practices. The following types of equipment may be used:
- Compartmented modular units supporting all types of single line diagram and layout
- Compact solution based on ring-main unit solution when the supply is provided by a ring.

A ring main unit includes two load break switches for the connection of the substation to the ring and a transformer protection unit. Some compact RMU designs are particularly suitable when harsh environmental conditions apply.

Fig. B36: SF6 modular unit

6.1.3 Modular metal-enclosed switchgear (Fig. B36)

The IEC 62271-200 standard specifies requirements for "AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV".
Different categories of prefabricated metal enclosed switchgear are defined with respect to the consequences on network service continuity in case of maintenance on the switchgear.
For classification in categories, various aspects have to be taken into account:
- Definition of functional unit: "a switchgear component contained in a metallic enclosure and incorporating all the main and auxiliary circuit equipment required to perform a single function" - usually a modular unit
- Definition of compartment: "a switchgear component contained in a closed metallic enclosure. The manufacturer defines the content (e.g. busbar, cable connections, etc.)
- Accessibility to individual compartments (see 3.4.1):
  - Controlled by interlocking
  - In accordance with procedures; for compartments which can be opened during normal operation
  - Using tools; for compartments which should not be opened during normal operation
  - Not accessible for compartments which must not be opened
- Loss of Service Continuity (LSC) (see 3.4.3) defining the extent to which other compartments can remain energised when one compartment is open. Four LSC categories are defined:
  - LSC1, LSC2, LSC2 A, LSC2 B
- Definition of partition: "a switchgear component contained in a metallic enclosure and separating one compartment from another". There are two types of partitions :
  - PM: metallic partitions
  - PI: insulating partitions.

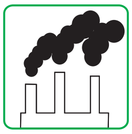
Metal-enclosed switchgear can be based on all modern switchgear technologies, such as:
- AIS (**A**ir **I**nsulated **S**witchgear)
- SIS (**S**olid **I**nsulated **S**witchgear)
- GIS (**G**as **I**nsulated **S**witchgear)
- 2SIS (**S**hielded **S**olid **I**nsulated **S**witchgear).

6.1.4 Choice of MV switchgear panel for a transformer circuit

Three types of MV switchgear panel can be used:
■ Load-break switch associated to MV fuses without coordination between the fuses and the breaking capability of the load break switch
■ Load-break switch/MV fuses combination with coordination between the fuses and the breaking capability of the load break switch
■ Circuit breaker
As explained in paragraph 3.3, a circuit breaker with a dedicated protection relay ensures a better protection of the transformer than the MV fuses coordinated or not with a load break switch.
Note: The fuses used in the load-break switch / fuses combination have striker-pins which ensure tripping of the 3-pole switch as soon as at least one fuse blows.

6.2 Instructions for use of MV equipment

The purpose of this chapter is to provide general guidelines on how to avoid or greatly reduce MV equipment degradation on sites exposed to humidity and pollution.



6.2.1 Normal service conditions for indoor MV equipment

All MV equipment are intented to be used in the normal services conditions as defined in IEC 62271-1 standard "Common specifications for high-voltage switchgear and controlgear".

For instance, regarding humidity, the standard mentions:
■ The average value of the relative humidity, measured over a period of 24 h does not exceed 95 %;
■ The average value of the water vapour pressure, over a period of 24 h does not exceed 2.2 kPa;
■ The average value of the relative humidity, over a period of one month does not exceed 90 %;
■ The average value of water vapour pressure, over a period of one month does not exceed 1.8 kPa.

As indicated in the standard, condensation may occasionally occur even under normal conditions. Either switchgear designed for such conditions shall be used and/or special measures concerning the substation premises can be implemented to prevent condensation, such as suitable ventilation and heating of the station.

Fig. B37: SM6 Modular Unit

6.2.2 Use under severe conditions

Under certain severe conditions concerning humidity and pollution, largely beyond the normal conditions of use mentioned above, electrical equipment can be subject to damage by rapid corrosion of metal parts and surface degradation of insulating parts. Examples of suitable measures of protection against condensation and pollution are listed bellow.

Remedial measures for condensation problems

■ Carefully design or adapt substation ventilation.
■ Avoid temperature variations.
■ Eliminate sources of humidity in the substation environment.
■ Install an **H**eating, **V**entilation, **A**ir **C**onditioning unit (HVAC)
■ Make sure cabling is in accordance with applicable rules.

Remedial measures for pollution problems

■ Equip substation ventilation openings with chevron-type baffles to reduce entry of dust and pollution especially when the transformer is installed in the same room with switchgears or controlgears.
■ Install the transformer in a different room to use more efficient ventilation grids if any,
■ Keep substation ventilation to the minimum required for evacuation of transformer heat to reduce entry of pollution and dust
■ Use MV cubicles with a sufficiently high degree of protection (IP)
■ Use air conditioning systems or air forced cooling with filters installed in air inlet to restrict entry of pollution and dust.
■ Regularly clean all traces of pollution from metal and insulating parts.
■ Instead of using AIS equipment (**Fig. B37**), use equipment that is insensitive to the environment such as GIS or 2SIS type (see **Fig. B38**).

Fig. B38: PREMSET. Shielded Solid Insulated MV equipment

6.3 Choice of MV/LV transformer

The transformers shall comply with IEC 60076. A transformer is characterized by its electrical parameters, but also by its technology and its conditions of use.

6.3.1 Characteristic parameters of a transformer

■ **Rated power:** the apparent-power in kVA on which the values of the design parameters and the construction of the transformer are based. Manufacturing tests and guarantee refer to this rated power
■ **Frequency:** for power distribution systems discussed in this guide, the frequency is either 50 Hz or 60 Hz
■ **Rated primary voltage:** the service voltage of the electrical network on which the transformer in connected
■ **Rated secondary voltage:** the voltage measured between the secondary terminals when the transformer is off load and energized at its rated primary voltage
■ **Transformer ratio:** RMS value of the rated primary voltage divided by the RMS value of the rated secondary voltage
■ **Rated insulation levels:** are defined by the values of the overvoltage power frequency withstand test, and high voltage lightning impulse tests.
For the voltage levels considered in this guide, the encountered switching over voltages are generally lower than the expected lightning over voltages, so no over voltage switching tests are required for these voltages
■ **Off-load tap-Changer switch:** allows to adjust the rated primary voltage and consequently the transformer ratio within the range ± 2.5 % and ± 5 %.
The transformer must be de-energized before the operation of the switch
■ **Winding configurations:** Star, Delta and Zigzag high and low voltage windings connections are defined by an alphanumeric code read from the left to the right. The first letter refers to the high voltage winding, the second letter to low voltage winding :
□ Capital letters are used for the high voltage windings
- D = delta connection
- Y = star connection
- Z = zigzag connection
- N = neutral point brought out to a dedicated terminal
□ Lower-case letters are used for the low voltage winding
- d = delta
- y = star
- z = interconnected-star (or zigzag)
- n = neutral point brought out to a dedicated terminal
□ A number between 0 and 11 indicates the phase shifting between the primary and the secondary voltages.
□ A common winding configuration used for distribution transformers is Dyn 11:
- High voltage primary windings connected in Delta
- Low voltage secondary windings connected in Star
- Low voltage neutral point brought out to a dedicated terminal.
- Phase shifting between the primary and the secondary voltage: 30°.

Fig. B39: Dry type transformer

6.3.2 Technology and utilization of the transformers

There are two basic types of distribution transformer:
■ Dry type (cast resin encapsulated) transformer
■ Liquid filled (oil-immersed) transformer.

According IEC 60076, the standard conditions of utilization of the transformers for outdoor and indoor installation are the following:
■ Altitude ⩽ 1000 m
■ Maximum ambient temperature: 40 °C
■ Monthly average temperature: 30 °C during the hottest month
■ Annual average temperature: 20 °C.

For other service conditions:
■ For oil immersed transformer the IEC 60076-2 specifies the oil and winding temperature rise.
■ For dry type transformer the IEC 60076-11 specifies the thermal class.

The temperature surrounding the transformer is linked to the outdoor service condition, its cooling mode and efficiency when installed in a room, and its load. Two loading guides can help to verify if the transformer is correctly defined according to the expected lifespan, which are respectively the IEC 60076-7 and IEC 60076-12. An annex within the HV/LV prefabricated substation standard IEC 62271-202 gives several examples of installation, based on these two guides.

6.3.3 Dry type transformers (see **Fig. B39**)

The dry type transformers shall comply with IEC 60076-11:
Each individual winding of these transformers is casted in resin according to a vacuum dedicated process.
The high voltage winding, the low voltage winding and the frame are separate by air.

The encapsulation of a winding uses three components:
■ Epoxy-resin based on biphenol A with a viscosity that ensures complete impregnation of the windings
■ Anhydride hardener modified to introduce a degree of resilience in the moulding, essential to avoid the development of cracks during the temperature cycles occurring in normal operation
■ Pulverulent additive composed of trihydrated alumina Al (OH)3 and silica which enhances its mechanical and thermal properties, as well as giving exceptional intrinsic qualities to the insulation in the presence of heat.
■ This three-component system of encapsulation gives insulation system temperature 155°C (F) with average winding temperature rise limit at rated current $\Delta\theta$ = 100 K which provides excellent fire-resisting qualities and immediate self-extinction.
The moulding of the windings contain no halogen compounds (chlorine, bromine, etc.) and no other compounds capable of producing corrosive or toxic pollutants, thereby guaranteeing a high degree of safety to personnel in emergency situations, notably in the event of a fire.
These transformers are classified as nonflammable. Transformers exposed to fire risk with low flammability and self extinguishing in a given time.
They are also exceptionally well adapted for hostile industrial atmospheres and comply with the following class of environment:
■ Class E3: up to 95 % of humidity and/or high level of pollution
■ Class C3: utilization, transport and storage down to -50 °C.

6.3.4 Liquid-filled transformers

The most common insulating liquid used in these transformers is mineral oil, which also acts as a cooling medium.
Mineral oils are specified in IEC 60296, they must not contain PCB (**P**oly**C**hlorinated **B**iphenyl).
Mineral oil can be replaced by an alternative insulating liquid such as high density hydrocarbons, esters, silicones, halogen liquids.
The oil being flammable, dedicated safety measures against fire are mandatory in many countries, especially for indoor substations.

The dielectric liquids are classified in several categories according to their fire performance. This latter is assessed according to two criteria (see **Fig. B40**):
- The flash-point temperature
- The minimum calorific power.

Code	Dielectric fluid	Flash-point (°C)	Minimum calorific power (MJ/kg)
O1	Mineral oil	< 300	-
K1	High-density hydrocarbons	> 300	48
K2	Esters	> 300	34 - 37
K3	Silicones	> 300	27 - 28
L3	Insulating halogen liquids	-	12

Fig. B40: Categories of dielectric fluids

Fig. B41: Hermetically-sealed totally-filled oil transformer

Fig. B42: Air-breathing oil transformer

There are two types of liquid filled transformers: Hermetically-sealed totally-filled transformers and Air-breathing transformer.

- Hermetically-sealed totally-filled transformers up to 10 MVA (see **Fig. B41**)

For this type of transformers the expansion of the insulating liquid is compensated by the elastic deformation of the oil-cooling radiators attached to the tank.
The protection against internal faults is ensured by means of a DGPT device: Detection of Gas, Internal Over Pressure and Oil Over Temperature.
The "total-fill" technique has many advantages:
- □ Water cannot enter the tank
- □ Oxidation of the dielectric liquid with atmospheric oxygen is entirely precluded
- □ No need for an air-drying device, and so no consequent maintenance (inspection and changing of saturated desiccant)
- □ No need for dielectric-strength test of the liquid for at least 10 years

- Air-breathing transformer (see **Fig. B42**)

This type of transformer is equipped with an expansion tank or conservator mounted above the main tank. The expansion of the insulating liquid is compensated inside the conservator by the raising of the oil level.

A conservator is required for transformers rated above10 MVA which is presently the upper limit for "totally filled type transformers".
In the conservator the top of the oil is in contact with the air which must remain dry to avoid any oxidation. This is achieved by admitting the outside air in the conservator through a desiccating device containing silica-gel crystals.
The protection of breathing transformers against internal faults is ensured by means of a buchholz mounted on the pipe linking the main tank to the conservator.
The buchholz ensures the detection of gas emission and internal over pressure.
The over temperature of the oil is commonly detected by an additional thermostat.

6.3.5 Choice of technology

As discussed above, the choice of transformer is between liquid-filled or dry type. For ratings up to 10 MVA, totally filled units are available as an alternative to conservator type transformers.
The choice depends on a number of considerations, including:
- Local regulations and recommendations. In some countries dry-type transformers are mandatory for specific buildings such as hospitals, commercial premises etc.
- Risk of fire
- Prices and technical considerations, taking account the relative advantages of each technology.

6.3.6 Determination of the optimal power

The over sizing of a transformer results in:
- Excessive investment
- Un necessarily high no-load losses
- Lower on-load losses.

Under sizing a transformer causes:
- A reduced efficiency when fully loaded. The highest efficiency is attained in the range 50 % - 70 % of the full load,
- On long-term overload, serious consequences for the transformer, owing to the premature ageing of the windings insulation, and in extreme cases, resulting in failure of insulation and loss of the transformer.

Definition of optimal power
In order to select an optimal power rating for a transformer, the following factors must be taken into account:
- List the consumers and define the factor of utilization ku and the diversity factor ks for each load as describe in chapter A
- Determine the load cycle of the installation, noting the duration of loads and overloads
- Take into account all possible future extensions of the installation.
- Arrange for power-factor correction, if justified, in order to:
  - Reduce billing penalties in tariffs based, in part, on maximum kVA demand
  - Reduce the value of the required apparent power: P(kVA) = P (kW)/cos ϕ
- Select the transformer, among the range of standard transformer ratings available.

To avoid over heating and consequently premature ageing of the transformer, it is important to ensure that cooling arrangements and temperature rise of the transformer are adequate.

Notes:

- A wrong choice of the winding temperature rise or thermal class can be at the origin of a reduced lifespan.
- A wrong assessment of the service conditions linked to the load profile can be at the origin of a reduced lifespan. Ex: Photovoltaic production where the load is during the day and when a 70°C maximum ambient temperature gradient is met as in Russia between winter and summer.

6.4 Ventilation in MV Substations

Substation ventilation is generally required to dissipate the heat produced by transformers and other equipment, and to allow drying after particularly wet or humid periods.
However, a number of studies have shown that excessive opening can drastically increase condensation.
The following paragraphs highlight a number of recommendations and good practices to ensure proper ventilation of MV substations. More details to design a natural ventilation of a transformer can be found within the MV Technical Guide § Ventilation.

6.4.1 Remark concerning HV/LV outdoor prefabricated substation in special service conditions

- Any installation of a transformer in the same room or in the same enclosure as HV and LV switchgears will impact the lifespan of the products.
- Any air flow generated by the transformer heating reduces the impact of irradiance. This air flow is the natural convection as required by the IEC 62271-202 standard.
- Any separation of the transformer by a partition wall with the HV and LV switchgears compartment improves the service condition of the switchgears for moderate climates, and avoids exposing them to harsh environment as example wind farms near coastal areas.
- For outdoor installations, any switchgear should be preferably installed in a thermal insulated enclosure protecting it from outdoor service conditions (dust, humidity, solar radiation etc.) especially for very hot and cold climates, and harsh environment.

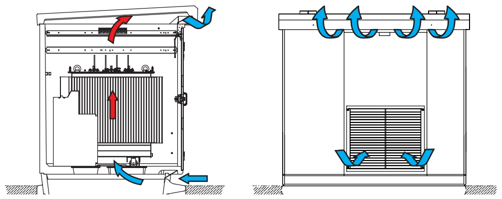


Fig. B43: Two different examples of HV/LV substation designs with natural ventilation, according to the layouts described in Fig B54

Fig. B44: Example of HV/LV prefabricated substation tested with 1250 kVA liquid filled transformer

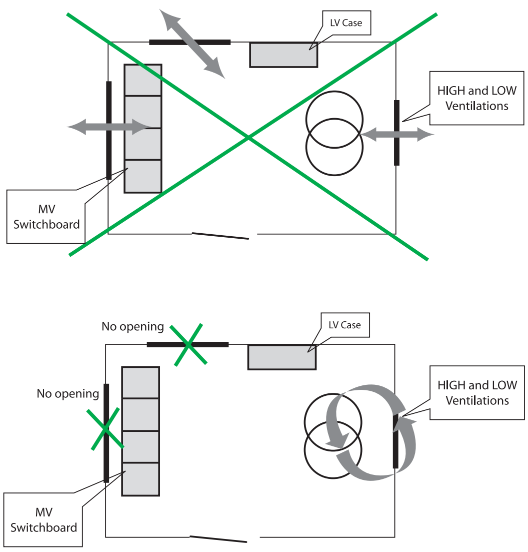


Fig. B45: Ventilation opening locations

6.4.2 Recommendations for HV/LV substation ventilation

General considerations

Ventilation should be kept to the minimum level required.

Furthermore, ventilation should never generate sudden temperature variations that can cause the dew point to be reached. For this reason, natural ventilation should be used whenever possible. Heating could be required when the application can be de-energized for a period; this is to maintain a minimum air flow. If forced ventilation is necessary, the fans should operate continuously to avoid temperature fluctuations. When forced ventilation is not enough to assure the indoor service condition of the switchgear or when the installation surrounding is a hazardous area, HVAC unit will be necessary to separate completely the indoor service conditions to the outdoor service conditions.

Natural ventilation is the mostly used method for MV installations (see **Fig. B43 and B44**). A guideline for sizing the air entry and exit openings of HV/LV substations is proposed in the "MV Technical Guide" by Schneider Electric.

Ventilation opening locations

To favor evacuation of the heat produced by the transformer via natural convection, ventilation openings should be located at the top and bottom of the wall near the transformer. The heat dissipated by the MV switchboard could be neglected. To avoid condensation problems, the substation ventilation openings should be located as far as possible from the switchboards (see **Fig. B45**).

Type of ventilation openings

To reduce the entry of dust, pollution, mist, etc., the substation ventilation openings should be equipped with chevron-blade baffles when the transformer is installed in a same room with the switchboards, otherwise the use of higher efficiency ventilation grids is allowed, especially advised when total losses are above 15kW.

Temperature variations inside cubicles

To reduce temperature variations, always install anti-condensation heaters inside MV cubicles if the average relative humidity can remain high over a long period of time. The heaters must operate continuously, 24 hours a day, all year long. Never connect them to a temperature control or regulation system as this could lead to temperature variations and condensation as well as a shorter service life for the heating elements. Make sure the heaters offer an adequate service life.

Temperature variations inside the substation

The following measures can be taken to reduce temperature variations inside the substation:

- Improve the thermal insulation of the substation to reduce the effects of outdoor temperature variations on the temperature inside the substation
- Avoid substation heating if possible. If heating is required, make sure the regulation system and/or thermostat are sufficiently accurate and designed to avoid excessive temperature swings (e.g. no greater than 1 °C). If a sufficiently accurate temperature regulation system is not available, leave the heating on continuously, 24 hours a day, all year long
- Eliminate cold air drafts from cable trenches under cubicles or from openings in the substation (under doors, roof joints, etc.).

Substation environment and humidity

Various factors outside the substation can affect the humidity inside.

- Plants: avoid excessive plant growth around the substation, and closing any opening.
- Substation waterproofing: the substation roof must not leak. Avoid flat roofs for which waterproofing is difficult to implement and maintain.
- Humidity from cable trenches: make sure cable trenches are dry under all conditions. A partial solution is to add sand to the bottom of the cable trench.

Pollution protection and cleaning

Excessive pollution favors leakage current, tracking and flashover on insulators.
To prevent MV equipment degradation by pollution, it is possible to either protect the equipment against pollution or regularly clean the resulting contamination.

Protection

Indoor MV switchgear can be protected by enclosures providing a sufficiently high degree of protection (IP).

Cleaning

If not fully protected, MV equipment must be cleaned regularly to prevent degradation by contamination from pollution.
Cleaning is a critical process. The use of unsuitable products can irreversibly damage the equipment.

7 Substation including generators and parallel operation of transformers

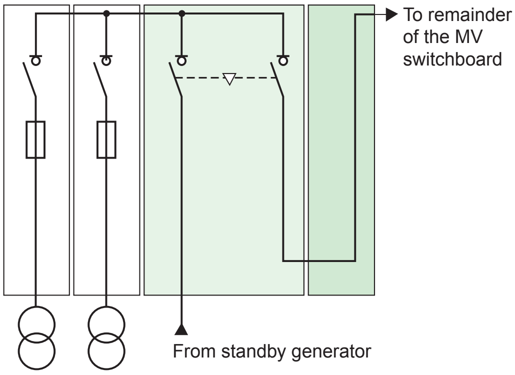


Fig. B51: Automatic change over associated with stand-alone generators

Only generators connected at MV level are considered in this chapter.

7.1 Generators in stand-alone operation, not working in parallel with the supply network

When the installation needs a high level of power availability, one or several MV standby generator set can be used.
In all the stand alone applications the installation includes an automatic changeover able to switch from the utility network supply to the generator(s) in case of failure of the utility supply (see **Fig. B51**).

The generators are protected by dedicated protections. For medium size generators the following protections are usually used:
- Phase to phase and phase to earth over current
- Percentage biased differential
- Negative sequence over current
- Overload
- Stator frame fault
- Rotor frame fault
- Reverse active power
- Reverse reactive power or loss of field
- Loss of synchronization
- Over and under voltage
- Over and under frequency
- Overheating of bearings.

It shall be noted that, due to the very low short-circuit current of the generator(s) compared to the one delivered from the utility supply network, a great attention must be paid to the settings of the protection and the discrimination. It is recommended when ordering a generator(s) to check with the manufacturer its (their) ability in providing a short circuit current ensuring the operation of the phase to phase short circuit protection. In case of difficulties the boosting of the generator's excitation is required and shall be specified.

Voltage and frequency control

The voltage and the frequency are controlled by the primary regulator(s) of the generator(s). The frequency is controlled by the speed regulator(s), while the voltage is controlled by the excitation regulator(s).

When several generators operate in parallel an additional control loop is required to perform the sharing of the active and reactive power between the generators. The principle of operation is the following:
- The active power delivered by a generator increases when the driven machine is accelerated and vice versa
- The reactive power delivered by a generator increases when its excitation current is increased and vice versa.

Dedicated modules are installed to perform this sharing, generally ensuring other tasks such as the automatic synchronization and coupling of the generators (see **Fig. B52**).

7.2 Generators operating in parallel with the utility supply network

When one or several generators are intended to operate in parallel with the supply network the agreement of the utility is usually required. The utility specifies the conditions of operation of the generators and specific requirements may be asked.
The utility generally requires information concerning the generators, such as:
- Level of the short circuit current injected by the generators in case of fault on the supply network
- Maximum active power intended to be injected in the supply network
- Operation principle of the voltage control
- Capability of the generators to control the power factor of the installation.

In case of fault on the utility supply network, the instantaneous disconnection of the generators is generally required. It is achieved by means of a dedicated protection specified by the utility. This protection may operate according to one or several of the following criteria:
- Under-voltage and over-voltage
- Under-frequency and over-frequency
- Zero sequence overvoltage

The protection generally orders the tripping of the main circuit breaker ensuring the connection of the installation to the utility while the generators continue to supply the totality of the internal consumers or a part only if they are not sized for the full power required (see **Fig. B34**). In this case load shedding must be simultaneously executed with the tripping of the main circuit breaker.

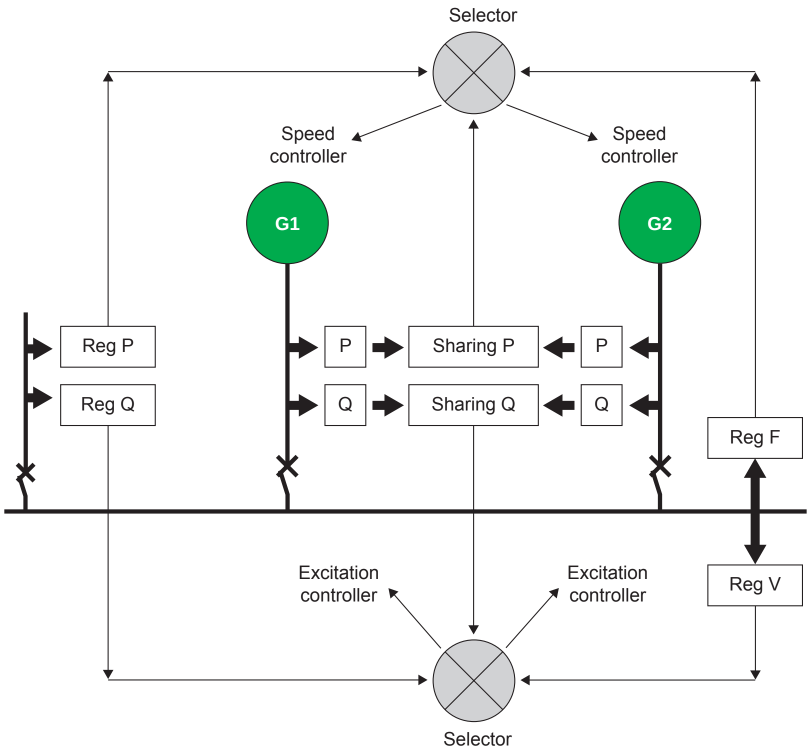


Fig. B52: Control of generators operating in parallel with the utility supply network

Control

When generators at a consumer's substation operate in island mode (Utility power supply disconnected) the voltage and the frequency at the main substation level are both fixed by the generators and consequently the control system of the generators operate in Voltage/Frequency mode (see **Fig. B52**).

When the utility power supply is connected the voltage and the frequency are both fixed by the utility and the control system of the generators must be switched from Voltage/Frequency mode (V/F control mode) to Active power/Reactive power mode (P/Q control mode) (see **Fig. B52**).

The function of the P/Q control mode is to control the exchange of active and reactive power with the utility. The typical principle of operation used in most of the applications is the following:

- The amount of the active and reactive power exchanged with the utility are set by the operator. The settings may be specified by the utility
- The control system maintains the values of the exchange at the required values by acting on the speed of the generators for the control of active power and on the excitation current for the control of the reactive power
- The sharing of the active and reactive power between the generators remains in operation.

The P/Q control mode allows:

- To strictly limit the value of the active power imported from the utility at the amount which can't be provided by the generators when the demand of the installation exceed their capability.
- To maintain at zero the imported active power, when the demand of the installation remains below the capability of the generators
- To maintain the power factor of the installation at the contractual value specified by the utility.

When the capability of the generators in providing reactive power is exceeded, the additional reactive power required to comply with the contractual power factor shall be supplied by a dedicated capacitor bank.

7.3 Parallel operation of transformers

The need to operate two or more transformers in parallel may be required when:

- The level of security of supply to be guarantied requires to duplicate the sources of supply
- The capacity of an existing transformer is exceeded due to the extension of the installation
- A single large transformer cannot be installed due to the lack of space
- The standardisation of the transformers throughout the installation is required.

It is not recommended to connect more than two transformers in parallel because the short circuit current at low voltage level may become too high.

7.3.1 Total power (kVA)

The total power (kVA) available when two or more transformers are connected in parallel, is equal to the sum of the individual transformer's ratings.
Transformers of equal power rating will each provide a load equal to the total load provided to the installation, divided by the number of transformers working in parallel.
Transformers of unequal power ratings will share the load in proportion to their ratings, providing that their voltage ratios and their short circuit impedances are identical.

7.3.2 Necessary conditions for parallel operation

The following conditions for the connection of power transformers in parallel are required:
It is preferred to connect in parallel transformers having the same characteristics:

- Same voltage ratio
- Same rated power
- Same short circuit impedance.
- Same coupling symbol of windings as for example D yn 11
- Same impedances of the LV links between the transformers and the main LV switchboard where the paralleling is realized.

For transformers having unequal rated power their internal impedances are in the ratio of the rated power of the transformers.

Connection in parallel of transformers having a power ratio equal or higher than two is not recommended.
When the transformers do not comply with the above requirements, recommendations for their paralleling shall be asked to the manufacturer.

8 Types and constitution of MV/LV distribution substations

MV/LV substations may be built in public places, such as parks, residential areas, etc. or in private premises. In this case the utility must have an unrestricted access to the substation. This is normally achieved by locating the substation in such a manner that one of the entrance can be directly accessible at any time from the public way.

8.1 Different types of substations

A substation may be installed:
- Indoor within a building, in a dedicated room
- Outdoor inside a dedicated housing prefabricated or not
- Outdoor without housing
- Pole mounted.

8.2 Indoor substation

8.2.1 General arrangement of a LV metering substation

Figures (**Fig. B53 and Fig. B54**) shows a typical layout recommended for a LV metering substation.

Remark: The cast-resin dry-type transformer does not need a fire protection oil sump. However, periodic cleaning of the transformer is needed.

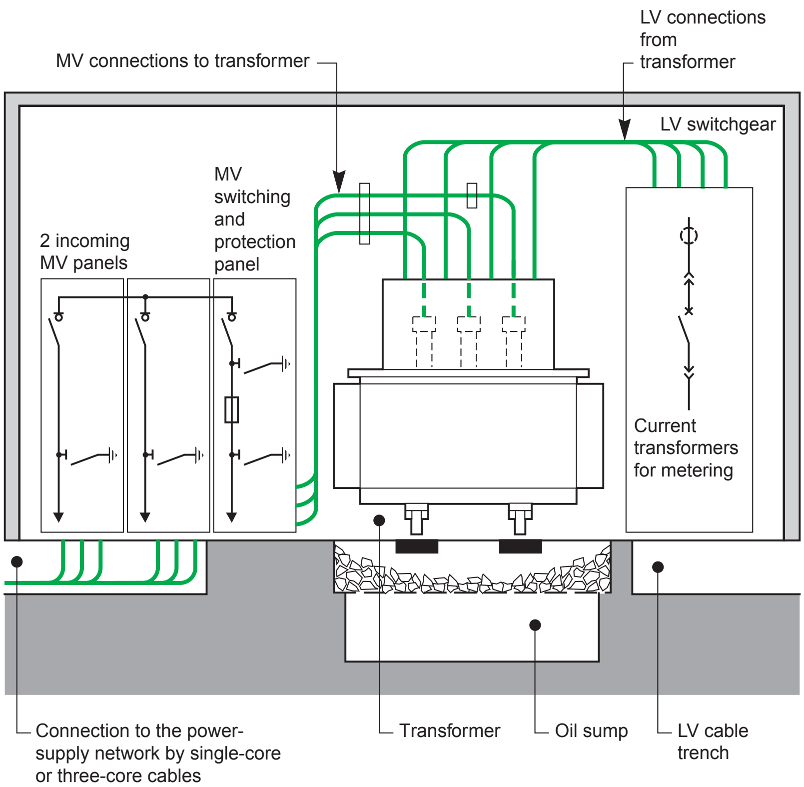
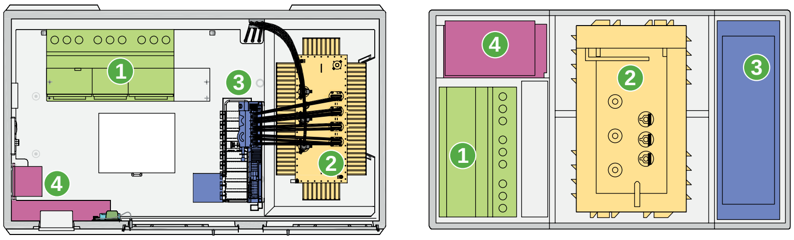


Fig. B53: General arrangement of a LV metering substation



1 HV Switchboard
2 Transformer
3 LV switchboard
4 Electronic devices / Capacitors

Fig. B54: Examples of general arrangements of LV metering substations, plan view

8.2.2 Connection to the utility and internal MV and LV interconnections

Connection to the MV utility network is made by, and is under the responsibility of the utility.

Connection between the MV switchgear and the transformer may be realized by:

- Short copper bars when the transformer is housed in a panel part of the MV switchboard
- By single-core or three cores screened cables with PR or EPR insulation, and possible connection to the transformers by plugin type terminals.

Connection between the LV terminals of the transformer and the LV switchgear may be realized with:

- Single-core cables
- LV busway with heat-shrinkable insulation.

It is highly recommended to use busway for the connection of transformers requiring more than five single LV cables in parallel per phase. Above five single core cables per phase the equal share of the current in each cable cannot be ensured and the laying becomes a real difficulty.

8.2.3 Earthing circuits

To ensure the safety of the persons an equipotential system must be created within the substation. It is realized according the following recommendations:

- Creation of an earthing electrode under the substation by burying copper conductors
- Inter-connection by means of protective conductors of all the exposed conductive parts of the installation:
  - Enclosures of the electrical equipment
  - Screens of the MV cables
  - Frame of the transformer
  - Metallic doors
  - Etc.
- Connection of all protective conductors at one single common point
- Connection of the common point of the protective conductors and the reinforcing rods of the concrete slab supporting the substation, should be connected to the earth electrode.

8.2.4 Lighting

The supply of the lighting circuits can be taken upstream or downstream from the main incoming LV circuit breaker. Appropriate LV circuit breakers must be provided for the protection of LV lighting circuits.

The lighting must adequately illuminate:

- The switchgear operating handles
- The mechanical flags indicating the position of electrical apparatus
- All the information displayed on the meters and on the protection relays
- All the instruction plates dedicated to the operations and the safety.

For safety reasons, it is recommended to add emergency lighting boxes including each an individual battery.

8.2.5 Materials for operation and safety

According to local safety rules, the substation shall be equiped with the following safety equipment:

- Devices for the safe exploitation of the substation:
  - An Insulated stool
  - An insulated mat
  - A pair of insulated gloves stored in a dedicated box
  - A detector of MV voltage presence
- Fire-extinguishing devices complying with the local regulations
- Warning and instruction plates dedicated to:
  - Operation of the substation
  - Safety of the persons
  - First-aid care to victims of electrical accidents.

8.3 Outdoor substations

8.3.1 Outdoor substations with prefabricated enclosures

The prefabricated outdoor MV/LV substations (see **Fig. B55**) comply with IEC 62271-202 standard.

- A type tested prefabricated outdoor substation is subjected to tests and verifications dedicated to:
  - Degree of protection
  - Temperature class
  - Non-flammable materials
  - Mechanical resistance of the enclosure
  - Sound level
  - Insulation level
  - Internal arc withstand
  - Earthing circuit
  - Retention of oil
  - Operation of the substation.

Main benefits:

The prefabricated substations provide a particularly interesting and optimized solution regarding:

- Delivery time
- Construction works
- Erection works
- Commissioning
- Total cost.

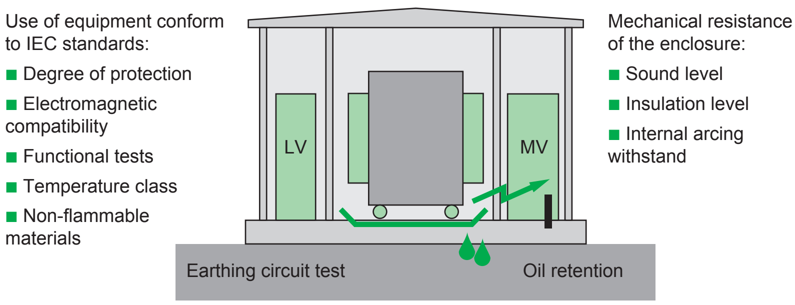


Fig. B55: Type tested substation according to IEC 62271-202

IEC 62271-202 standard defines requirements for two types of outdoor prefabricated substations (see **Fig. B56**):

- Walk-in type substation
- Non walk-in type substation.

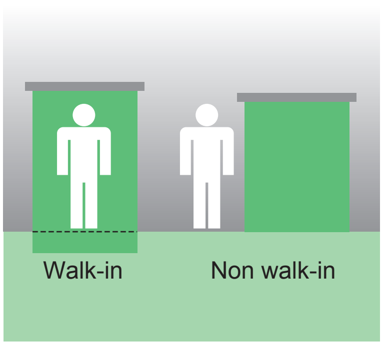


Fig. B56: Walk in and non-walk in type substations

The substations may be situated at ground level, half buried or completely buried (underground substation), resulting in three types of design (see **Fig. B57** and **Fig. B58**).

8.3.2 Outdoor substation without enclosure (see Fig. B59)

This kind of outdoor substations based on weatherproof equipment is commonly used in countries such as UK and India for example.
These substations are generally included in MV rings and include:

- Two functional units dedicated to the connection of the substation to the ring
- One functional unit for the supply and the protection of the MV/LV power transformer generally done by a circuit breaker unit
- One single MV/LV Power transformer
- One LV distribution panel.

The transformer and the LV panel can be installed in dedicated outdoor type housing.

8.3.3 Pole mounted substation

Application

These substations are mainly used for the supply of isolated rural consumers from MV overhead lines.

Constitution

This type of substation includes (see **Fig. B60**):

- A single pole mounted MV/LV power transformer that is, according to the local rules associated or not with:
  - A load break switch
  - A set of three fuses
  - A set of three surge arrestors
- A low voltage circuit breaker
- An earthing electrode realized at the bottom of the pole supporting the equipment.

The location of the substation must allow easy access of the personnel and handling equipment.

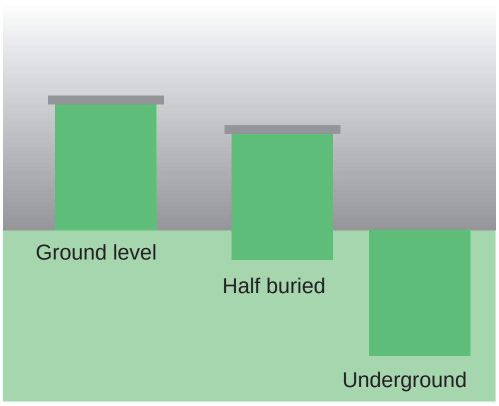


Fig. B57: Outdoor substations. The three type of design

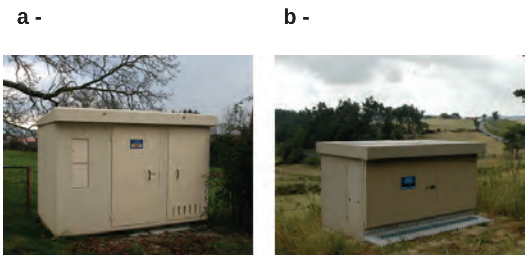


*Fig. B58: Outdoor substations **[a]** Ground level walk in type substation; **[b]** Half buried non walk in type substation*

Fig. B59: Outdoor substation without enclosure

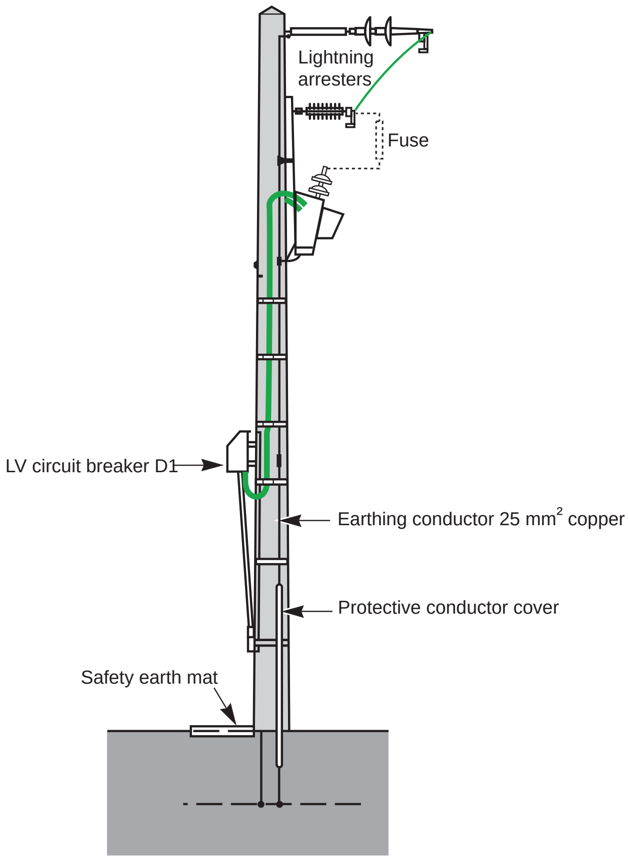


Fig. B60: Pole mounted MV/LV substation

Chapter C
Connection to the LV utility distribution network

Contents

1 Low-voltage utility distribution networks C2

1.1 Low-voltage consumers C2
1.2 LV distribution networks C10
1.3 The consumer-service connection C11
1.4 Quality of supply voltage C15

2 Tariffs and metering C16

1 Low-voltage utility distribution networks

The most-common LV supplies are within the range 120 V single phase to 240/415 V 3-phase 4-wires.
Loads up to 250 kVA can be supplied at LV, but power-supply organizations generally propose a MV service at load levels for which their LV networks are marginally adequate.
An international voltage standard for 3-phase 4-wire LV systems is recommended by the IEC 60038 to be 230/400 V

1.1 Low-voltage consumers

In Europe, the transition period on the voltage tolerance to "230V/400V + 10% / - 10%" has been extended for another 5 years up to the year 2008.

Low-voltage consumers are, by definition, those consumers whose loads can be satisfactorily supplied from the low-voltage system in their locality.

The voltage of the local LV network may be 120/208 V or 240/415 V, i.e. the lower or upper extremes of the most common 3-phase levels in general use, or at some intermediate level, as shown in **Figure C1**.

An international voltage standard for 3-phase 4-wire LV systems is recommended by the IEC 60038 to be 230/400 V.

Loads up to 250 kVA can be supplied at LV, but power-supply organizations generally propose a MV service at load levels for which their LV networks are marginally adequate.

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
Afghanistan	50 220 (k)	380/220 (a)	380/220 (a)	380/220 (a)
Algeria	50 ± 1.5	220/127 (e) 220 (k)	380/220 (a) 220/127 (a)	10,000 5,500 6,600 380/220 (a)
Angola	50	380/220 (a) 220 (k)	380/220 (a)	380/220 (a)
Antigua and Barbuda	60	240 (k) 120 (k)	400/230 (a) 120/208 (a)	400/230 (a) 120/208 (a)
Argentina	50 ± 2	380/220 (a) 220 (k)	380/220 (a) 220 (k)	
Armenia	50 ± 5	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Australia	50 ± 0.1	415/240 (a) 240 (k)	415/240 (a) 440/250 (a) 440 (m)	22,000 11,000 6,600 415/240 440/250
Austria	50 ± 0.1	230 (k)	380/230 (a) (b) 230 (k)	5,000 380/220 (a)
Azerbaijan	50 ± 0.1	208/120 (a) 240/120 (k)	208/120 (a) 240/120 (k)	
Bahrain	50 ± 0.1	415/240 (a) 240 (k)	415/240 (a) 240 (k)	11,000 415/240 (a) 240 (k)
Bangladesh	50 ± 2	410/220 (a) 220 (k)	410/220 (a)	11,000 410/220 (a)
Barbados	50 ± 6	230/115 (j) 115 (k)	230/115 (j) 200/115 (a) 220/115 (a)	230/400 (g) 230/155 (j)
Belarus	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)
Belgium	50 ± 5	230 (k) 230 (a) 3N, 400	230 (k) 230 (a) 3N, 400	6,600 10,000 11,000 15,000
Bolivia	50 ± 0.5	230 (k)	400/230 (a) 230 (k)	400/230 (a)
Botswana	50 ± 3	220 (k)	380/220 (a)	380/220 (a)
Brazil	60 ± 3	220 (k, a) 127 (k, a)	220/380 (a) 127/220 (a)	69,000 23,200 13,800 11,200 220/380 (a) 127/220 (a)
Brunei	50 ± 2	230	230	11,000 68,000
Bulgaria	50 ± 0.1	220	220/240	1,000 690 380

Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
Cambodia	50 ± 1	220 (k)	220/300	220/380
Cameroon	50 ± 1	220/260 (k)	220/260 (k)	220/380 (a)
Canada	60 ± 0.02	120/240 (j)	347/600 (a) 480 (f) 240 (f) 120/240 (j) 120/208 (a)	7,200/12,500 347/600 (a) 120/208 600 (f) 480 (f) 240 (f)
Cape Verde		220	220	380/400
Chad	50 ± 1	220 (k)	220 (k)	380/220 (a)
Chile	50 ± 1	220 (k)	380/220 (a)	380/220 (a)
China	50 ± 0.5	220 (k)	380/220 (a) 220 (k)	380/220 (a) 220 (k)
Colombia	60 ± 1	120/240 (g) 120 (k)	120/240 (g) 120 (k)	13,200 120/240 (g)
Congo	50	220 (k)	240/120 (j) 120 (k)	380/220 (a)
Croatia	50	400/230 (a) 230 (k)	400/230 (a) 230 (k)	400/230 (a)
Cyprus	50 ± 0.1	240 (k)	415/240	11,000 415/240
Czech Republic	50 ± 1	230	500 230/400	400,000 220,000 110,000 35,000 22,000 10,000 6,000 3,000
Denmark	50 ± 1	400/230 (a)	400/230 (a)	400/230 (a)
Djibouti	50		400/230 (a)	400/230 (a)
Dominica	50	230 (k)	400/230 (a)	400/230 (a)
Egypt	50 ± 0.5	380/220 (a) 220 (k)	380/220 (a) 220 (k)	66,000 33,000 20,000 11,000 6,600 380/220 (a)
Estonia	50 ± 1	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Ethiopia	50 ± 2.5	220 (k)	380/231 (a)	15 000 380/231 (a)
Falkland Islands	50 ± 3	230 (k)	415/230 (a)	415/230 (a)
Fidji Islands	50 ± 2	415/240 (a) 240 (k)	415/240 (a) 240 (k)	11,000 415/240 (a)
Finland	50 ± 0.1	230 (k)	400/230 (a)	690/400 (a) 400/230 (a)
France	50 ± 1	400/230 (a) 230 (a)	400/230 690/400 590/100	20,000 10,000 230/400
Gambia	50	220 (k)	220/380	380
Georgia	50 ± 0.5	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Germany	50 ± 0.3	400/230 (a) 230 (k)	400/230 (a) 230 (k)	20,000 10,000 6,000 690/400 400/230
Ghana	50 ± 5	220/240	220/240	415/240 (a)
Gibraltar	50 ± 1	415/240 (a)	415/240 (a)	415/240 (a)
Greece	50	220 (k) 230	6,000 380/220 (a)	22,000 20,000 15,000 6,600
Granada	50	230 (k)	400/230 (a)	400/230 (a)
Hong Kong	50 ± 2	220 (k)	380/220 (a) 220 (k)	11,000 386/220 (a)
Hungary	50 ± 5	220	220	220/380
Iceland	50 ± 0.1	230	230/400	230/400

Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
India	50 ± 1.5	440/250 (a) 230 (k)	440/250 (a) 230 (k)	11,000 400/230 (a) 440/250 (a)
Indonesia	50 ± 2	220 (k)	380/220 (a)	150,000 20,000 380/220 (a)
Iran	50 ± 5	220 (k)	380/220 (a)	20,000 11,000 400/231 (a) 380/220 (a)
Iraq	50	220 (k)	380/220 (a)	11,000 6,600 3,000 380/220 (a)
Ireland	50 ± 2	230 (k)	400/230 (a)	20,000 10,000 400/230 (a)
Israel	50 ± 0.2	400/230 (a) 230 (k)	400/230 (a) 230 (k)	22,000 12,600 6,300 400/230 (a)
Italy	50 ± 0.4	400/230 (a) 230 (k)	400/230 (a)	20,000 15,000 10,000 400/230 (a)
Jamaica	50 ± 1	220/110 (g) (j)	220/110 (g) (j)	4,000 2,300 220/110 (g)
Japan (east)	+ 0.1 - 0.3	200/100 (h)	200/100 (h) (up to 50 kW)	140,000 60,000 20,000 6,000 200/100 (h)
Jordan	50	380/220 (a) 400/230 (k)	380/220 (a)	400 (a)
Kazakhstan	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)
Kenya	50	240 (k)	415/240 (a)	415/240 (a)
Kirghizia	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)
Korea (North)	60 +0, -5	220 (k)	220/380 (a)	13,600 6,800
Korea (South)	60	100 (k)	100/200 (j)	
Kuwait	50 ± 3	240 (k)	415/240 (a)	415/240 (a)
Laos	50 ± 8	380/220 (a)	380/220 (a)	380/220 (a)
Lesotho		220 (k)	380/220 (a)	380/220 (a)
Latvia	50 ± 0.4	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Lebanon	50	220 (k)	380/220 (a)	380/220 (a)
Libya	50	230 (k) 127 (k)	400/230 (a) 220/127 (a) 230 (k) 127 (k)	400/230 (a) 220/127 (a)
Lithuania	50 ± 0.5	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Luxembourg	50 ± 0.5	380/220 (a)	380/220 (a)	20,000 15,000 5,000
Macedonia	50	380/220 (a) 220 (k)	380/220 (a) 220 (k)	10,000 6,600 380/220 (a)
Madagascar	50	220/110 (k)	380/220 (a)	35,000 5,000 380/220

Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
Malaysia	50 ± 1	240 (k) 415 (a)	415/240 (a)	415/240 (a)
Malawi	50 ± 2.5	230 (k)	400 (a) 230 (k)	400 (a)
Mali	50	220 (k) 127 (k)	380/220 (a) 220/127 (a) 220 (k) 127 (k)	380/220 (a) 220/127 (a)
Malta	50 ± 2	240 (k)	415/240 (a)	415/240 (a)
Martinique	50	127 (k)	220/127 (a) 127 (k)	220/127 (a)
Mauritania	50 ± 1	230 (k)	400/230 (a)	400/230 (a)
Mexico	60 ± 0.2	127/220 (a) 120/240 (j)	127/220 (a) 120/240 (j)	4,160 13,800 23,000 34,500 277/480 (a) 127/220 (b)
Moldavia	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)
Morocco	50 ± 5	380/220 (a)	380/220 (a)	225,000
		220/110 (a)		150,000 60,000 22,000 20,000
Mozambique	50	380/220 (a)	380/220 (a)	6,000 10,000
Nepal	50 ± 1	220 (k)	440/220 (a) 220 (k)	11,000 440/220 (a)
Netherlands	50 ± 0.4	230/400 (a) 230 (k)	230/400 (a)	25,000 20,000 12,000 10,000 230/400
New Zealand	50 ± 1.5	400/230 (e) (a) 230 (k) 460/230 (e)	400/230 (e) (a) 230 (k)	11,000 400/230 (a)
Niger	50 ± 1	230 (k)	380/220 (a)	15,000 380/220 (a)
Nigeria	50 ± 1	230 (k) 220 (k)	400/230 (a) 380/220 (a)	15,000 11,000 400/230 (a) 380/220 (a)
Norway	50 ± 2	230/400	230/400	230/400 690
Oman	50	240 (k)	415/240 (a) 240 (k)	415/240 (a)
Pakistan	50	230 (k)	400/230 (a) 230 (k)	400/230 (a)
Papua New Guinea	50 ± 2	240 (k)	415/240 (a) 240 (k)	22,000 11,000 415/240 (a)
Paraguay	50 ± 0.5	220 (k)	380/220 (a) 220 (k)	22,000 380/220 (a)
Philippines (Rep of the)	60 ± 0.16	110/220 (j)	13,800 4,160 2,400 110/220 (h)	13,800 4,160 2,400 440 (b) 110/220 (h)
Poland	50 ± 0.1	230 (k)	400/230 (a)	1,000 690/400 400/230 (a)
Portugal	50 ± 1	380/220 (a) 220 (k)	15,000 5,000 380/220 (a) 220 (k)	15,000 5,000 380/220 (a)

Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
Qatar	50 ± 0.1	415/240 (k)	415/240 (a)	11,000 415/240 (a)
Romania	50 ± 0.5	220 (k) 220/380 (a)	220/380 (a)	20,000 10,000 6,000 220/380 (a)
Russia	50 ± 0.2	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a)
Rwanda	50 ± 1	220 (k)	380/220 (a)	15,000 6,600 380/220 (a)
Saint Lucia	50 ± 3	240 (k)	415/240 (a)	11,000 415/240 (a)
Samoa		400/230		
San Marino	50 ± 1	230/220	380	15,000 380
Saudi Arabia	60	220/127 (a)	220/127 (a) 380/220 (a)	11,000 7,200 380/220 (a)
The Solomon Islands	50 ± 2	240	415/240	415/240
Senegal	50 ± 5	220 (a) 127 (k)	380/220 (a) 220/127 (k)	90,000 30,000 6,600
Serbia and Montenegro	50	380/220 (a) 220 (k)	380/220 (a) 220 (k)	10,000 6,600 380/220 (a)
Seychelles	50 ± 1	400/230 (a)	400/230 (a)	11,000 400/230 (a)
Sierra Leone	50 ± 5	230 (k)	400/230 (a) 230 (k)	11,000 400
Singapore	50	400/230 (a) 230 (k)	400/230 (a)	22,000 6,600 400/230 (a)
Slovakia	50 ± 0.5	230	230	230/400
Slovenia	50 ± 0.1	220 (k)	380/220 (a)	10,000 6,600 380/220 (a)
Somalia	50	230 (k) 220 (k) 110 (k)	440/220 (j) 220/110 (j) 230 (k)	440/220 (g) 220/110 (g)
South Africa	50 ± 2.5	433/250 (a) 400/230 (a) 380/220 (a) 220 (k)	11,000 6,600 3,300 433/250 (a) 400/230 (a) 380/220 (a)	11,000 6,600 3,300 500 (b) 380/220 (a)
Spain	50 ± 3	380/220 (a) (e) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220/127 (a) (e)	15,000 11,000 380/220 (a)
Sri Lanka	50 ± 2	230 (k)	400/230 (a) 230 (k)	11,000 400/230 (a)
Sudan	50	240 (k)	415/240 (a) 240 (k)	415/240 (a)
Swaziland	50 ± 2.5	230 (k)	400/230 (a) 230 (k)	11,000 400/230 (a)
Sweden	50 ± 0.5	400/230 (a) 230 (k)	400/230 (a) 230 (k)	6,000 400/230 (a)
Switzerland	50 ± 2	400/230 (a)	400/230 (a)	20,000 10,000 3,000 1,000 690/500
Syria	50	220 (k) 115 (k)	380/220 (a) 220 (k) 200/115 (a)	380/220 (a)
Tadzhikistan	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)

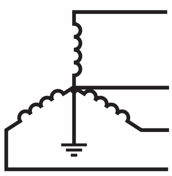
Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
Tanzania	50	400/230 (a)	400/230 (a)	11,000 400/230 (a)
Thailand	50	220 (k)	380/220 (a) 220 (k)	380/220 (a)
Togo	50	220 (k)	380/220 (a)	20,000 5,500 380/220 (a)
Tunisia	50 ± 2	380/220 (a) 220 (k)	380/220 (a) 220 (k)	30,000 15,000
				10,000 380/220 (a)
Turkmenistan	50	380/220 (a) 220 (k) 220/127 (a) 127 (k)	380/220 (a) 220 (k)	380/220 (a)
Turkey	50 ± 1	380/220 (a)	380/220 (a)	15,000 6,300 380/220 (a)
Uganda	+ 0.1	240 (k)	415/240 (a)	11,000 415/240 (a)
Ukraine	+ 0.2 / - 1.5	380/220 (a) 220 (k)	380/220 (a) 220 (k)	380/220 (a) 220 (k)
United Arab Emirates	50 ± 1	220 (k)	415/240 (a) 380/220 (a) 220 (k)	6,600 415/210 (a) 380/220 (a)
United Kingdom (except Northern Ireland)	50 ± 1	230 (k)	400/230 (a)	22,000 11,000 6,600 3,300 400/230 (a)
United Kingdom (Including Northern Ireland)	50 ± 0.4	230 (k) 220 (k)	400/230 (a) 380/220 (a)	400/230 (a) 380/220 (a)
United States of America Charlotte (North Carolina)	60 ± 0.06	120/240 (j) 120/208 (a)	265/460 (a) 120/240 (j) 120/208 (a)	14,400 7,200 2,400 575 (f) 460 (f) 240 (f) 265/460 (a) 120/240 (j) 120/208 (a)
United States of America Detroit (Michigan)	60 ± 0.2	120/240 (j) 120/208 (a)	480 (f) 120/240 (h) 120/208 (a)	13,200 4,800 4,160 480 (f) 120/240 (h) 120/208 (a)
United States of America Los Angeles (California)	60 ± 0.2	120/240 (j)	4,800 120/240 (g)	4,800 120/240 (g)
United States of America Miami (Florida)	60 ± 0.3	120/240 (j) 120/208 (a)	120/240 (j) 120/240 (h) 120/208 (a)	13,200 2,400 480/277 (a) 120/240 (h)
United States of America New York (New York)	60	120/240 (j) 120/208 (a)	120/240 (j) 120/208 (a) 240 (f)	12,470 4,160 277/480 (a) 480 (f)
United States of America Pittsburg (Pennsylvania)	60 ± 0.03	120/240 (j)	265/460 (a) 120/240 (j) 120/208 (a) 460 (f) 230 (f)	13,200 11,500 2,400 265/460 (a) 120/208 (a) 460 (f) 230 (f)

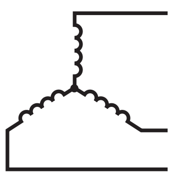
Fig. C1 : Voltage of local LV network and their associated circuit diagrams (continued on next page)

Country	Frequency & tolerance (Hz & %)	Domestic (V)	Commercial (V)	Industrial (V)
United States of America Portland (Oregon)	60	120/240 (j)	227/480 (a) 120/240 (j) 120/208 (a) 480 (f) 240 (f)	19,900 12,000 7,200 2,400 277/480 (a) 120/208 (a) 480 (f) 240 (f)
United States of America San Francisco (California)	60 ± 0.08	120/240 (j)	277/480 (a) 120/240 (j)	20,800 12,000 4,160 277/480 (a) 120/240 (g)
United States of America Toledo (Ohio)	60 ± 0.08	120/240 (j) 120/208 (a)	277/480 (c) 120/240(h) 120/208 (j)	12,470 7,200 4,800 4,160 480 (f) 277/480 (a) 120/208 (a)
Uruguay	50 ± 1	220 (b) (k)	220 (b) (k)	15,000 6,000 220 (b)
Vietnam	50 ± 0.1	220 (k)	380/220 (a)	35,000 15,000 10,000 6,000
Yemen	50	250 (k)	440/250 (a)	440/250 (a)
Zambia	50 ± 2.5	220 (k)	380/220 (a)	380 (a)
Zimbabwe	50	225 (k)	390/225 (a)	11,000 390/225 (a)

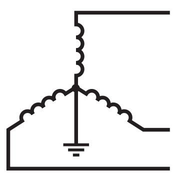
Circuit diagrams



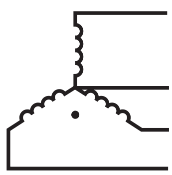
(**a**) Three-phase star; Four-wire: Earthed neutral



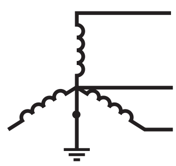
(**b**) Three-phase star: Three-wire



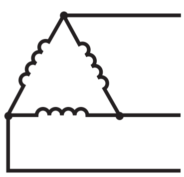
(**c**) Three-phase star; Three-wire: Earthed neutral



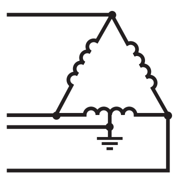
(**d**) Three-phase star; Four-wire: Non-earthed neutral



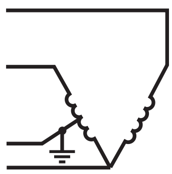
(**e**) Two-phase star; Three-wire Earthed neutral



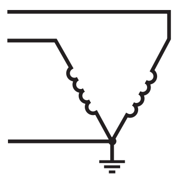
(**f**) Three-phase delta: Three-wire



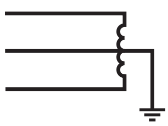
(**g**) Three-phase delta; Four-wire: Earthed mid point of one phase



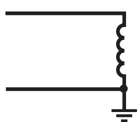
(**h**) Three-phase open delta; Four-wire: Earthed mid point of one phase



(**i**) Three-phase open delta: Earthed junction of phases

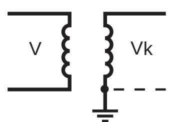


(**j**) Single-phase; Three-wire: Earthed mid point

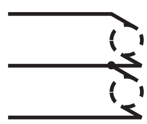


(**k**) Single-phase; Two-wire: Earthed end of phase

(**l**) Single-phase; Two-wire Unearthed



(**m**) Single-wire: Earthed return (swer)



(**n**) DC: Three-wire: Unearthed

Fig. C1 : Voltage of local LV network and their associated circuit diagrams (concluded)

Residential and commercial consumers

The function of a LV “mains” distributor is to provide service connections (underground cable or overhead line) to a number of consumers along its route.

The current-rating requirements of distributors are estimated from the number of consumers to be connected and an average demand per consumer.

The two principal limiting parameters of a distributor are:
■ The maximum current which it is capable of carrying indefinitely, and
■ The maximum length of cable which, when carrying its maximum current, will not exceed the statutory voltage-drop limit

These constraints mean that the magnitude of loads which utilities are willing to connect to their LV distribution mains, is necessarily restricted.

For the range of LV systems mentioned in the second paragraph of this sub-clause (1.1) viz: 120 V single phase to 240/415 V 3-phase, typical maximum permitted loads connected to a LV distributor might(1) be (see **Fig. C2**):

System	Assumed max. permitted current per consumer service	kVA
120 V 1-phase 2-wire	60 A	7.2
120/240 V 1-phase 3-wire	60 A	14.4
120/208 V 3-phase 4-wire	60 A	22
220/380 V 3-phase 4-wire	120 A	80
230/400 V 3-phase 4-wire	120 A	83
240/415 V 3-phase 4-wire	120 A	86

***Fig. C2** : Typical maximum permitted loads connected to a LV distributor*

Practices vary considerably from one power supply organization to another, and no “standardized” values can be given.

Factors to be considered include:
■ The size of an existing distribution network to which the new load is to be connected
■ The total load already connected to the distribution network
■ The location along the distribution network of the proposed new load, i.e. close to the substation, or near the remote end of the distribution network, etc

In short, each case must be examined individually.
The load levels listed above are adequate for all normal residential consumers, and will be sufficient for the installations of many administrative, commercial and similar buildings.

Medium-size and small industrial consumers (with dedicated LV lines direct from a utility supply MV/LV substation)

Medium and small industrial consumers can also be satisfactorily supplied at low-voltage.

For loads which exceed the maximum permitted limit for a service from a distributor, a dedicated cable can usually be provided from the LV distribution fuse- (or switch-) board, in the power utility substation.

Generaly, the upper load limit which can be supplied by this means is restricted only by the available spare transformer capacity in the substation.

In practice, however:
■ Large loads (e.g. > 300 kVA) require correspondingly large cables, so that, unless the load centre is close to the substation, this method can be economically unfavourable
■ Many utilities prefer to supply loads exceeding 200 kVA (this figure varies with different suppliers) at medium voltage
For these reasons, dedicated supply lines at LV are generally applied (at 220/380 V to 240/415 V) to a load range of 80 kVA to 250 kVA.
Consumers normally supplied at low voltage include:
■ Residential dwellings
■ Shops and commercial buildings
■ Small factories, workshops and filling stations
■ Restaurants
■ Farms, etc

(1) The Figure C2 values shown are indicative only, being (arbitrarily) based on 60 A maximum service currents for the first three systems, since smaller voltage drops are allowed at these lower voltages, for a given percentage statutory limit. The second group of systems is (again, arbitrarily) based on a maximum permitted service current of 120 A.

*In cities and large towns, standardized LV distribution cables form a network through link boxes. Some links are removed, so that each (fused) distributor leaving a substation forms a branched open-ended radial system, as shown in **Figure C3***

1.2 LV distribution networks

In European countries the standard 3-phase 4-wire distribution voltage level is 230/400 V. Many countries are currently converting their LV systems to the latest IEC standard of 230/400 V nominal (IEC 60038). Medium
to large-sized towns and cities have underground cable distribution systems. MV/LV distribution substations, mutually spaced at approximately 500-600 metres, are typically equipped with:

- A 3-or 4-way MV switchboard, often made up of incoming and outgoing load-break switches forming part of a ring main, and one or two MV circuit-breakers or combined fuse/ load-break switches for the transformer circuits
- One or two 1,000 kVA MV/LV transformers
- One or two (coupled) 6-or 8-way LV 3-phase 4-wire distribution fuse boards, or moulded-case circuit-breaker boards, control and protect outgoing 4-core distribution cables, generally referred to as "distributors"

The output from a transformer is connected to the LV busbars via a load-break switch, or simply through isolating links.

In densely-loaded areas, a standard size of distributor is laid to form a network, with (generally) one cable along each pavement and 4-way link boxes located in manholes at street corners, where two cables cross.

Recent trends are towards weather-proof cabinets above ground level, either against a wall, or where possible, flush-mounted in the wall.

Links are inserted in such a way that distributors form radial circuits from the substation with open-ended branches (see Fig. C3). Where a link box unites a distributor from one substation with that from a neighbouring substation, the phase links are omitted or replaced by fuses, but the neutral link remains in place.

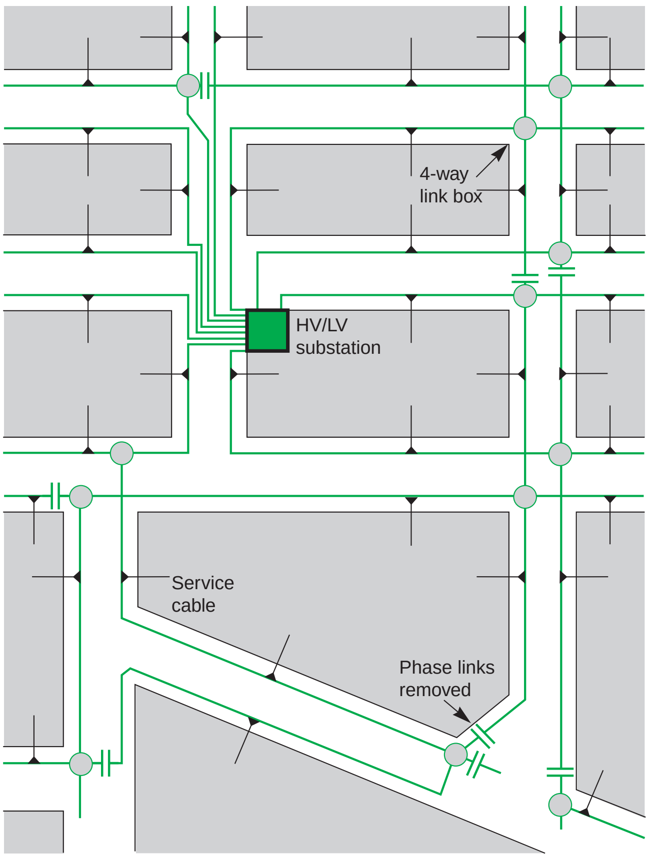


Fig. C3 : Showing one of several ways in which a LV distribution network may be arranged for radial branched-distributor operation, by removing (phase) links

This arrangement provides a very flexible system in which a complete substation can be taken out of service, while the area normally supplied from it is fed from link boxes of the surrounding substations.

Moreover, short lengths of distributor (between two link boxes) can be isolated for fault-location and repair.

In less-densely loaded urban areas a more-economic system of tapered radial distribution is commonly used, in which conductors of reduced size are installed as the distance from a substation increases

Where the load density requires it, the substations are more closely spaced, and transformers up to 1,500 kVA are sometimes necessary.

Other forms of urban LV network, based on free-standing LV distribution pillars, placed above ground at strategic points in the network, are widely used in areas of lower load density. This scheme exploits the principle of tapered radial distributors in which the distribution cable conductor size is reduced as the number of consumers downstream diminish with distance from the substation.

In this scheme a number of large-sectioned LV radial feeders from the distribution board in the substation supply the busbars of a distribution pillar, from which smaller distributors supply consumers immediately surrounding the pillar.

Distribution in market towns, villages and rural areas generally has, for many years, been based on bare copper conductors supported on wooden, concrete or steel poles, and supplied from pole-mounted or ground-mounted transformers.

Improved methods using insulated twisted conductors to form a pole mounted aerial cable are now standard practice in many countries

In recent years, LV insulated conductors, twisted to form a two-core or 4-core self supporting cable for overhead use, have been developed, and are considered to be safer and visually more acceptable than bare copper lines.

This is particularly so when the conductors are fixed to walls (e.g. under-eaves wiring) where they are hardly noticeable.

As a matter of interest, similar principles have been applied at higher voltages, and self supporting "bundled" insulated conductors for MV overhead installations are now available for operation at 24 kV.

Where more than one substation supplies a village, arrangements are made at poles on which the LV lines from different substations meet, to interconnect corresponding phases.

In Europe, each utility-supply distribution substation is able to supply at LV an area corresponding to a radius of approximately 300 metres from the substation.
North and Central American systems of distribution consist of a MV network from which numerous (small) MV/LV transformers each supply one or several consumers, by direct service cable (or line) from the transformer location

North and Central American practice differs fundamentally from that in Europe, in that LV networks are practically nonexistent, and 3-phase supplies to premises in residential areas are rare.

The distribution is effectively carried out at medium voltage in a way, which again differs from standard European practices. The MV system is, in fact, a 3-phase 4-wire system from which single-phase distribution networks (phase and neutral conductors) supply numerous single-phase transformers, the secondary windings of which are centre-tapped to produce 120/240 V single-phase 3-wire supplies. The central conductors provide the LV neutrals, which, together with the MV neutral conductors, are solidly earthed at intervals along their lengths.

Each MV/LV transformer normally supplies one or several premises directly from the transformer position by radial service cable(s) or by overhead line(s).

Many other systems exist in these countries, but the one described appears to be the most common.

Figure C4 (next page) shows the main features of the two systems.

1.3 The consumer-service connection

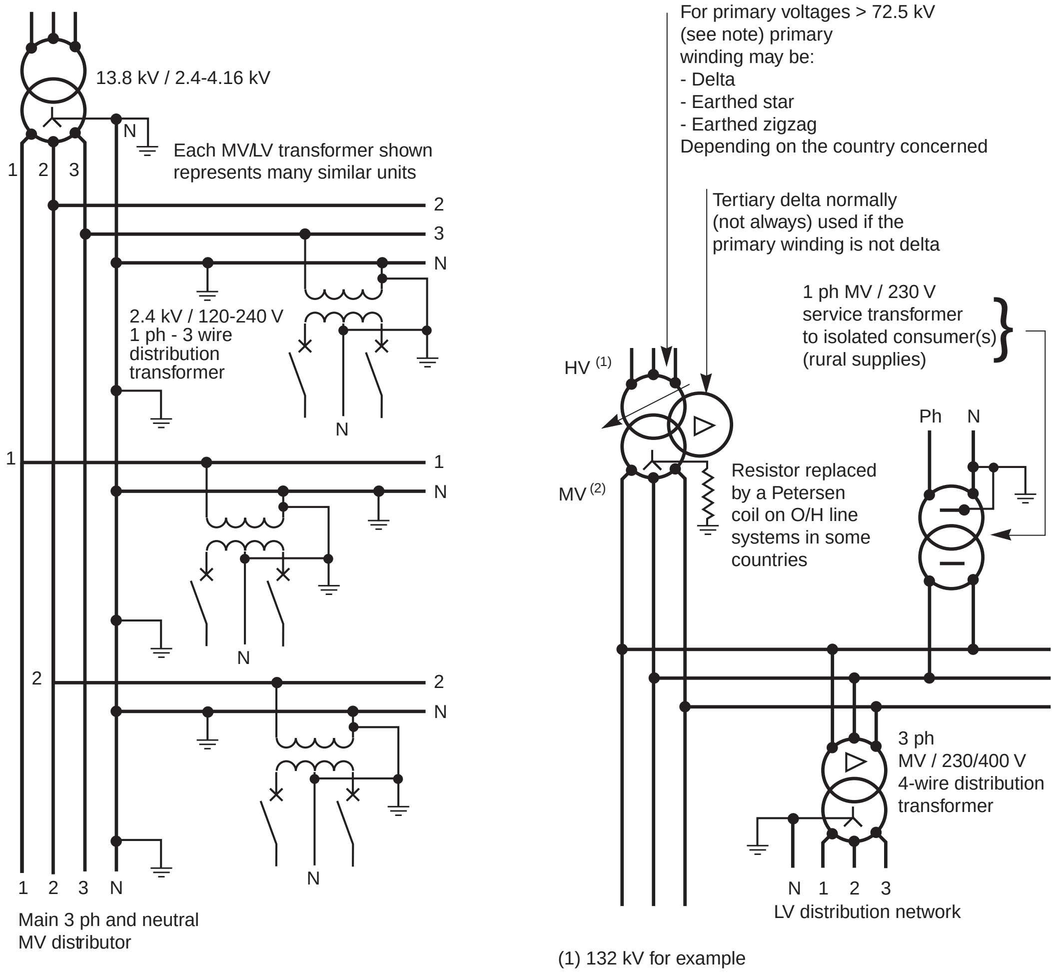
Service components and metering equipment were formerly installed inside a consumer's building. The modern tendency is to locate these items outside in a weatherproof cabinet

In the past, an underground cable service or the wall-mounted insulated conductors from an overhead line service, invariably terminated inside the consumer's premises, where the cable-end sealing box, the utility fuses (inaccessible to the consumer) and meters were installed.

A more recent trend is (as far as possible) to locate these service components in a weatherproof housing outside the building.

The utility/consumer interface is often at the outgoing terminals of the meter(s) or, in some cases, at the outgoing terminals of the installation main circuit-breaker (depending on local practices) to which connection is made by utility staff, following a satisfactory test and inspection of the installation.

A typical arrangement is shown in **Figure C5** (next page).



(1) 132 kV for example
(2) 11 kV for example

Note: At primary voltages greater than 72.5 kV in bulk-supply substations, it is common practice in some European countries to use an earthed-star primary winding and a delta secondary winding. The neutral point on the secondary side is then provided by a zigzag earthing reactor, the star point of which is connected to earth through a resistor.
Frequently, the earthing reactor has a secondary winding to provide LV 3-phase supplies for the substation. It is then referred to as an "earthing transformer".

Fig. C4 : Widely-used American and European-type systems

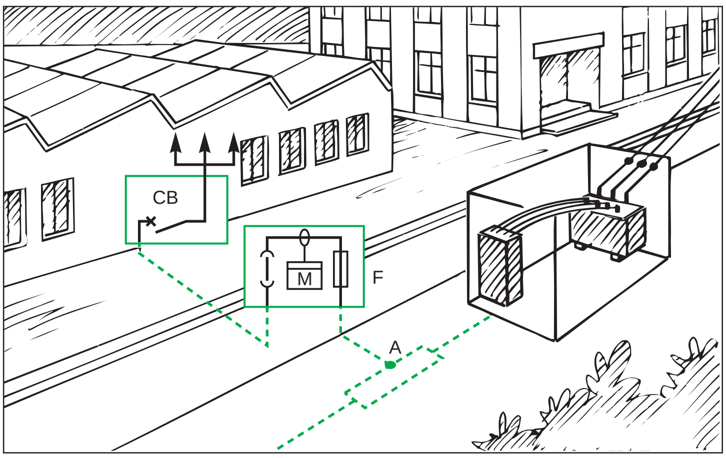


Fig. C5 : Typical service arrangement for TT-earthed systems

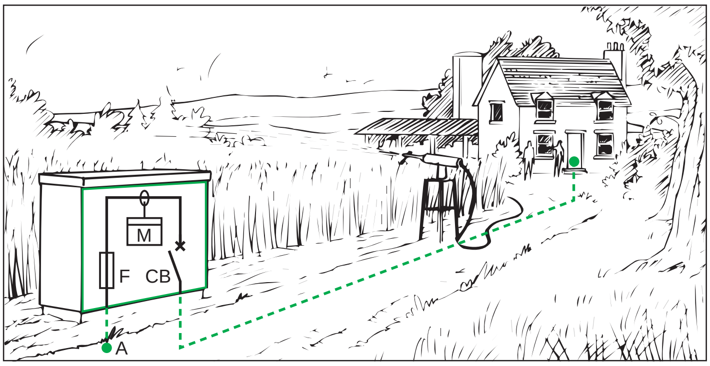
LV consumers are normally supplied according to the TN or TT system, as described in chapters F and G. The installation main circuit-breaker for a TT supply must include a residual current earth-leakage protective device. For a TN service, overcurrent protection by circuit-breaker or switch-fuse is required

A MCCB -moulded case circuit-breaker- which incorporates a sensitive residual-current earth-fault protective feature is mandatory at the origin of any LV installation forming part of a TT earthing system. The reason for this feature and related leakage-current tripping levels are discussed in Clause 3 of Chapter G.

A further reason for this MCCB is that the consumer cannot exceed his (contractual) declared maximum load, since the overload trip setting, which is sealed by the supply authority, will cut off supply above the declared value. Closing and tripping of the MCCB is freely available to the consumer, so that if the MCCB is inadvertently tripped on overload, or due to an appliance fault, supplies can be quickly restored following correction of the anomaly.

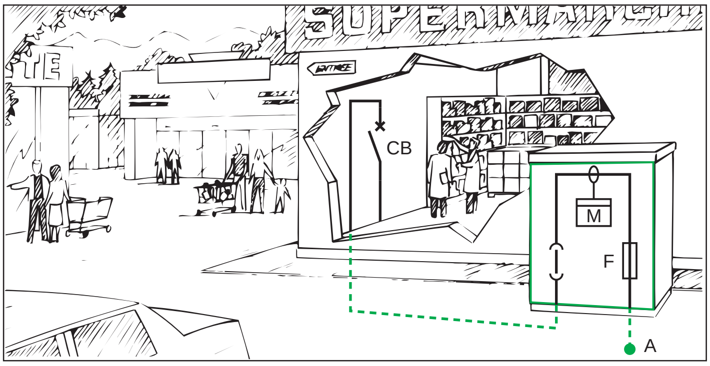
In view of the inconvenience to both the meter reader and consumer, the location of meters is nowadays generally outside the premises, either:

- In a free-standing pillar-type housing as shown in **Figures C6** and **C7**
- In a space inside a building, but with cable termination and supply authority's fuses located in a flush-mounted weatherproof cabinet accessible from the public way, as shown in **Figure C8** next page
- For private residential consumers, the equipment shown in the cabinet in Figure C5 is installed in a weatherproof cabinet mounted vertically on a metal frame in the front garden, or flush-mounted in the boundary wall, and accessible to authorized personnel from the pavement. **Figure C9** (next page) shows the general arrangement, in which removable fuse links provide the means of isolation



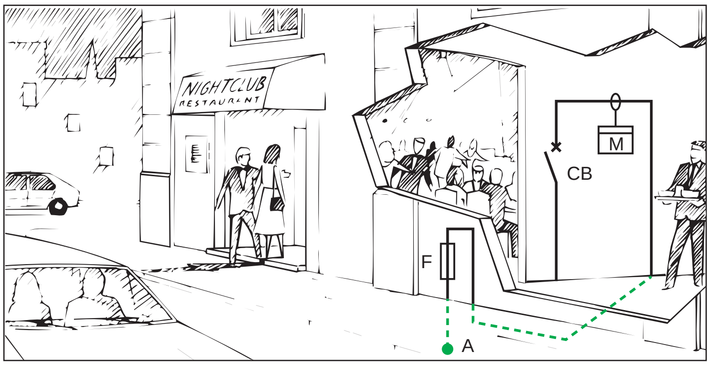
In this kind of installation it is often necessary to place the main installation circuit-breaker some distance from the point of utilization, e.g. saw-mills, pumping stations, etc.

Fig. C6 *: Typical rural-type installation*



The main installation CB is located in the consumer's premises in cases where it is set to trip if the declared kVA load demand is exceeded.

Fig. C7 *: Semi-urban installations (shopping precincts, etc.)*



The service cable terminates in a flushmounted wall cabinet which contains the isolating fuse links, accessible from the public way. This method is preferred for esthetic reasons, when the consumer can provide a suitable metering and main-switch location.

***Fig. C8** : Town centre installations*

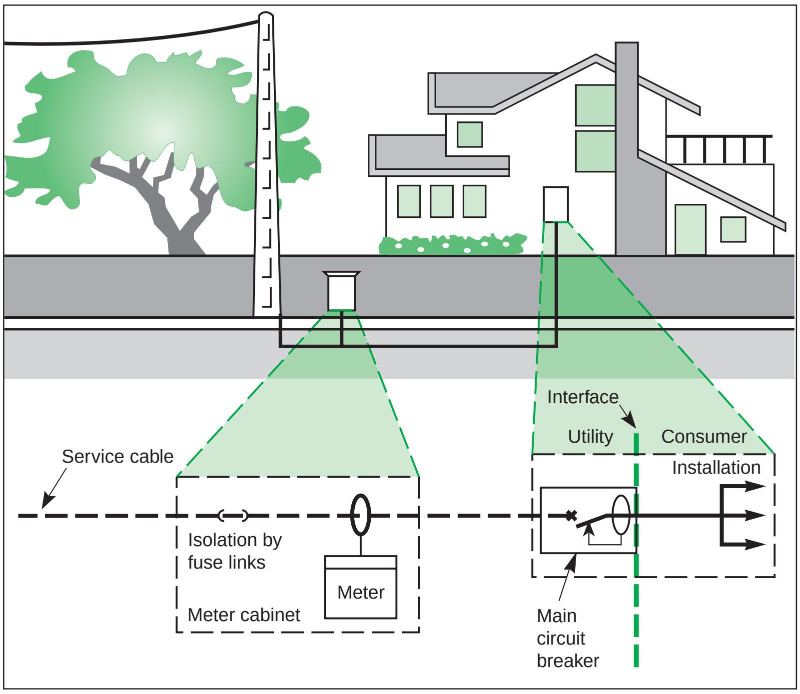


***Fig. C9** : Typical LV service arrangement for residential consumers*

In the field of electronic metering, techniques have developed which make their use attractive by utilities either for electricity metering and for billing purposes, the liberalisation of the electricity market having increased the needs for more data collection to be returned from the meters. For example electronic metering can also help utilities to understand their customers' consumption profiles. In the same way, they will be useful for more and more power line communication and radio-frequency applications as well.

In this area, prepayment systems are also more and more employed when economically justified. They are based on the fact that for instance consumers having made their payment at vending stations, generate tokens to pass the information concerning this payment on to the meters. For these systems the key issues are security and inter-operability which seem to have been addressed successfully now. The attractiveness of these systems is due to the fact they not only replace the meters but also the billing systems, the reading of meters and the administration of the revenue collection.

An adequate level of voltage at the consumers supply-service terminals is essential for satisfactory operation of equipment and appliances. Practical values of current, and resulting voltage drops in a typical LV system, show the importance of maintaining a high Power Factor as a means of reducing voltage drop.

1.4 Quality of supply voltage

The quality of the LV network supply voltage in its widest sense implies:

- Compliance with statutory limits of magnitude and frequency
- Freedom from continual fluctuation within those limits
- Uninterrupted power supply, except for scheduled maintenance shutdowns, or as a result of system faults or other emergencies
- Preservation of a near-sinusoidal wave form

In this Sub-clause the maintenance of voltage magnitude only will be discussed.

In most countries, power-supply authorities have a statutory obligation to maintain the level of voltage at the service position of consumers within the limits of ± 5% (or in some cases ± 6% or more-see table C1) of the declared nominal value.

Again, IEC and most national standards recommend that LV appliances be designed and tested to perform satisfactorily within the limits of ± 10% of nominal voltage. This leaves a margin, under the worst conditions (of minus 5% at the service position, for example) of 5% allowable voltage drop in the installation wiring.

The voltage drops in a typical distribution system occur as follows: the voltage at the MV terminals of a MV/LV transformer is normally maintained within a ± 2% band by the action of automatic onload tapchangers of the transformers at bulk-supply substations, which feed the MV network from a higher-voltage subtransmission system.

If the MV/LV transformer is in a location close to a bulk-supply substation, the ± 2% voltage band may be centered on a voltage level which is higher than the nominal MV value. For example, the voltage could be 20.5 kV ± 2% on a 20 kV system. In this case, the MV/LV distribution transformer should have its MV off-circuit tapping switch selected to the + 2.5% tap position.

Conversely, at locations remote from bulk supply substations a value of 19.5 kV ± 2% is possible, in which case the off-circuit tapping switch should be selected to the - 5% position.

The different levels of voltage in a system are normal, and depend on the system powerflow pattern. Moreover, these voltage differences are the reason for the term "nominal" when referring to the system voltage.

Practical application

With the MV/LV transformer correctly selected at its off-circuit tapping switch, an unloaded transformer output voltage will be held within a band of ± 2% of its no-load voltage output.

To ensure that the transformer can maintain the necessary voltage level when fully loaded, the output voltage at no-load must be as high as possible without exceeding the upper + 5% limit (adopted for this example). In present-day practice, the winding ratios generally give an output voltage of about 104% at no-load(1), when nominal voltage is applied at MV, or is corrected by the tapping switch, as described above. This would result in a voltage band of 102% to 106% in the present case.

A typical LV distribution transformer has a short-circuit reactance voltage of 5%. If it is assumed that its resistance voltage is one tenth of this value, then the voltage drop within the transformer when supplying full load at 0.8 power factor lagging, will be:

$V\%\ drop = R\%\cos\varphi + X\%\sin\varphi$

$= 0.5 \times 0.8 + 5 \times 0.6$

$= 0.4 + 3 = 3.4\%$

The voltage band at the output terminals of the fully-loaded transformer will therefore be (102 - 3.4) = 98.6% to (106 - 3.4) = 102.6%.

The maximum allowable voltage drop along a distributor is therefore 98.6 - 95 = 3.6%.

This means, in practical terms, that a medium-sized 230/400 V 3-phase 4-wire distribution cable of 240 mm^2 copper conductors would be able to supply a total load of 292 kVA at 0.8 PF lagging, distributed evenly over 306 metres of the distributor. Alternatively, the same load at the premises of a single consumer could be supplied at a distance of 153 metres from the transformer, for the same volt-drop, and so on...

As a matter of interest, the maximum rating of the cable, based on calculations derived from IEC 60287 (1982) is 290 kVA, and so the 3.6% voltage margin is not unduly restrictive, i.e. the cable can be fully loaded for distances normally required in LV distribution systems.

Furthermore, 0.8 PF lagging is appropriate to industrial loads. In mixed semi-industrial areas 0.85 is a more common value, while 0.9 is generally used for calculations concerning residential areas, so that the volt-drop noted above may be considered as a "worst case" example.

(1) Transformers designed for the 230/400 V IEC standard will have a no-load output of 420 V, i.e. 105% of the nominal voltage

2 Tariffs and metering

No attempt will be made in this guide to discuss particular tariffs, since there appears to be as many different tariff structures around the world as there are utilities.

Some tariffs are very complicated in detail but certain elements are basic to all of them and are aimed at encouraging consumers to manage their power consumption in a way which reduces the cost of generation, transmission and distribution.

The two predominant ways in which the cost of supplying power to consumers can be reduced, are:

- Reduction of power losses in the generation, transmission and distribution of electrical energy. In principle the lowest losses in a power system are attained when all parts of the system operate at unity power factor
- Reduction of the peak power demand, while increasing the demand at low-load periods, thereby exploiting the generating plant more fully, and minimizing plant redundancy

Reduction of losses

Although the ideal condition noted in the first possibility mentioned above cannot be realized in practice, many tariff structures are based partly on kVA demand, as well as on kWh consumed. Since, for a given kW loading, the minimum value of kVA occurs at unity power factor, the consumer can minimize billing costs by taking steps to improve the power factor of the load (as discussed in Chapter L). The kVA demand generally used for tariff purposes is the maximum average kVA demand occurring during each billing period, and is based on average kVA demands, over fixed periods (generally 10, 30 or 60 minute periods) and selecting the highest of these values. The principle is described below in “principle of kVA maximum-demand metering”.

Reduction of peak power demand

The second aim, i.e. that of reducing peak power demands, while increasing demand at low-load periods, has resulted in tariffs which offer substantial reduction in the cost of energy at:

- Certain hours during the 24-hour day
- Certain periods of the year

The simplest example is that of a residential consumer with a storage-type water heater (or storage-type space heater, etc.). The meter has two digital registers, one of which operates during the day and the other (switched over by a timing device) operates during the night. A contactor, operated by the same timing device, closes the circuit of the water heater, the consumption of which is then indicated on the register to which the cheaper rate applies. The heater can be switched on and off at any time during the day if required, but will then be metered at the normal rate. Large industrial consumers may have 3 or 4 rates which apply at different periods during a 24-hour interval, and a similar number for different periods of the year. In such schemes the ratio of cost per kWh during a period of peak demand for the year, and that for the lowest-load period of the year, may be as much as 10: 1.

Meters

It will be appreciated that high-quality instruments and devices are necessary to implement this kind of metering, when using classical electro-mechanical equipment. Recent developments in electronic metering and micro-processors, together with remote ripple-control(1) from an utility control centre (to change peak-period timing throughout the year, etc.) are now operational, and facilitate considerably the application of the principles discussed.

In most countries, some tariffs, as noted above, are partly based on kVA demand, in addition to the kWh consumption, during the billing periods (often 3-monthly intervals). The maximum demand registered by the meter to be described, is, in fact, a maximum (i.e. the highest) average kVA demand registered for succeeding periods

(1) Ripple control is a system of signalling in which a voice frequency current (commonly at 175 Hz) is injected into the LV mains at appropriate substations. The signal is injected as coded impulses, and relays which are tuned to the signal frequency and which recognize the particular code will operate to initiate a required function. In this way, up to 960 discrete control signals are available.

during the billing interval.
Figure C10 shows a typical kVA demand curve over a period of two hours divided into succeeding periods of 10 minutes. The meter measures the average value of kVA during each of these 10 minute periods.

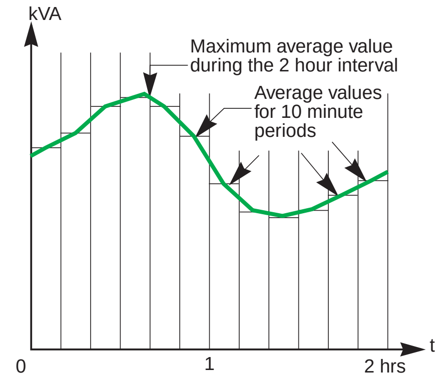


Fig. C10 : Maximum average value of kVA over an interval of 2 hours

Principle of kVA maximum demand metering

A kVAh meter is similar in all essentials to a kWh meter but the current and voltage phase relationship has been modified so that it effectively measures kVAh (kilo-volt-ampere-hours). Furthermore, instead of having a set of decade counter dials, as in the case of a conventional kWh meter, this instrument has a rotating pointer. When the pointer turns it is measuring kVAh and pushing a red indicator before it. At the end of 10 minutes the pointer will have moved part way round the dial (it is designed so that it can never complete one revolution in 10 minutes) and is then electrically reset to the zero position, to start another 10 minute period. The red indicator remains at the position reached by the measuring pointer, and that position, corresponds to the number of kVAh (kilo-volt-ampere-hours) taken by the load in 10 minutes. Instead of the dial being marked in kVAh at that point however it can be marked in units of average kVA. The following figures will clarify the matter.

Supposing the point at which the red indicator reached corresponds to 5 kVAh. It is known that a varying amount of kVA of apparent power has been flowing for 10 minutes, i.e. 1/6 hour.

If now, the 5 kVAh is divided by the number of hours, then the average kVA for the period is obtained.

In this case the average kVA for the period will be:

$$5 \times \frac{1}{\frac{1}{6}} = 5 \times 6 = 30 \text{ kVA}$$

Every point around the dial will be similarly marked i.e. the figure for average kVA will be 6 times greater than the kVAh value at any given point. Similar reasoning can be applied to any other reset-time interval.

At the end of the billing period, the red indicator will be at the maximum of all the average values occurring in the billing period.

The red indicator will be reset to zero at the beginning of each billing period. Electro-mechanical meters of the kind described are rapidly being replaced by electronic instruments. The basic measuring principles on which these electronic meters depend however, are the same as those described above.

Chapter D
MV & LV architecture selection guide for buildings

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1 Stakes of architecture design

Choice of distribution architecture

This chapter is dedicated to electrical architecture design for medium and large buildings. Despite the various types of buildings (office, hotel, industrial, collective housing, etc.) the stakes for electrical design rely on a key process with practical considerations described in this chapter.

The choice of distribution architecture has a decisive impact on installation performance throughout its lifecycle:

- right from the construction phase, choices can greatly influence the installation time, possibilities of work rate, required competencies of installation teams, etc.
- there will also be an impact on performance during the operation phase in terms of quality and continuity of power supply to sensitive loads, power losses in power supply circuits,
- and lastly, there will be an impact on the proportion of the installation that can be recycled in the end-of-life phase.

The Electrical Distribution architecture of an installation involves the spatial configuration, the choice of power sources, the definition of different distribution levels, the single-line diagram and the choice of equipment.

The choice of the best architecture is often expressed in terms of seeking a compromise between the various performance criteria that interest the customer who will use the installation at different phases in its lifecycle. The earlier we search for solutions, the more optimization possibilities exist (see Fig. D1).

These topics are now part of IEC60364 standard in chapter 8 (IEC 60364-8-1: Low voltage electrical installations - Energy Efficiency).

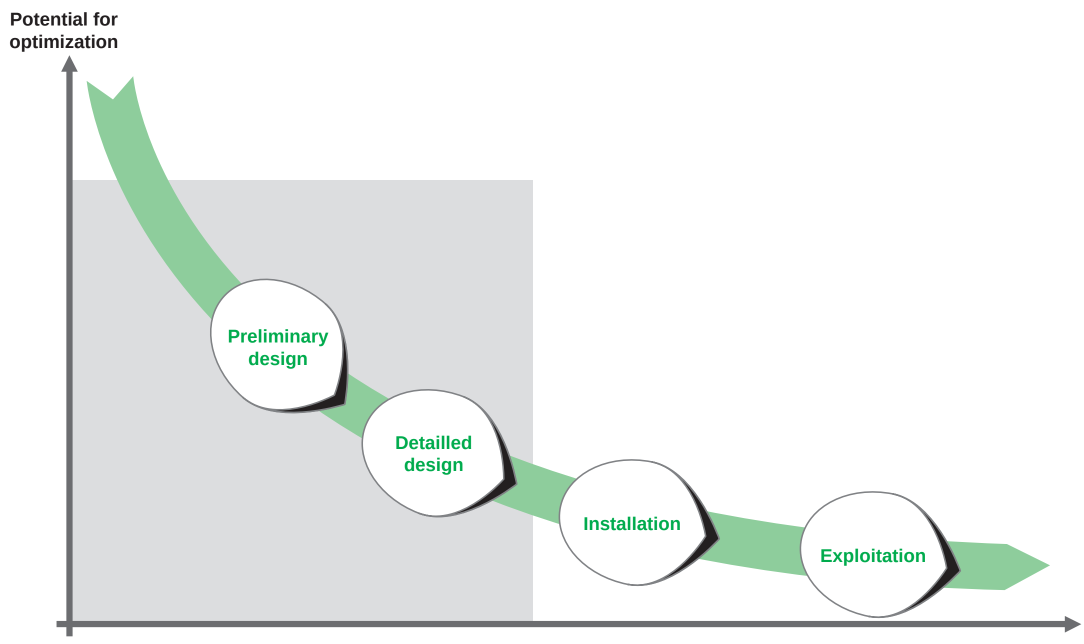


Fig. D1 : Optimization potential

A successful search for an optimal solution is also strongly linked to the ability for exchange between the various players involved in designing the various sections of a project:

- the architect who defines the organization of the building according to user requirements,
- the designers of different technical sections (lighting, heating, air conditioning, fluids, etc.),
- the user's representatives e.g. defining the process.

The following paragraphs present the selection criteria as well as the architecture design process to meet the project performance criteria in the context of industrial and tertiary buildings (excluding large sites).

2 Simplified architecture design process

2.1 The architecture design

The architecture design considered in this document starts at the preliminary design stage (see **Fig. D3** step1). It generally covers the levels of MV/LV main distribution, LV power distribution, and exceptionally the terminal distribution level. (see **Fig. D2**).

In buildings all consumers are connected in low voltage. It means that MV distribution consists in:

- connection to utility,
- distribution to MV/LV substation(s),
- MV/LV substation(s) itself.

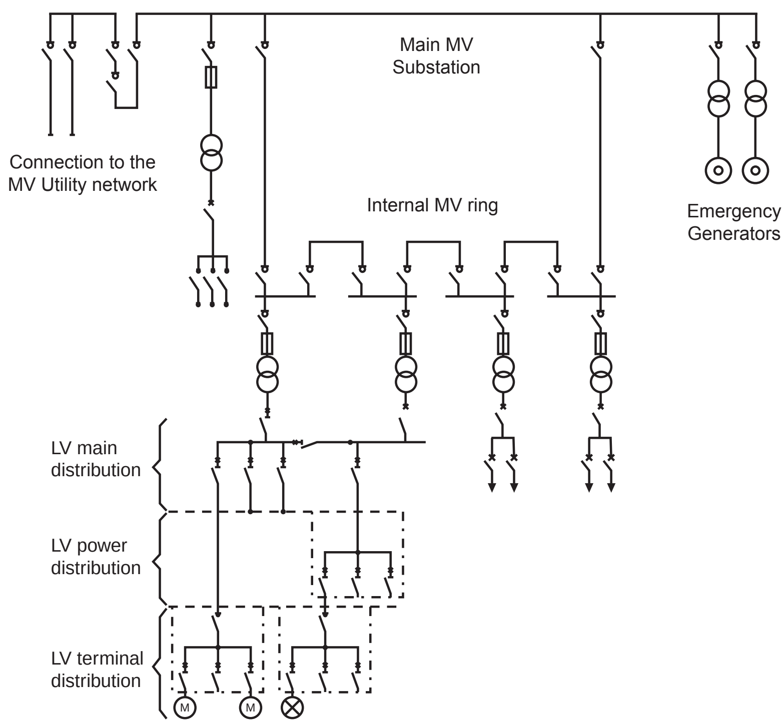


Fig. D2 : *Example of single-line diagram*

The design of an electrical distribution architecture can be described by a 3-stage process, with iterative possibilities. This process is based on taking account of the installation characteristics and criteria to be satisfied.

2.2 The whole process

The whole process is described briefly in the following paragraphs and illustrated on **Figure D3**.

The process described in this document is not intended as the only solution. This document is a guide intended for the use of electrical installation designers.

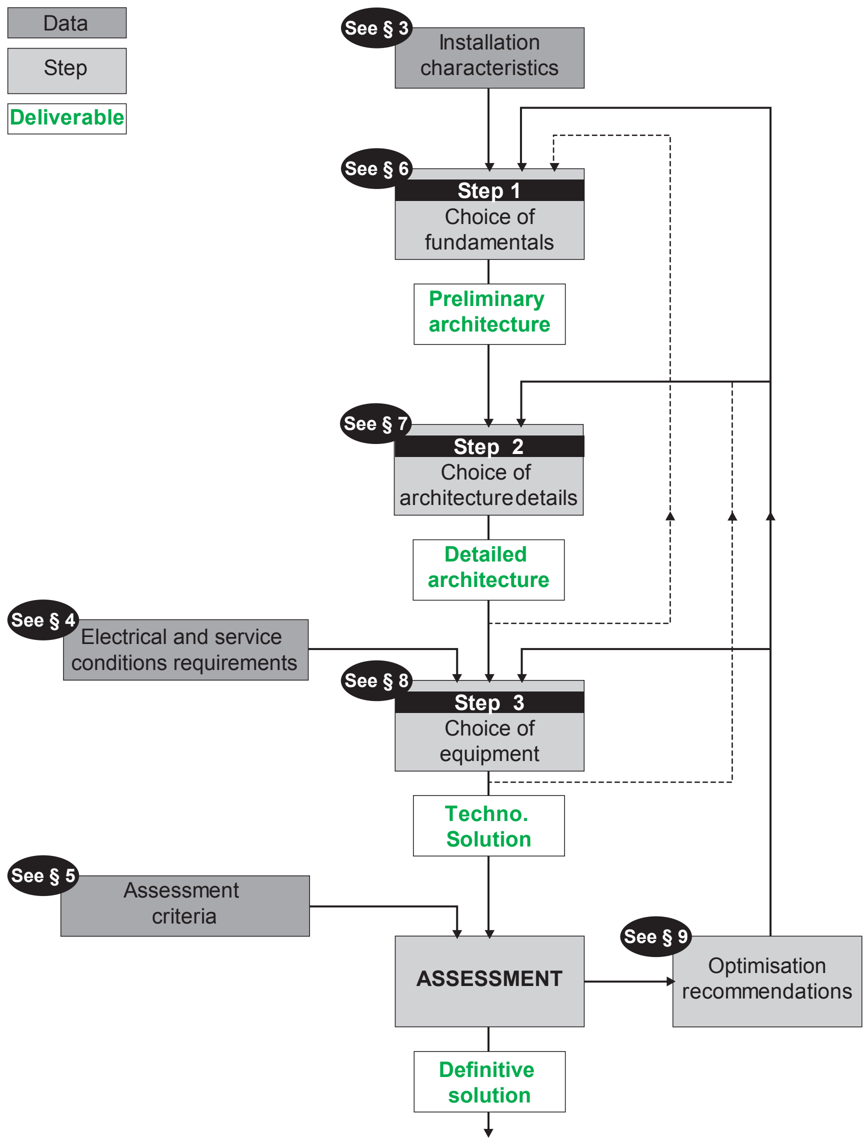


Fig. D3 : Flow diagram for choosing the electrical distribution architecture

Step 1: Choice of distribution architecture fundamentals

This involves defining the general features of the electrical installation. It is based on taking account of macroscopic characteristics concerning the installation and its usage.
These characteristics have an impact on the connection to the upstream network, MV circuits, the number of MV/LV substation, etc.
At the end of this step, we may have several distribution schematic diagram solutions, which are used as a starting point for the single-line diagram. The definitive choice is confirmed at the end of the step 2.

2 Simplified architecture design process

Step 2: choice of architecture details

This involves defining the electrical installation in more detail. It is based on the results of the previous step, as well as on satisfying criteria relative to implementation and operation of the installation.
The process loops back into step1 if the criteria are not satisfied. An iterative process allows several assessment criteria combinations to be analyzed.
At the end of this step, we have a detailed single-line diagram.

Step 3: choice of equipment

The choice of equipment to be implemented is carried out in this stage, and results from the choice of architecture. The choices are made from the manufacturer catalogues, in order to satisfy electrical requirements and service conditions.
This stage is looped back into step 2 if the characteristics are not satisfied.

Assessment

This assessment step allows the design office to have figures as a basis for discussions with the customer and other players.
According to the result of these discussions, it may be possible to loop back into steps 1, 2 or 3.

3 Electrical installation characteristics

These are the main installation characteristics enabling the defining of the fundamentals and details of the electrical distribution architecture. For each of these characteristics, we supply a definition and the different categories or possible values.

3.1 Sectors of activities

Definition:

Among the definitions proposed by IEC60364-8-1 § 3.4, mainly those listed below are part of this chapter.

Residential buildings

- Premises designed and constructed for private habitation

Commercial

- Premises designed and constructed for commercial operations (1)

Industry

- Premises designed and constructed for manufacturing and processing of operations (2)

Infrastructure

- Systems or premises designed and constructed for the transport and utility operation (3)

3.2 Site topology

Definition:

Architectural characteristic of the building(s), taking account of the number of buildings, number of floors, and of the surface area of each floor.

Different categories:

- Single storey building,
- Multi-storey building,
- Multi-building site,
- High-rise building.

3.3 Layout latitude

Definition:

Characteristic taking account of constraints in terms of the layout of the electrical equipment in the building:
- aesthetics,
- accessibility,
- presence of dedicated locations,
- use of technical corridors (per floor),
- use of technical ducts (vertical).

Different categories:

- Low: the position of the electrical equipment is virtually imposed
- Medium: the position of the electrical equipment is partially imposed, to the detriment of the criteria to be satisfied
- High: no constraints. The position of the electrical equipment can be defined to best satisfy the criteria.

(1) Examples of commercial building: offices, retail, distribution, public buildings, banks, hotels.
(2) Examples of industrial buildings: factories, workshops, distribution centers.
(3) Examples of infrastructure: airport, harbours, rails, transport facilites.

3.4 Service reliability

Definition:

The ability of a power system to meet its supply function under stated conditions for a specified period of time.

Different categories:

- Minimum: this level of service reliability implies risk of interruptions related to constraints that are geographical (separate network, area distant from power production centers), technical (overhead line, poorly meshed system), or economic (insufficient maintenance, under-dimensioned generation).
- Standard
- Enhanced: this level of service reliability can be obtained by special measures taken to reduce the probability of interruption (underground network, strong meshing, dedicated architectures, emergency generators, etc.)

3.5 Maintainability

Definition:

Features input during design to limit the impact of maintenance actions on the operation of the whole or part of the installation.

Different categories:

- Minimum: the installation must be stopped to carry out maintenance operations.
- Standard: maintenance operations can be carried out during installation operations, but with deteriorated performance. These operations must be preferably scheduled during periods of low activity. Example: several transformers with partial redundancy and load shedding.
- Enhanced: special measures are taken to allow maintenance operations without disturbing the installation operations. Example: double-ended configuration.

3.6 Installation flexibility

Definition:

Possibility of easily moving electricity delivery points within the installation, or to easily increase the power supplied at certain points. Flexibility is a criterion which also appears due to the uncertainty of the building during the pre-project summary stage.

Different categories:

- No flexibility: the position of loads is fixed throughout the lifecycle, due to the high constraints related to the building construction or the high weight of the supplied process. E.g.: smelting works.
- Flexibility of design: the number of delivery points, the power of loads or their location are not precisely known.
- Implementation flexibility: the loads can be installed after the installation is commissioned.
- Operating flexibility: the position of loads will fluctuate, according to process re-organization.

Examples:
  - industrial building: extension, splitting and changing usage
  - office building: splitting

3.7 Power demand

Definition:

It's the maximum power and apparent power demands actually required to dimension the installation (see chapter A section 4 for more information):

- < 630kVA
- from 630 to 1250kVA
- from 1250 to 2500kVA
- > 2500kVA

3.8 Load distribution

Definition:

A characteristic related to the uniformity of load distribution (in kVA / m²) over an area or throughout the building.

Different categories:

- Uniform distribution: the loads are generally of an average or low unit power and spread throughout the surface area or over a large area of the building (uniform density).
E.g.: lighting, individual workstations
- intermediate distribution: the loads are generally of medium power, placed in groups over the whole building surface area
E.g.: machines for assembly, conveying, workstations, modular logistics “sites”
- localized loads: the loads are generally high power and localized in several areas of the building (non-uniform density).
E.g.: HVAC

3.9 Voltage Interruption Sensitivity

Definition:

The aptitude of a circuit to accept a power interruption.

Different categories:

- “Sheddable” circuit: possible to shut down at any time for an indefinite duration
- Long interruption acceptable: interruption time > 3 minutes *
- Short interruption acceptable: interruption time < 3 minutes *
- No interruption acceptable.

We can distinguish various levels of severity of an electrical power interruption, according to the possible consequences:

- No notable consequence,
- Loss of production,
- Deterioration of the production facilities or loss of sensitive data,
- Causing mortal danger.

This is expressed in terms of the criticality of supplying of loads or circuits.

- Non-critical:
The load or the circuit can be “shed” at any time. E.g.: sanitary water heating circuit.
- Low criticality:
A power interruption causes temporary discomfort for the occupants of a building, without any financial consequences. Prolonging of the interruption beyond the critical time can cause a loss of production or lower productivity. E.g.: heating, ventilation and air conditioning circuits (HVAC).
- Medium criticality
A power interruption causes a short break in process or service. Prolonging of the interruption beyond a critical time can cause a deterioration of the production facilities or a cost of starting for starting back up.
E.g.: refrigerated units, lifts.
- High criticality
Any power interruption causes mortal danger or unacceptable financial losses.
E.g.: operating theatre, IT department, security department.

* indicative value, supplied by standard EN50160: “Characteristics of the voltage supplied by public distribution networks”.

3.10 Disturbance sensitivity

Definition

The ability of a circuit to work correctly in presence of an electrical power disturbance.

A disturbance can lead to varying degrees of malfunctioning. E.g.: stopping working, incorrect working, accelerated ageing, increase of losses, etc
Types of disturbances with an impact on circuit operations:
- overvoltages
- voltage harmonic distorsion,
- voltage drop, voltage dip
- voltage fluctuation,
- voltage imbalance.

Different categories:

- low sensitivity: disturbances in supply voltages have very little effect on operations. E.g.: heating device.
- medium sensitivity: voltage disturbances cause a notable deterioration in operations.
E.g.: motors, lighting.
- high sensitivity: voltage disturbances can cause operation stoppages or even the deterioration of the supplied equipment.
E.g.: IT equipment.

The sensitivity of circuits to disturbances determines the design of shared or dedicated power circuits. Indeed it is better to separate “sensitive” loads from “disturbing” loads. E.g.: separating lighting circuits from motor supply circuits.
This choice also depends on operating features. E.g.: separate power supply of lighting circuits to enable measurement of power consumption.

3.11 Disturbance potential of circuits

Definition

The ability of a circuit to disturb the operation of surrounding circuits due to phenomena such as: harmonics, in-rush current, imbalance, High Frequency currents, electromagnetic radiation, etc.

Different categories

- Non disturbing: no specific precaution to take
- moderate or occasional disturbance: separate power supply may be necessary in the presence of medium or high sensitivity circuits. E.g.: lighting circuit generating harmonic currents.
- Very disturbing: a dedicated power circuit or ways of attenuating disturbances are essential for the correct functioning of the installation. E.g.: electrical motor with a strong start-up current, welding equipment with fluctuating current.

3.12 Other considerations or constraints

- Specific rules
E.g.: hospitals, high rise buildings, etc.
- Rule of the Energy Distributor
Example: limits of connection power for LV, access to MV substation, etc
- Attachment loads
Loads attached to 2 independent circuits for reasons of redundancy.
- Designer experience
Consistency with previous designs or partial usage of previous designs, standardization of sub-assemblies, existence of an installed equipment base.
- Load power supply constraints
Voltage level (230V, 400V, 690V), voltage system (single-phase, three-phase with or without neutral, etc)

4 Technological characteristics

The technological solutions considered concern the various types of MV and LV equipment, as well as Busbar Trunking Systems .
The choice of technological solutions is made following the choice of single-line diagram and according to characteristics given below.

4.1 Environment, atmosphere

A notion taking account of all of the environmental constraints (average ambient temperature, altitude, humidity, corrosion, dust, impact, etc.) and bringing together protection indexes IP and IK.

Different categories:
- Standard: no particular environmental constraints
- Enhanced: severe environment, several environmental parameters generate important constraints for the installed equipment
- Specific: atypical environment, requiring special enhancements

4.2 Service Index

The Service Index (IS), is a tool dedicated to electrical designers in order to specify LV switchboards with reference to user's need rather than to technical aspects. It ensures the effective definition of the switchboards according to IEC61439-1 and 2 criteria for any:
- future evolution,
- maintenance,
- operation needs.

IS have been defined by the french standard commitee (AFNOR/UTE) in 2002 under the reference C63-429.

The IS is charactered by 3 numbers from 1 to 3, reflecting respectively:
- level of operation needs,
- level of maintenance request,
- level of evolution request.

The levels are described in **Fig. D4**

	Operation(1): first number	Maintenance(2): second number	Evolution(3): third number
Level 1	Full shutdown of the switchboard is accepted	Full shutdown of the switchboard is accepted	Full shutdown of the switchboard is accepted
Level 2	Only shut down of the concerned functional unit(4) is accepted	Only shutdown of the concerned functional unit (4) is accepted. But reconnection of the functional unit requests an action on connections	Only shutdown of the concerned functional unit (4) is accepted. Spare functional units are provided
Level 3	Only the shutdown of the power of the functional unit (4) is accepted (control circuits are still available)	Only shutdown of the concerned functional unit (4) is accepted. Reconnection of the functional unit requests no action on connections	Only shutdown of the concerned functional unit (4) is accepted. Evolution does not request pre-equiped spare functional units.

Fig. D4 : Definition of Service Index values

4.3 Other considerations

Other considerations have an impact on the choice of technological solutions:
- Previous experience,
- Consistency with past designs or the partial use of past designs,
- Standardization of sub-assemblies,
- The existence of an installed equipment base,
- Utilities requirements,
- Technical criteria: target power factor, backed-up load power, presence of harmonic generators…

These considerations should be taken into account during the detailed electrical definition phase following the draft design stage.

*(1) **Operation**: set of actions on the switchboard, which can be done by non-electrician people.*
*(2) **Maintenance:** concerns action of control, diagnostic, servicing, reparation, refurbishment, made by professionals.*
*(3) **Evolution:** adaptation of the equipment by addition of devices, increase of power demand.*
*(4) **functional unit:** subset of a LV switchboard including all mechanical and electrical parts dedicated to a specific function like : incomer, main feeder, auxiliary, etc.*

5 Architecture assessment criteria

Certain decisive criteria are assessed at the end of the 3 stages in defining architecture, in order to validate the architecture choice. These criteria are listed below with the different allocated levels of priority.

5.1 On-site work time

Time for implementing the electrical equipment on the site.

Different levels of priority:

- Standard: the on-site work time can be extended, if this gives a reduction in overall installation costs,
- Special: the on-site work time must be minimized, without generating any significant excess cost,
- Critical: the on-site work time must be reduced as far as possible, imperatively, even if this generates a higher total installation cost,

5.2 Environmental impact

Taking into consideration environmental constraints in the installation design. This takes account of: consumption of natural resources, Joule losses (related to CO_2 emission), “recyclability” potential, throughout the installation’s lifecycle.

Different levels of priority:

- Non significant: environmental constraints are not given any special consideration,
- Minimal: the installation is designed with minimum regulatory requirements,
- Proactive: the installation is designed with a specific concern for protecting the environment (low ernergy building, green buildings, etc.).

The environmental impact of an installation will be determined according to the method carrying out an installation lifecycle analysis, in which we distinguish between the following 3 phases:

- construction,
- operation,
- end of life (dismantling, recycling).

In terms of environmental impact, 3 indicators (at least) can be taken into account and influenced by the design of an electrical installation. Although each lifecycle phase contributes to the three indicators, each of these indicators is mainly related to one phase in particular:

- Manufacturing phase mainly impact the consumption of natural resources (steel, copper, aluminium),
- Operation phase impacts mainly the energy consumption (power losses cumulated during all the operating period).
- End of life is mainly impacted by the recyclability potential of equipment and material (presence of hazardous material, quantity of insulation material).

The following table details the contributing factors to the 3 environmental indicators (**Fig. D5**).

Indicators	Contributors
Natural resources consumption	Mass and type of conductor material: copper, steel, aluminium
Power consumption	Joule losses in conductors, transformers, no-load losses of transformers
"Recyclability" potential	Mass and type of insulation material, presence of hazardous material.

Fig. D5 : Contributing factors to the 3 environmental indicators

5.3 Preventive maintenance level

Definition:

Number of hours and sophistication of maintenance carried out during operations in conformity with manufacturer recommendations to ensure dependable operation of the installation and the maintaining of performance levels (avoiding failure: tripping, down time, etc).

Different categories:

- Standard: according to manufacturer recommendations.
- Enhanced: according to manufacturer recommendations, with a severe environment,
- Specific: specific maintenance plan, meeting high requirements for continuity of service, and requiring a high level of maintenance staff competency.

5.4 Availability of electrical power supply

Definition:

This is the probability that an electrical installation be capable of supplying quality power in conformity with the specifications of the equipment it is supplying. This is expressed by an availability level:

Availability (%) = (1 - MTTR/ MTBF) x 100

MTTR (Mean Time To Repair): the average time to make the electrical system once again operational following a failure (this includes detection of the reason for failure, its repair and re-commissioning),

MTBF (Mean Time Between Failure): measurement of the average time for which the electrical system is operational and therefore enables correct operation of the application.

The different availability categories can only be defined for a given type of installation. E.g.: hospitals, data centers.

Example of classification used in data centers:

Tier 1: the power supply and air conditioning are provided by one single channel, without redundancy, which allows availability of 99.671%,

Tier 2: the power supply and air conditioning are provided by one single channel, with redundancy, which allows availability of 99.741%,

Tier 3: the power supply and air conditioning are provided by several channels, with one single redundant channel, which allows availability of 99.982%,

Tier 4: the power supply and air conditioning are provided by several channels, each with redundancy, which allows availability of 99.995%.

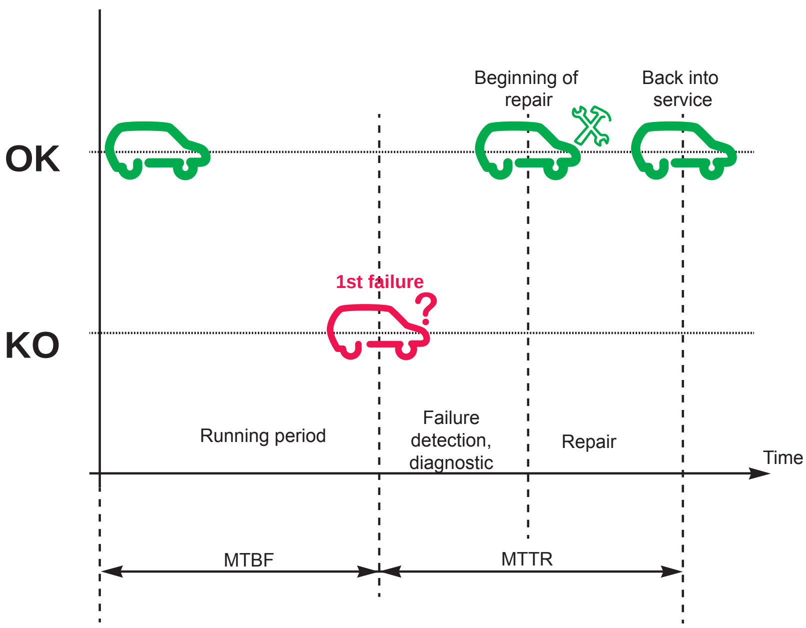


Fig D6: Definition of MTBF and MTTR

6 Choice of architecture fundamentals

For the installations considered in this guide, the selection of an electrical architecture can be performed in two stages.

- The first stage is generally dedicated to:
  - The selection of the mode of connection of the installation to the utility network,
  - The choice of the internal MV distribution including:
    - The definition of the number of MV/LV substations,
    - The definition of the number of MV/LV transformers,
    - The definition of the MV back-up generator when needed.
- The second stage deals with the principle of supply of the LV consumers

6.1 Connection to the utility network

The possible solutions for the connection of an installation to the utility network are the following:

- Connection to the LV network for small and medium size installations requiring less than 400 kVA. Fixing this limit is always under the responsibility of the local utility managing the LV network
- Above this previous limit, connection to the MV network with either LV or MV metering.

LV metering is generally authorized for installation including a single MV/LV transformer not exceeding the rated power limit fixed by the utility, generally around 1250 kVA.

The possible connections to a MV utility network are the following, (see **Fig. D8, D9 and D10**):

- MV single-line service,
- MV ring-main service,
- MV duplicate supply service, including two load break switches equipped with an automatic change over,
- MV dual supply service with two independent connections to the utility and two bus bars connected with a bus tie. The two utility incomers and the bus tie are equipped with an automatic change over.

Comparison of this four modes of connection are summarized in **Fig. D7**

	Configuration				
	LV	MV			
Characteristic to consider		**Single-line**	**Ring-main**	**Duplicate supply**	**Dual supply**
Activity	Any	Any	Any	High tech, sensitive office, health-care	Very sensitive installations
Site topology	Single building	Single building	Single or several buildings	Single or several buildings	Single or several buildings
Service reliability	Minimal	Minimal	Standard	Enhanced	Very high
Power demand	< 400 kVA	≤ 1250kVA	Any	Any	Any
Other connection constraints	Any	Isolated site	Low density urban area	High density urban area	Dedicated measures taken by the utility

Fig. D7: Comparison of the modes of connection

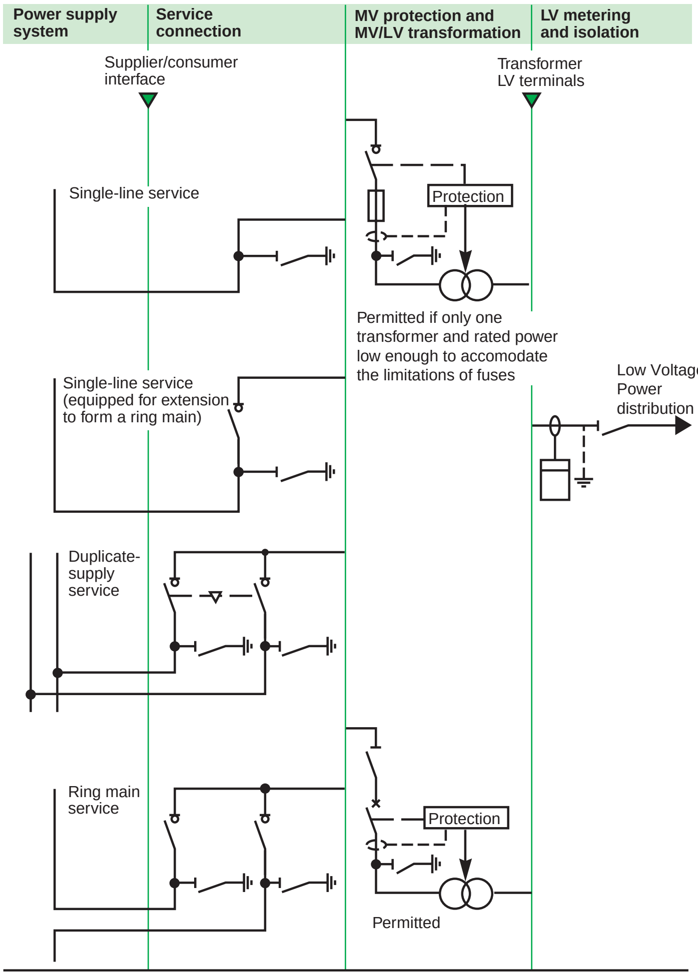


Fig. D8: MV connection with LV metering

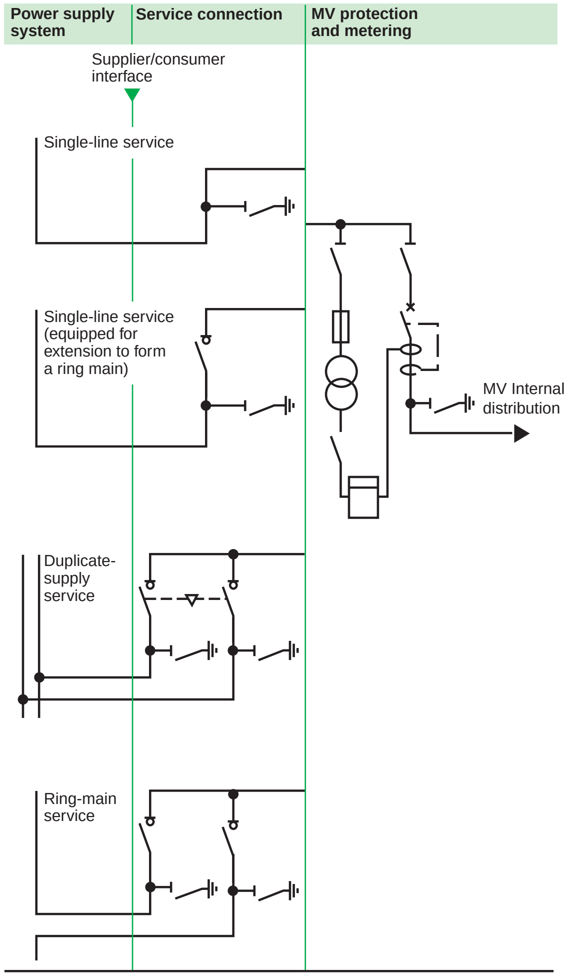


Fig. D9: MV connection with MV metering

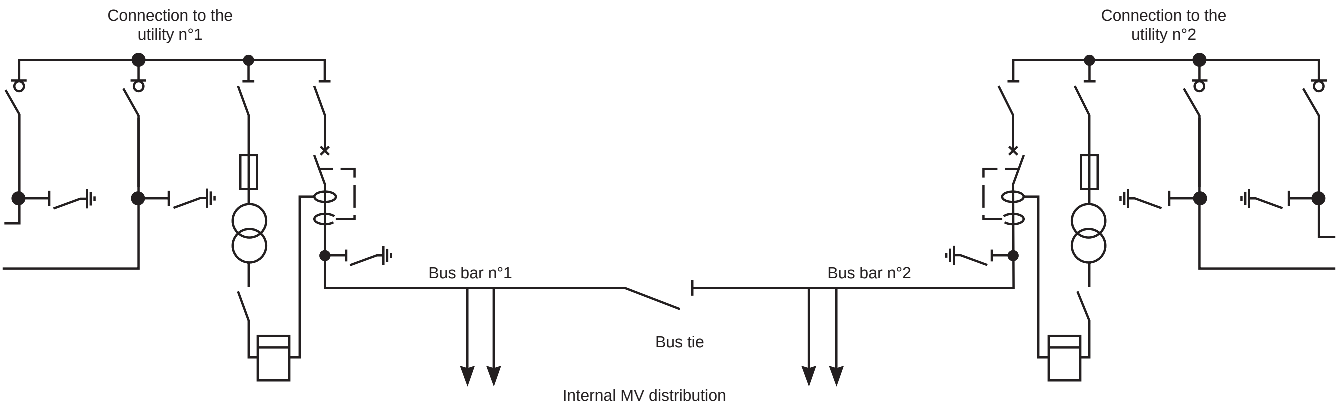


Fig. D10: Dual MV connection with MV metering

6.2 Internal MV circuits

Internal MV circuits are dedicated to the supply of the secondary MV/LV substations dispersed in the installation. They are three typical principles commonly used for this purpose (**Fig. D11**):

- Single feeder
- Dual feeder
- Open ring

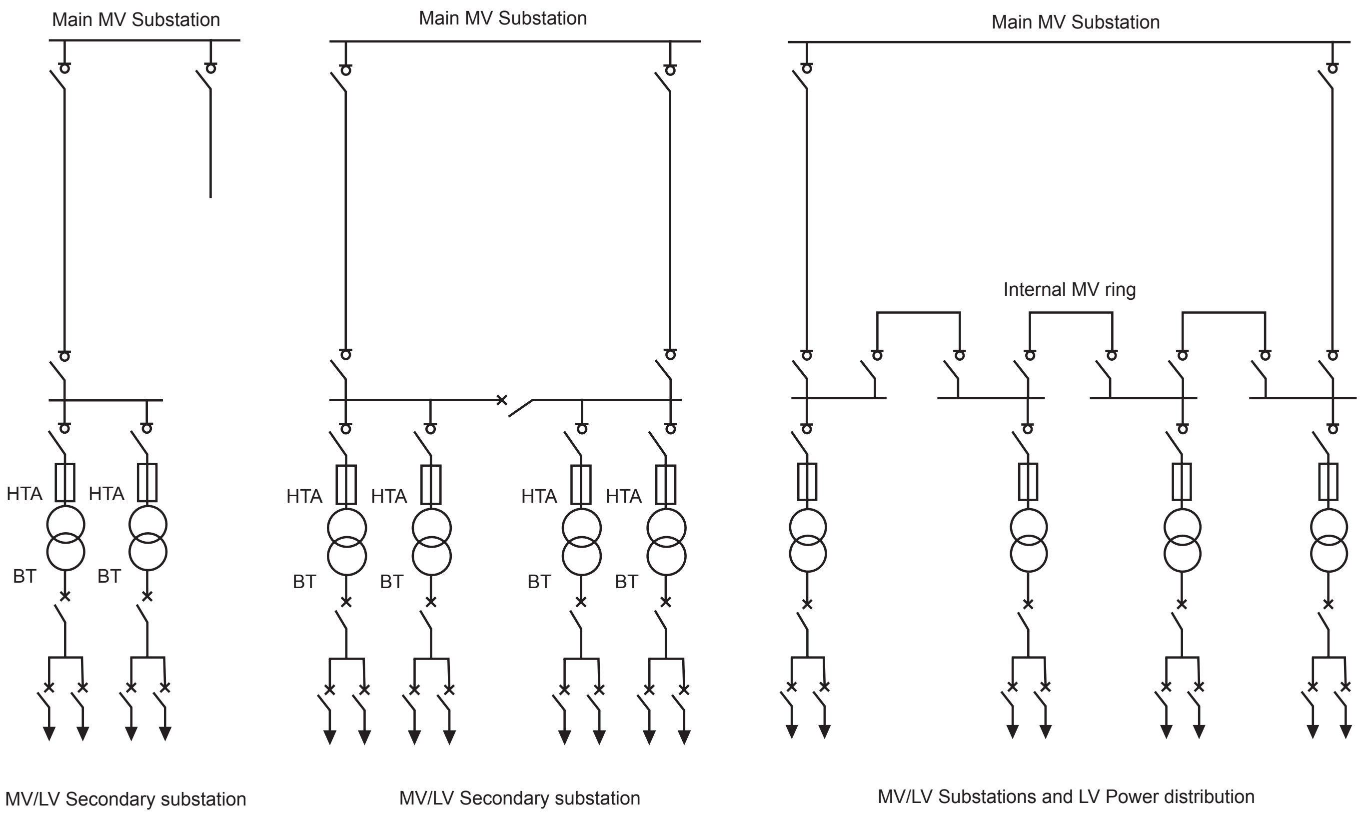


Fig. D11: Single feeder, Dual feeder, Open ring

Comparison of these three typical principles of internal distribution is given **Fig D12**.

	MV circuit configuration		
Characteristic to consider	**Single feeder**	**Open ring**	**Dual feeder**
Site topology	Any	Single or several buildings	Single or several buildings
Power demand	Any	> 1250kVA	> 2500kVA
Disturbance sensitivity	Long interruption acceptable	Short interruption acceptable	Short interruption not acceptable

Fig. D12 : Comparison of the typical internal circuits

6.3 Number and localisation of MV/LV transformer substations

The main criteria to consider for determination of the number and the location of the MV/LV substations are the following:

- Number of buildings
- Surface of each building
- Number of floors per building
- Repartition and power of the consumers
- Power demand per area, floor, building
- Sensitivity to interruption, need for redundancy

To determine the number and the location of the MV/LV substations, we may however give the following basic indications:

- Small and medium size building: One single MV/LV substation
- Large building: One or several MV/LV substations depending on the power and the repartition of the consumers
- Building with several floors: One or several MV/LV substations depending on the power and the repartition of the consumers. One MV/LV substation may be dedicated to each floor
- Large site with several buildings: One MV/LV substation may be dedicated to each building.

6.4 Number of MV/LV transformers

For every MV/LV substation, the definition of the number of MV/LV transformers takes into account the following criteria:

- Total power supplied by the substation
- Standardization of the rated power to reduce the number of spare transformers
- Limit of the rated power. It is recommended to set this limit at 1250 kVA in order to facilitate the handling and the replacement of the transformers
- Scalability of the installation
- Need to separate the loads having a high level of sensitivity to the electrical perturbations
- Need to dedicate a transformer to the load generating a high level of perturbation such as voltage dips, harmonics, flicker
- Need for partial or total redundancy. When required, two transformers each sized for the full load and equipped with an automatic change-over are installed
- Loads requiring a dedicated neutral system. IT for example to ensure the continuity of operation in case of phase to earth fault

6.5 MV back-up generator

MV back-up generators are required when in case of the utility failure it is necessary to ensure the supply of the totality of the loads or the major part of them.

For all the other situations LV back generators may be enough

The main criteria to consider for the implementation of MV back-up generators are the following:

- Site activity
- Sensitivity of the loads to power interruptions
- Level of availability of the public distribution network
- Process including a co-generation system
- Need to optimize the energy bill.

7 Choice of architecture details

This is the second stage in designing of electrical distribution design. During this stage we carry out the following choices:

- Layout,
- Centralized or decentralized distribution,
- Presence of back-up generators,
- Presence of uninterruptible power supplies,
- Configuration of LV distribution,
- Architecture combinations.

7.1 Layout

Position of the main MV and LV equipment on the site or in the building.

This layout choice is applied to the results of stage 1.

Selection guide:

As recommended in IEC60364-8-1 §6.3, MV/LV substation location can be determined by using the barycenter method:

- taking into account service conditions: in dedicated premises if the layout in the workshop is too restrictive (temperature, vibrations, dust, etc.)
- Placing heavy equipment (transformers, generators, etc.) close to walls or to main exits for ease of maintenance.

A layout example is given in the following diagram (**Fig. D13**):

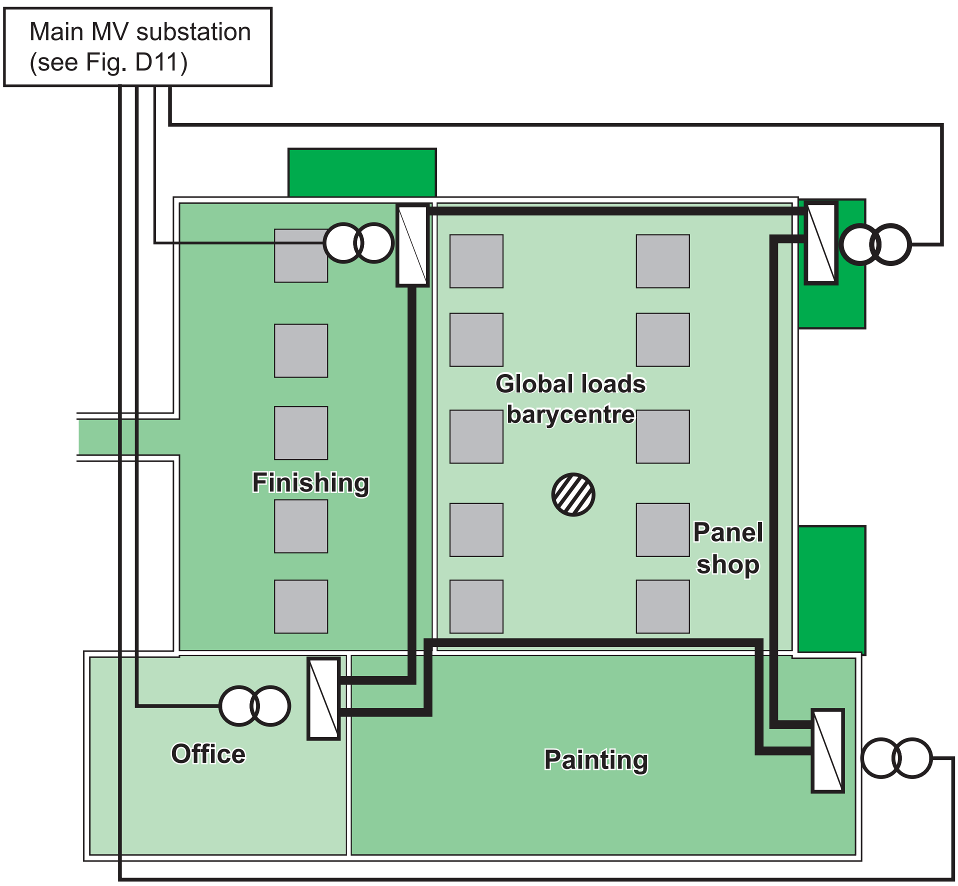


Fig. D13: The position of the global load barycentre guides the positioning of power sources

7.2 Centralized or distributed layout of LV distribution

In **centralized layout**, each load is connected directly to the power source. (**Fig. D14**):

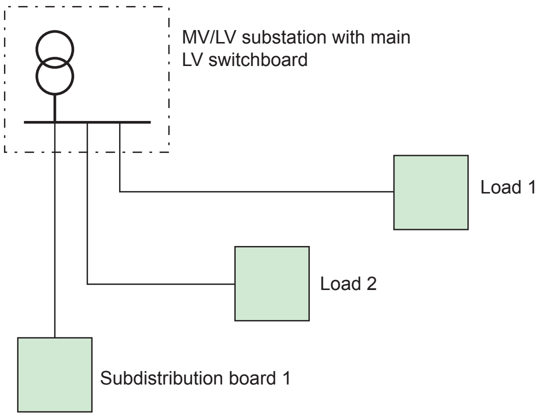


Fig. D14: Example of centralized layout with point to point links

In **distributed layout**, loads are connected to sources via a busway. This type of distribution is well adapted to supply many loads that are spread out, where easy change is requested or future new connection (need of flexibility) (**Fig D15**):

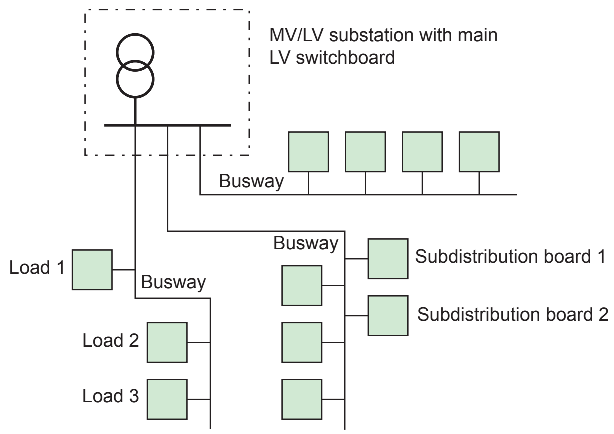


Fig. D15: Example of distributed layout, with busway

Factors in favour of centralized layout (see summary table in **Fig. D16**):
- Installation flexibility: no,
- Load distribution: localized loads (high unit power loads).

Factors in favor of distributed layout:
- Installation flexibility: "Implementation" flexibility (moving of workstations, etc…),
- Load distribution: uniform distribution of low or medium unit power loads

<table>
<tr><td></td><td colspan="3">Load distribution</td></tr>
<tr><td>Flexibility (see § 3.6 for definition of the flexibility levels)</td><td>Localized loads</td><td>Intermediate distribution loads</td><td>Uniformly distributed loads</td></tr>
<tr><td>No flexibility</td><td colspan="2" rowspan="2">Centralized</td><td rowspan="2">Decentralized</td></tr>
<tr><td>Flexibility of design</td></tr>
<tr><td>Implementation flexibility</td><td rowspan="2">Centralized</td><td colspan="2" rowspan="2">Decentralized</td></tr>
<tr><td>Operation flexibility</td></tr>
</table>

Fig. D16: Recommendations for centralized or distributed layout

Centralized distribution gives greater independence of circuits, reducing the consequences of a failure from power availability point of view.

The use of decentralized distribution with busway is a way to merge all the circuits in one: it makes it possible to take into account the diversity factor (ks), which means cost savings on conductor sizing (See fig. D17). The choice between centralized and decentralized solutions, according to the diversity factor, allows to find an economic optimum between investment costs, installation costs and operating costs.

These two distribution modes are often combined.

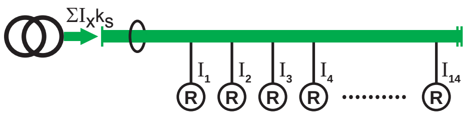
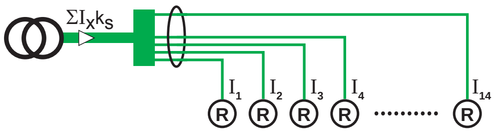
Distribution type	Insulation material	Power losses along life cycle
Decentralized		
 ks: diversity factor = 0.6	23 kg	1 600 Joules
Centralized		
 ks: diversity factor = 0.6	90 kg	2 000 Joules

Fig. D17: Example of a set of 14 x 25A loads distributed along 34 meters (for busway, Canalis KS 250A)

7.3 Presence of LV back-up generators

(see **Fig. D18***)*

LV backup-up generator is the association of an alternator mechanically powered by a thermal engine.

No electrical power can be delivered until the generator has reached its rated speed. This type of device is therefore not suitable for an uninterrupted power supply.
Depending, if the generator is sized to supply power to all or only part of the installation, there is either total or partial redundancy.
A back-up generator runs generally disconnected from the network. A source changeover and an interlocking system is therefore required (see **Fig. D18**).
The generator back-up time depends on the quantity of available fuel.

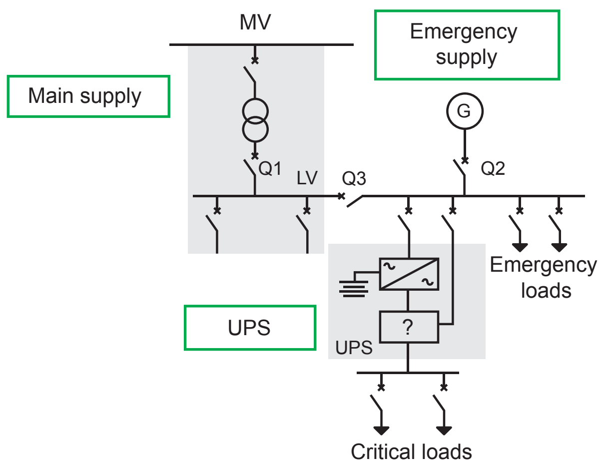


***Fig. D18**: Connection of a back-up generator*

The main characteristics to consider for implementing LV back-up generator:
- Sensitivity of loads to power interruption (see § 3.9 for definition),
- Availability of the public distribution network (see § 3.4 for the definition),
- Other constraints (e.g.: generators compulsory in hospitals or high buildings)

In addition the presence of generators can be decided to reduce the energy bill or due to the opportunity for co-generation. These two aspects are not taken into account in this guide.

The presence of a back-up generator is essential if the loads cannot be shed (only short interruption acceptable) or if the utility network availability is low.

Determining the number of back-up generator units is in line with the same criteria as determining the number of transformers, as well as taking account of economic and availability considerations (redundancy, start-up reliability, maintenance facility).

Determining the generator apparent power, depends on:
- installation power demand of loads to be supplied,
- transient constraints that can occur by motors inrush current for example.

7.4 Presence of an Uninterruptible Power Supply (UPS)

The electrical power from a UPS is supplied from a storage unit: batteries or inertia wheel. This system prevent any power failure. The back-up time of the system is limited: from several minutes to several hours.
The simultaneous presence of a back-up generator and a UPS unit is used for permanently supply loads for which no failure is acceptable (**Fig. D19**). The back-up time of the battery must be compatible with the maximum time for the generator to start up and take over the load supply.
A UPS unit is also used to supply loads that are sensitive to power quality (generating a “clean” voltage that is independent of the network).

Main characteristics to be considered for implementing a UPS:
■ Sensitivity of loads to power interruptions (see § 3.9 for definition),
■ Sensitivity of loads to disturbances (see § 3.10 for definition).

The presence of a UPS unit is essential if and only if no failure is acceptable.

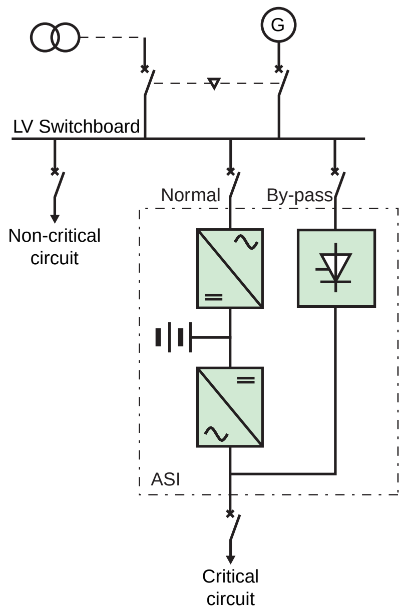


Fig. D19: Example of connection for a UPS

7.5 Configuration of LV circuits

Main possible configurations:
■ **Single feeder configuration (fig.D20):** This is the reference configuration and the most simple. A load is connected to one single source. This configuration provides a minimum level of availability, since there is no redundancy in case of power source failure.
■ **Parallel transformers configuration (fig.D21)**: The power supply is provided by more than 1 transformer generally connected in parallel to the same main LV switchboard.
■ **Variant: Normally open coupled transformers (fig.D22):** In order to increase the availability it is possible to split the main LV switchboard into 2 parts, with a normally open bus-coupler (NO). This configuration may require an Automatic Transfer Switch between the coupler and transformer incomers.
These 2 configurations are more often used when power demand is greater than 1 MVA.
■ **Main LV switchboard interconnected by a busway (fig D23):** Transformers are physically distant, and operated in parallel. They are connected by a busway, the load can always be supplied in the case of failure of one of the sources. The redundancy can be:
□ Total: each transformer being able to supply all of the installation,
□ Partial: each transformer only being able to supply part of the installation. In this case, part of the loads must be disconnected (load-shedding) in the case of one of transformer failure.

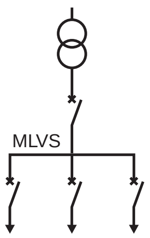


Fig. D20: Single feeder configuration

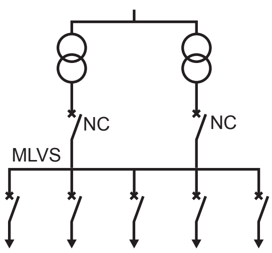


Fig. D21: Parallel transformers configuration

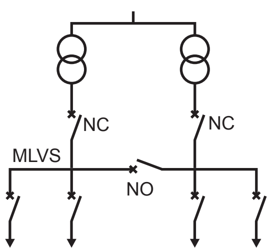


Fig. D22: Normally open coupled transformers

■ **LV ring configuration (fig. D24)**: This configuration can be considered as an extension of the previous configuration with interconnection between switchboards. Typically, 4 transformers connected in parallel to the same MV line, supply a ring using busway. A given load is then supplied by several transformers. This configuration is well suited to large sites, with high load density (in kVA/m²). If all of the loads can be supplied by 3 transformers, there is total redundancy in the case of failure of one of the transformers. In fact, each busbar can be fed by one or other of its ends. Otherwise, downgraded operation must be considered (with partial load shedding). This configuration requires special design of the protection plan in order to ensure discrimination in all of the fault circumstances.

As the previous configuration this type of installation is commonly used in automotive industry or large site manufacturing industry.

■ **Double-ended power supply (fig. D25)**: This configuration is implemented in cases where maximum availability is required. The principle involves having 2 independent power sources, e.g.:

□ 2 transformers supplied by different MV lines,

□ 1 transformer and 1 generator,

□ 1 transformer and 1 UPS.

An automatic transfer switch (ATS) is used to avoid the sources being parallel connected. This configuration allows preventive and curative maintenance to be carried out on all of the electrical distribution system upstream without interrupting the power supply.

■ **Configuration combinations (fig D.26)**: An installation can be made up of several sub-asssemblies with different configurations, according to requirements for the availability of the different types of load. E.g.: generator unit and UPS, choice by sectors (some sectors supplied by cables and others by busways).

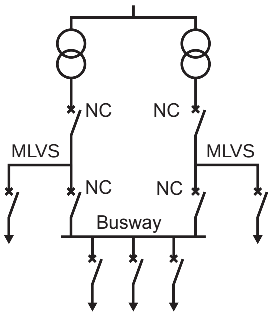


Fig. D23: Main LV switchboard interconnected by a busway

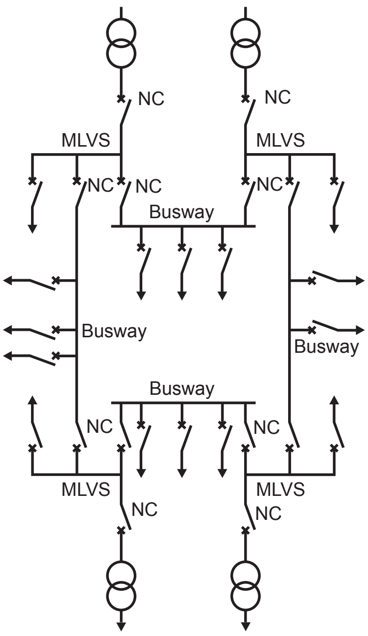


Fig. D24: Ring configuration

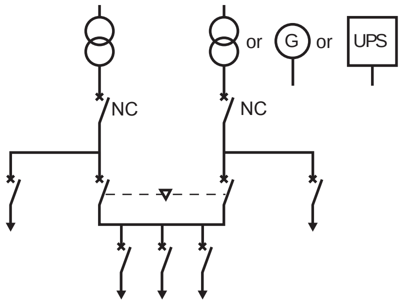


Fig. D25: Double-ended configuration with automatic transfer switch

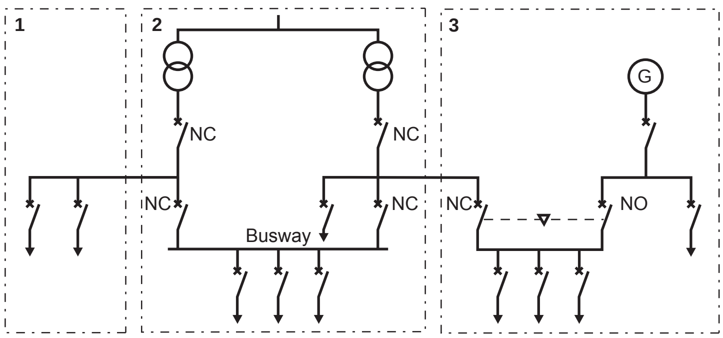


Fig. D26: Example of a configuration combination
1: Single feeder, 2: Main LV switchboard interconnected by a busway, 3: Double-ended

For the different possible configurations, the most probable and usual set of characteristics is given in the following table:

Characteristic to be considered	Configuration				
	Single feeder (fig. D20)	Parallel transformer or transformers connected via a coupler (fig. D21-D22)	Main LV switchboard interconnected by a busway (fig D24)	LV ring	Double-ended
Site topology	Any	Any	1 level 5000 to 25000 m²	1 level 5000 to 25000 m²	Any
Power demand	< 2500kVA	Any	≥ 2500kVA	> 2500kVA	Any
Location latitude	Any	Any	Medium or high	Medium or high	Any
Load distribution	Localized loads	Localized loads	Intermediate or uniform load distribution	Intermediate or uniform load distribution	Localized loads
Maintainability	Minimal	Standard	Standard	Standard	Enhanced
Disturbances sensitivity	Low sensitivity	High sensitivity	High sensitivity	High sensitivity	High sensitivity

Fig. D27: Recommendations for the configuration of LV circuits

8 Choice of equipment

The choice of equipment is step 3 in the design of an electrical installation. The aim of this step is to select equipment from the manufacturers' catalogues. The choice of technological solutions results from the choice of architecture.

List of equipment to consider:

- MV/LV substation,
- MV switchboards,
- Transformers,
- LV switchboards,
- Busway,
- UPS units,
- Power factor correction and filtering equipment.
- Generators

Criteria to consider:

- Service conditions (presence of water, dust, etc.),
- Power availability, including service index for LV switchboards,
- Safety (for people using or operating the installation),
- Local regulations,
- Footprint,
- Offer availability per country,
- Utilities requirements,
- Previous architecture choices.

The choice of equipment is basically linked to the offer availability in the country. This criterion takes into account the availability of certain ranges of equipment or local technical support.

The detailed selection of equipment is out of the scope of this document.

9 Recommendations for architecture optimization

These recommendations are intended to guide the designer towards architecture upgrades which allow him to improve assessment criteria.

9.1 On-site work

To be compatible with the “special” or “critical” work-site time, it is recommended to limit uncertainties by applying the following recommendations:
- Use of proven solutions and equipment that has been validated and tested by manufacturers (“functional” switchboard or “manufacturer” switchboard according to the application criticality),
- Prefer the implementation of equipment for which there is a reliable distribution network and for which it is possible to have local support (supplier well established),
- Prefer the use of factory-built equipment (MV/LV substation, busway), allowing the volume of operations on site to be limited,
- Limit the variety of equipment implemented for example, when possible harmonize transformers power,
- Avoid mixing equipment from different manufacturers.

9.2 Environmental impact

The optimization of the environmental impact of an installation will involve reducing:
- Power losses at loaded and also no-load conditions during all the period of operation of the installation,
- Overall, the mass of materials used to build the installation.

Taken separately and when looking at only one piece of equipment, these 2 objectives may seem contradictory. However, when applied to whole installation, it is possible to design the architecture to contribute to both objectives. The optimal installation will therefore not be the sum of the optimal equipment taken separately, but the result of an optimization of the overall installation.
Figure D28 gives an example of the contribution per equipment category to the weight and energy dissipation for a 3500 kVA of installed power spread over an area of 10000m².
- Installation is operating at 50% load on average, with 0,8 power factor
- Site is operating 6500 hours per years : 3 shifts + week ends with reduced activity at night and week ends and full stop 1 month per year for site maintenance.
- Energy consumption is 9,1 GWh per year.

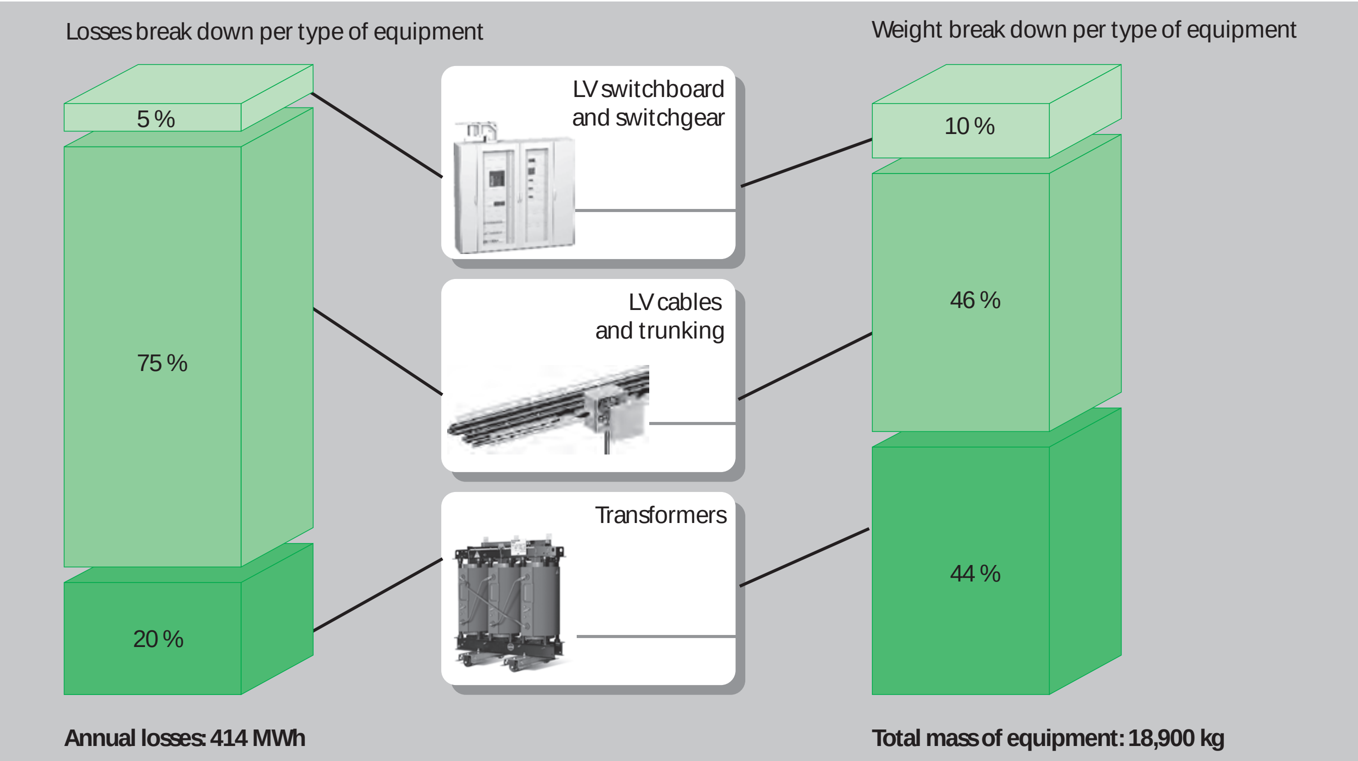


Fig. D28: Example of the break down of losses and the weight for each type of equipment

9 Recommendations for architecture optimization

These data helps to understand and prioritize energy consumption and costs factors.

- Very first factor of power consumption is... energy usage. This can be optimized with appropriate metering and analysis of loads actual consumption.
- Second is reactive energy. This lead to additional load on upstream electrical network. and additional energy invoicing. This can be optimized with power factor correction solutions.
- Third is wiring system which represent 75% of the installation losses. Cable losses can be reduced by appropriate organisation and design of site and use of busway wherever appropriate.
- MV/LV transformers are fourth with approx. 20% of the losses (1% of the site energy consumption).
- MV and LV switchboards come last with approximately 5% of the losses (0,25% of the site energy consumption).

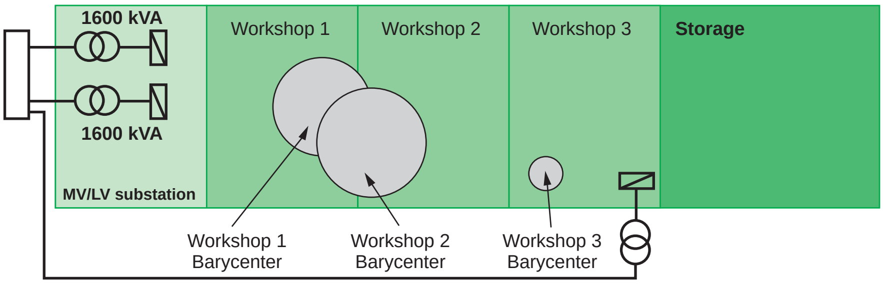
Generally speaking, LV cables and busway as well as the MV/LV transformers are the main contributors to losses and weight of equipment used.

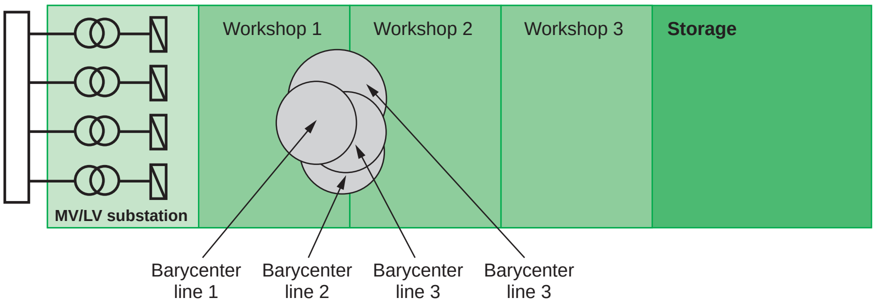
Environmental optimization of the installation by the architecture design will therefore involve:

- reducing the length of LV circuits in the installation, as proposed by the barycentre method in IEC60364-8-1 §6.3, and § 7.1 of this chapter
- clustering LV circuits wherever possible to take advantage of the diversity ks (see chapter A: General rules of electrical installation design, Subclause 4.3 "Estimation of actual maximum kVA demand")

Objectives	Resources
Reducing the length of LV circuits	Placing MV/LV substations as close as possible to the barycenter of all of the LV loads to be supplied
Clustering LV circuits	When the diversity factor of a group of loads to be supplied is less than 0.7, the clustering of circuits allows us to limit the volume of conductors supplying power to these loads. In real terms this involves: ■ setting up sub-distribution switchboards as close as possible to the barycenter of the groups of loads if they are localized, ■ setting up busbar trunking systems as close as possible to the barycenter of the groups of loads if they are distributed. The search for an optimal solution may lead to consider several clustering scenarios. In all cases, reducing the distance between the barycenter of a group of loads and the equipment that supplies them power allows to reduce environmental impact.

Fig. D29: Environmental optimization : Objectives and Ressources.

<table>
<tr><th>Solution</th><th>Barycenter position</th></tr>
<tr><td>N°1</td><td>

Solution 1: 1 transformer per workshop, 2 x 1600 kVA, 1 x 630 kVA</td></tr>
<tr><td>N°2</td><td>

Solution 2: 1 transformer per line of process, 4 x 1000 kVA</td></tr>
</table>

Fig. D30: Example of barycentres positioning according to load clustering

As an example **figure D30** shows the impact of clustering circuits on different ways and the impact on the barycentres of the clustered loads. This example concerns a mineral water bottling plant for which:

- the installed power is around 4 MVA.

In solution No.1, the circuits are clustered by workshop.
In solution No. 2, the circuits are clustered by process functions (production lines).

In this example 2 different solutions can be used at the MV/LV level:

- solution 1, a MV/LV transformer is moved close to workshop 3 to optimize its place according to the barycentre of the loads (its more economic to transmit the power in MV when possible)
- solution 2, all MV/LV transformers are in the same substation, and with the same size, allowing also a partial operation of the plant (1/2 of the plant).

In addition, in the 2 solutions the optimization can also be carried out by the following points:

- the setting up of LV power factor correction to limit losses in the transformers and LV circuits if this compensation is distributed,
- the use of low losses transformers,
- the use of aluminum busway when possible, since natural resources of this metal are greater.

9.3 Preventive maintenance volume

Recommendations for reducing the volume of preventive maintenance:
- Use the same recommendations as for reducing the work site time,
- Focus maintenance work on critical circuits,
- Standardize the choice of equipment,
- Use equipment designed for severe atmospheres (requires less maintenance).

9.4 Electrical power availability

Recommendations for improving the electrical power availability:
- Reduce the number of feeders per switchboard, in order to limit the effects of a possible failure of a switchboard,
- Distributing circuits according to availability requirements,
- Using equipment that is in line with requirements (see Service Index, 4.2),
- Follow the selection guides proposed for steps 1 & 2 (see **Fig. D3 page D5**).

Recommendations to increase the level of availability:
- Change from a radial single feeder configuration to a parallel transformers configuration,
- Change from a parallel transformers configuration to a double-ended configuration,
- Add to a double-ended configuration a UPS unit and a Static Transfer Switch
- Increase the level of maintenance (reducing the MTTR, increasing the MTBF)

10 Glossary

Architecture: choice of a single-line diagram and technological solutions, from connection to the utility network through load power supply circuits.

Main MV/LV distribution: Level upstream of the architecture, from connection to the network utility through to LV distribution equipment on the site (MLVS – or equivalent).

MLVS – Main Low Voltage Switchboard: Main switchboard downstream of the MV/LV transformer, starting point of power distribution circuits in the installation

LV power distribution: intermediate level in the architecture, downstream of the main level through to the sub-distribution switchboards (spatial and functional distribution of electrical power in the circuits).

LV terminal distribution: Downstream level of the architecture, downstream of the sub-distribution switchboards through to the loads. This level of distribution is not dealt with in this guide.

Single-line diagram: general electrical schematic diagram to represent the main electrical equipment and their interconnection.

MV substation, transformation substation: Enclosures grouping together MV equipment and/or MV/LV transformers. These enclosures can be shared or separate, according to the site layout, or the equipment technology. In certain countries, the MV substation is assimilated with the delivery substation.

Technological solution: Resulting from the choice of technology for an installation sub-assembly, from among the different products and equipment proposed by the manufacturer.

Characteristics: Technical or environmental data relative to the installation, enabling the best-suited architecture to be selected.

Criteria: Parameters for assessing the installation, enabling selection of the architecture that is the best-suited to the needs of the customer.

11 Example: electrical installation in a printworks

11.1 Brief description

Printing of personalized mailshots intended for mail order sales.

11.2 Installation characteristics

Characteristic	Category
Activity	Mechanical
Site topology	single storey building, 10000m² (8000m² dedicated to the process, 2000m² for ancillary areas)
Layout latitude	High
Service reliability	Standard
Maintainability	Standard
Installation flexibility	■ No flexibility planned: □ HVAC □ Process utilities □ Office power supply ■ Possible flexibility: □ finishing, putting in envelopes □ special machines, installed at a later date □ rotary machines (uncertainty at the draft design stage)
Power demand	3500kVA
Load distribution	Intermediate distribution
Power interruptions sensitivity	■ Sheddable circuits: □ offices (apart from PC power sockets) □ air conditioning, office heating □ social premises □ maintenance premises ■ long interruptions acceptable: □ printing machines □ workshop HVAC (hygrometric control) □ Finishing, envelope filling □ Process utilities (compressor, recycling of cooled water) ■ No interruptions acceptable: □ servers, office PCs
Disturbance sensitivity	■ Average sensitivity: □ motors, lighting ■ High sensitivity: □ IT No special precaution to be taken due to the connection to the EdF network (low level of disturbance)
Disturbance capability	Non disturbing
Other constraints	■ Building with lightning classification: lightning surge arresters installed ■ Power supply by overhead single feeder line

11.3 Technological characteristics

Criteria	Category
Service conditions	■ IP: standard (no dust, no water protection) ■ IK: standard (use of technical pits, dedicated premises) ■ °C: standard (temperature regulation)
Required service index	211
Offer availability by country	No problem (project carried out in Europe)
Other criteria	Not applicable

11.4 Architecture assessment criteria

Criteria	Category
On-site work time	Standard (see 5.1)
Environmental impact	Minimal: compliance with European standard regulations
Preventive maintenance costs	Standard (see 5.3)
Power supply availability	Pier 1 (see 5.4)

Step 1: Architecture fundamentals

Choice	Main criteria	Solution
Connection to upstream network	Isolated site, 3500 kVA	MV single-line service
MV Circuits	Layout + criticality	single feeder
Number of transformers	Power > 2500kVA	2 x 2000kVA
Number and distribution of substations	Surface area and power distribution	2 possible solutions: 1 substation or 2 substations ■ if 1 substations: Normaly open bus-coupler between MLVS ■ if 2 substations: Main LV switchboard interconnected by a busway
MV Generator	Site activity	No

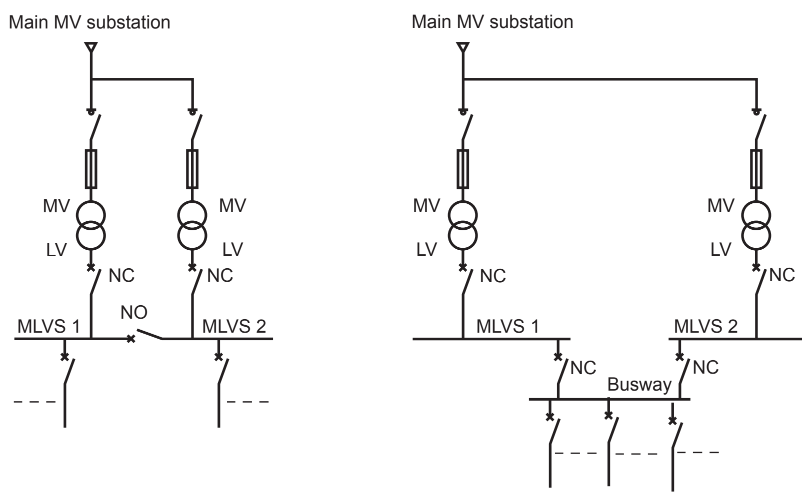


Fig. D31: Two possible single-line diagrams

Step 2: Architecture details

Choice	Main criteria	Solution
Layout	Service conditions	Dedicated premises
LV circuit configuration	2 transformers, requested by the power demand	Solution from fig.D22 or D23 are possible
Centralized or distributed layout	Uniform loads, distributed power, scalability possibilities Non-uniform loads, direct link from MLVS	■ Decentralized with busbar trunking: □ finishing sector, envelope filling ■ Centralized with cables: □ special machines, rotary machines, HVAC, process utilities, offices (2 switchboards), office air conditioning, social premises, maintenance
Presence of back-up generator	Criticality ≤ low Network availability: standard	No back-up generator
Presence of UPS	Criticality	UPS unit for IT devices and office workstations

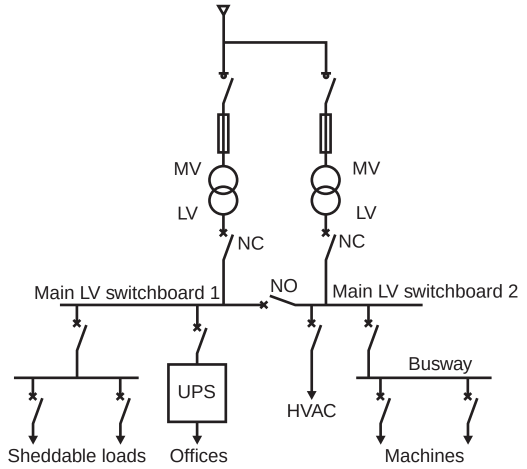


Fig. D32 : Detailed single-line diagram (1 substation based on fig.D22)

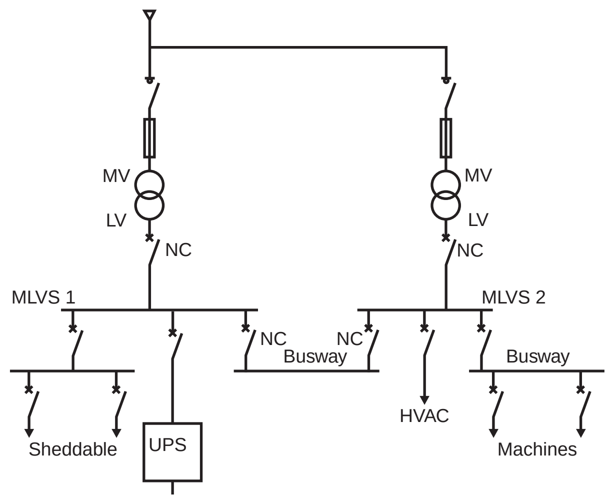


Fig. D33 : Detailed single-line diagram (2 substation based on fig.D24)

11.5 Choice of technological solutions

Choice	Main criteria	Solution
MV/LV substation	Service conditions	indoor (dedicated premises)
MV switchboard	Offer availability by country	SM6 (installation in Europe)
Transformers	Service conditions	cast resin transfo (avoids constraints related to oil)
LV switchboard	Service conditions, service index for LV switchboards	MLVS: Prisma P Sub-distribution: Prisma
Busway	Load distribution	Canalis KS (fig.D32 or D33) Canalis KT for main distribution (fig D33)
UPS units	Installed power to be supplied, back-up time	Galaxy PW
Power factor correction	Reactive power to provide for the minimum up to the full load without harmonic (see chapter L for more information), presence of harmonics	LV automatic compensation (without detuned reactor).

Chapter E
LV Distribution

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1 Earthing schemes

In a building, the connection of all metal parts of the building and all exposed conductive parts of electrical equipment to an earth electrode prevents the appearance of dangerously high voltages between any two simultaneously accessible metal parts

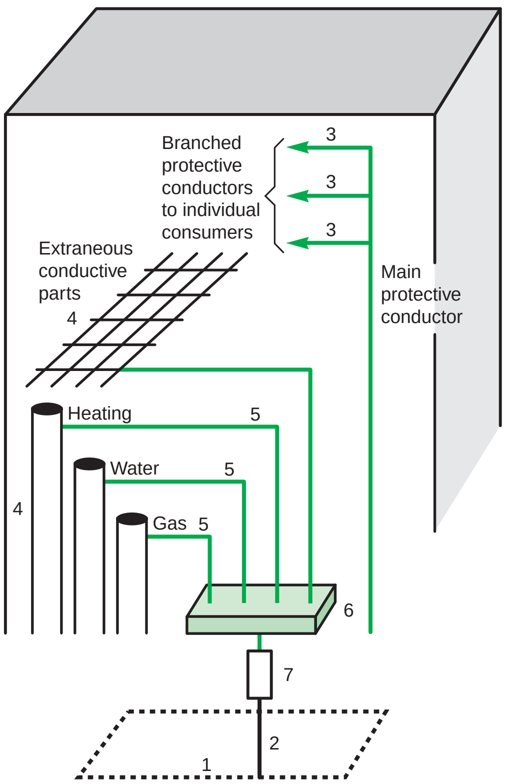


Fig. E1: An example of a block of flats in which the main earthing terminal (6) provides the main equipotential connection; the removable link (7) allows an earth-electrode-resistance check

1.1 Earthing connections

Definitions

National and international standards (IEC 60364) clearly define the various elements of earthing connections. The following terms are commonly used in industry and in the literature. Bracketed numbers refer to **Figure E1**:

- Earth electrode (1): A conductor or group of conductors in intimate contact with, and providing an electrical connection with Earth (cf details in section 1.6 of Chapter E.)
- Earth: The conductive mass of the Earth, whose electric potential at any point is conventionally taken as zero
- Electrically independent earth electrodes: Earth electrodes located at such a distance from one another that the maximum current likely to flow through one of them does not significantly affect the potential of the other(s)
- Earth electrode resistance: The contact resistance of an earth electrode with the Earth
- Earthing conductor (2): A protective conductor connecting the main earthing terminal (6) of an installation to an earth electrode (1) or to other means of earthing (e.g. TN systems);
- Exposed-conductive-part: A conductive part of equipment which can be touched and which is not a live part, but which may become live under fault conditions
- Protective conductor (3): A conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts:
  - Exposed-conductive-parts
  - Extraneous-conductive-parts
  - The main earthing terminal
  - Earth electrode(s)
  - The earthed point of the source or an artificial neutral
- Extraneous-conductive-part: A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation (4). For example:
  - Non-insulated floors or walls, metal framework of buildings
  - Metal conduits and pipework (not part of the electrical installation) for water, gas, heating, compressed-air, etc. and metal materials associated with them
- Bonding conductor (5): A protective conductor providing equipotential bonding
- Main earthing terminal (6): The terminal or bar provided for the connection of protective conductors, including equipotential bonding conductors, and conductors for functional earthing, if any, to the means of earthing.

Connections

The main equipotential bonding system

The bonding is carried out by protective conductors and the aim is to ensure that, in the event of an incoming extraneous conductor (such as a gas pipe, etc.) being raised to some potential due to a fault external to the building, no difference of potential can occur between extraneous-conductive-parts within the installation.

The bonding must be effected as close as possible to the point(s) of entry into the building, and be connected to the main earthing terminal (6).

However, connections to earth of metallic sheaths of communications cables require the authorisation of the owners of the cables.

Supplementary equipotential connections

These connections are intended to connect all exposed-conductive-parts and all extraneous-conductive-parts simultaneously accessible, when correct conditions for protection have not been met, i.e. the original bonding conductors present an unacceptably high resistance.

Connection of exposed-conductive-parts to the earth electrode(s)

The connection is made by protective conductors with the object of providing a low-resistance path for fault currents flowing to earth.

Components (see **Fig. E2**)

Effective connection of all accessible metal fixtures and all exposed-conductive-parts of electrical appliances and equipment, is essential for effective protection against electric shocks.

Component parts to consider:	
as exposed-conductive-parts	**as extraneous-conductive-parts**
Cableways ■ Conduits ■ Impregnated-paper-insulated lead-covered cable, armoured or unarmoured ■ Mineral insulated metal-sheathed cable (pyrotenax, etc.)	Elements used in building construction ■ Metal or reinforced concrete (RC): □ Steel-framed structure □ Reinforcement rods □ Prefabricated RC panels ■ Surface finishes: □ Floors and walls in reinforced concrete without further surface treatment □ Tiled surface ■ Metallic covering: □ Metallic wall covering
Switchgear ■ cradle of withdrawable switchgear	
Appliances ■ Exposed metal parts of class 1 insulated appliances	
Non-electrical elements ■ metallic fittings associated with cableways (cable trays, cable ladders, etc.) ■ Metal objects: □ Close to aerial conductors or to busbars □ In contact with electrical equipment.	Building services elements other than electrical ■ Metal pipes, conduits, trunking, etc. for gas, water and heating systems, etc. ■ Related metal components (furnaces, tanks, reservoirs, radiators) ■ Metallic fittings in wash rooms, bathrooms, toilets, etc. ■ Metallised papers

Component parts not to be considered:	
as exposed-conductive-parts	**as extraneous-conductive-parts**
Diverse service channels, ducts, etc. ■ Conduits made of insulating material ■ Mouldings in wood or other insulating material ■ Conductors and cables without metallic sheaths	■ Wooden-block floors ■ Rubber-covered or linoleum-covered floors ■ Dry plaster-block partition ■ Brick walls ■ Carpets and wall-to-wall carpeting
Switchgear ■ Enclosures made of insulating material	
Appliances ■ All appliances having class II insulation regardless of the type of exterior envelope	

Fig. E2: List of exposed-conductive-parts and extraneous-conductive-parts

The different earthing schemes (often referred to as the type of power system or system earthing arrangements) described characterise the method of earthing the installation downstream of the secondary winding of a MV/LV transformer and the means used for earthing the exposed conductive-parts of the LV installation supplied from it

1.2 Definition of standardised earthing schemes

The choice of these methods governs the measures necessary for protection against indirect-contact hazards.

The earthing system qualifies three originally independent choices made by the designer of an electrical distribution system or installation:

■ The type of connection of the electrical system (that is generally of the neutral conductor) and of the exposed parts to earth electrode(s)

■ A separate protective conductor or protective conductor and neutral conductor being a single conductor

■ The use of earth fault protection of overcurrent protective switchgear which clear only relatively high fault currents or the use of additional relays able to detect and clear small insulation fault currents to earth.

In practice, these choices have been grouped and standardised as explained below.

Each of these choices provides standardised earthing systems with three advantages and drawbacks:

■ Connection of the exposed conductive parts of the equipment and of the neutral conductor to the PE conductor results in equipotentiality and lower overvoltages but increases earth fault currents

■ A separate protective conductor is costly even if it has a small cross-sectional area but it is much more unlikely to be polluted by voltage drops and harmonics, etc. than a neutral conductor is. Leakage currents are also avoided in extraneous conductive parts

■ Installation of residual current protective relays or insulation monitoring devices are much more sensitive and permits in many circumstances to clear faults before heavy damage occurs (motors, fires, electrocution). The protection offered is in addition independent with respect to changes in an existing installation.

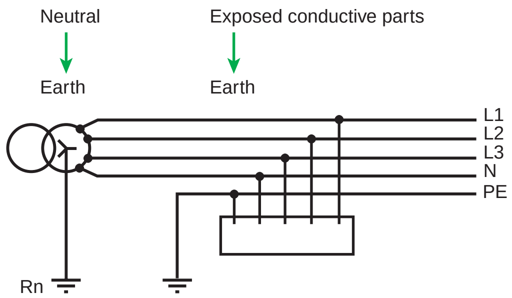


Fig. E3: TT System

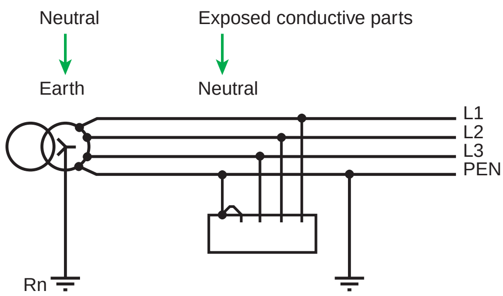


Fig. E4: TN-C system

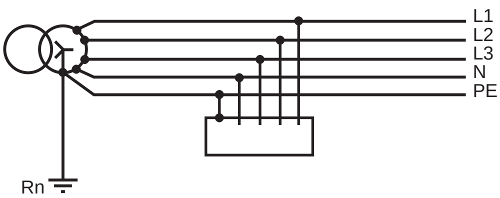


Fig. E5: TN-S system

TT system (earthed neutral) (see Fig. E3)

One point at the supply source is connected directly to earth. All exposed- and extraneous-conductive-parts are connected to a separate earth electrode at the installation. This electrode may or may not be electrically independent of the source electrode. The two zones of influence may overlap without affecting the operation of protective devices.

TN systems (exposed conductive parts connected to the neutral)

The source is earthed as for the TT system (above). In the installation, all exposed- and extraneous-conductive-parts are connected to the neutral conductor. The several versions of TN systems are shown below.

TN-C system (see Fig. E4)

The neutral conductor is also used as a protective conductor and is referred to as a PEN (**P**rotective **E**arth and **N**eutral) conductor. This system is not permitted for conductors of less than 10 mm^2 or for portable equipment.

The TN-C system requires an effective equipotential environment within the installation with dispersed earth electrodes spaced as regularly as possible since the PEN conductor is both the neutral conductor and at the same time carries phase unbalance currents as well as 3rd order harmonic currents (and their multiples).

The PEN conductor must therefore be connected to a number of earth electrodes in the installation.

Caution: In the TN-C system, the “protective conductor” function has priority over the “neutral function”. In particular, a PEN conductor must always be connected to the earthing terminal of a load and a jumper is used to connect this terminal to the neutral terminal.

TN-S system (see Fig. E5)

The TN-S system (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm^2 for portable equipment.

The protective conductor and the neutral conductor are separate. On underground cable systems where lead-sheathed cables exist, the protective conductor is generally the lead sheath. The use of separate PE and N conductors (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm^2 for portable equipment.

TN-C-S system (see Fig. E6 below and Fig. E7 next page)

The TN-C and TN-S systems can be used in the same installation. In the TN-C-S system, the TN-C (4 wires) system must never be used downstream of the TN-S (5 wires) system, since any accidental interruption in the neutral on the upstream part would lead to an interruption in the protective conductor in the downstream part and therefore a danger.

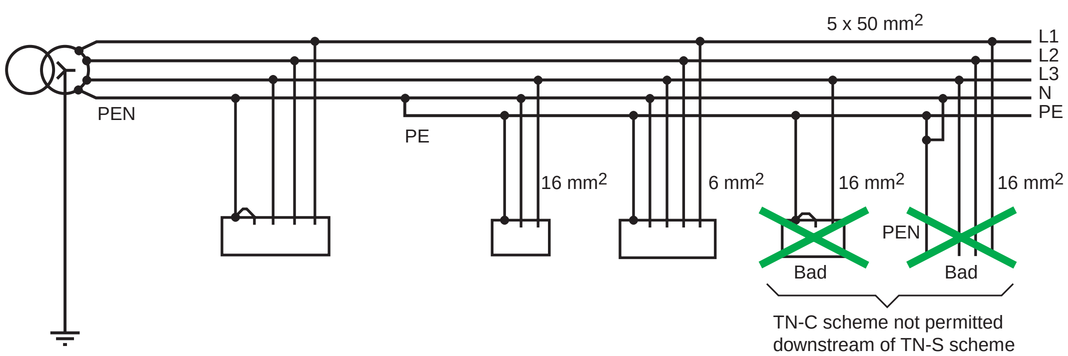


Fig. E6: TN-C-S system

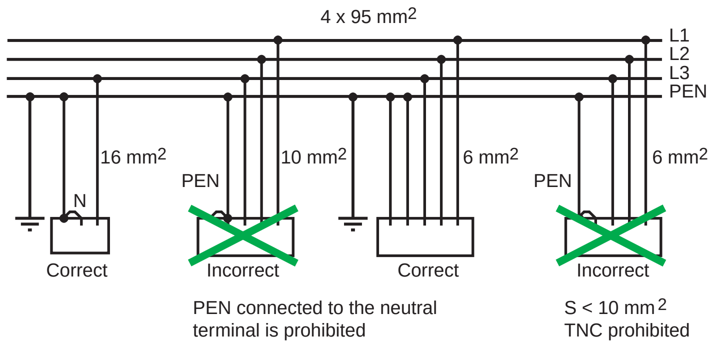


Fig. E7: Connection of the PEN conductor in the TN-C system

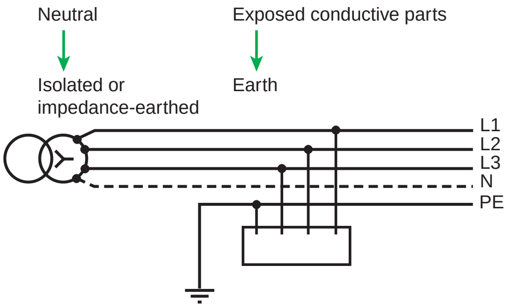


Fig. E8: IT system (isolated neutral)

IT system (isolated or impedance-earthed neutral)

IT system (isolated neutral)

No intentional connection is made between the neutral point of the supply source and earth (see **Fig. E8**).

Exposed- and extraneous-conductive-parts of the installation are connected to an earth electrode.

In practice all circuits have a leakage impedance to earth, since no insulation is perfect. In parallel with this (distributed) resistive leakage path, there is the distributed capacitive current path, the two paths together constituting the normal leakage impedance to earth (see **Fig. E9**).

Example (see **Fig. E10**)

In a LV 3-phase 3-wire system, 1 km of cable will have a leakage impedance due to C1, C2, C3 and R1, R2 and R3 equivalent to a neutral earth impedance Zct of 3000 to 4000 Ω, without counting the filtering capacitances of electronic devices.

IT system (impedance-earthed neutral)

An impedance Zs (in the order of 1000 to 2000 Ω) is connected permanently between the neutral point of the transformer LV winding and earth (see **Fig. E11**).

All exposed- and extraneous-conductive-parts are connected to an earth electrode.

The reasons for this form of power-source earthing are to fix the potential of a small network with respect to earth (Zs is small compared to the leakage impedance) and to reduce the level of overvoltages, such as transmitted surges from the MV windings, static charges, etc. with respect to earth. It has, however, the effect of slightly increasing the first-fault current level.

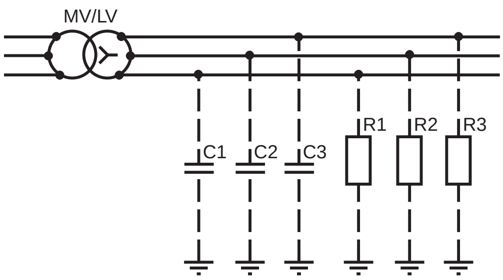


Fig. E9: IT system (isolated neutral)

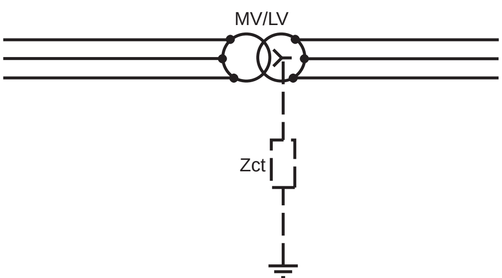


Fig. E10: Impedance equivalent to leakage impedances in an IT system

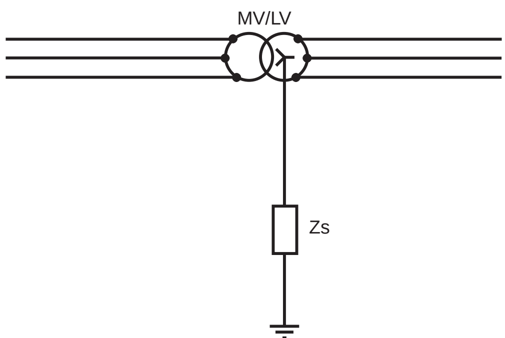


Fig. E11: IT system (impedance-earthed neutral)

1.3 Characteristics of TT, TN and IT systems

The TT system:

■ *Technique for the protection of persons: the exposed conductive parts are earthed and residual current devices (RCDs) are used*

■ *Operating technique: interruption for the first insulation fault*

TT system (see **Fig. E12**)

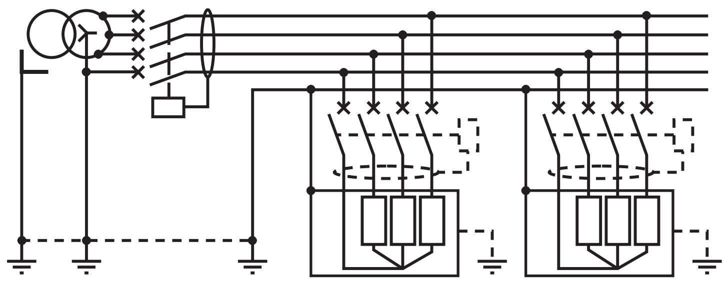


Fig. E12: TT system

Note: If the exposed conductive parts are earthed at a number of points, an RCD must be installed for each set of circuits connected to a given earth electrode.

Main characteristics

■ Simplest solution to design and install. Used in installations supplied directly by the public LV distribution network.

■ Does not require continuous monitoring during operation (a periodic check on the RCDs may be necessary).

■ Protection is ensured by special devices, the residual current devices (RCD), which also prevent the risk of fire when they are set to ⩽ 500 mA.

■ Each insulation fault results in an interruption in the supply of power, however the outage is limited to the faulty circuit by installing the RCDs in series (selective RCDs) or in parallel (circuit selection).

■ Loads or parts of the installation which, during normal operation, cause high leakage currents, require special measures to avoid nuisance tripping, i.e. supply the loads with a separation transformer or use specific RCDs (see section 5.1 in chapter F).

The TN system:

■ *Technique for the protection of persons:*
□ *Interconnection and earthing of exposed conductive parts and the neutral are mandatory*
□ *Interruption for the first fault using overcurrent protection (circuit breakers or fuses)*

■ *Operating technique: interruption for the first insulation fault*

TN system (see **Fig. E13** and **Fig. E14**)

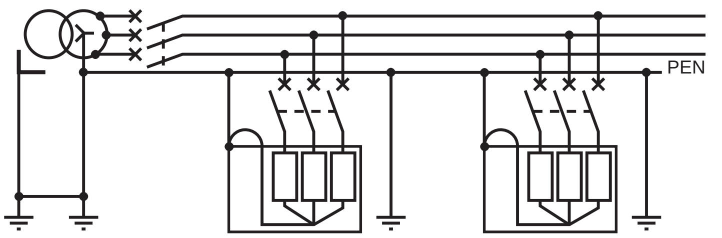


Fig. E13: TN-C system

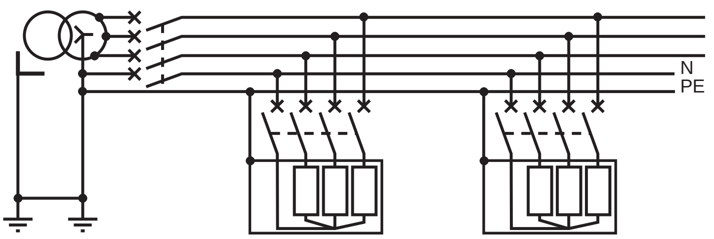


Fig. E14: TN-S system

Main characteristics

■ Generally speaking, the TN system:

□ requires the installation of earth electrodes at regular intervals throughout the installation

□ Requires that the initial check on effective tripping for the first insulation fault be carried out by calculations during the design stage, followed by mandatory measurements to confirm tripping during commissioning

□ Requires that any modification or extension be designed and carried out by a qualified electrician

□ May result, in the case of insulation faults, in greater damage to the windings of rotating machines

□ May, on premises with a risk of fire, represent a greater danger due to the higher fault currents

■ In addition, the TN-C system:

□ At first glance, would appear to be less expensive (elimination of a device pole and of a conductor)

□ Requires the use of fixed and rigid conductors

□ Is forbidden in certain cases:

- Premises with a risk of fire
- For computer equipment (presence of harmonic currents in the neutral)

■ In addition, the TN-S system:

□ May be used even with flexible conductors and small conduits

□ Due to the separation of the neutral and the protection conductor, provides a clean PE (computer systems and premises with special risks).

IT system:

■ *Protection technique:*

□ *Interconnection and earthing of exposed conductive parts*

□ *Indication of the first fault by an insulation monitoring device (IMD)*

□ *Interruption for the second fault using overcurrent protection (circuit breakers or fuses)*

■ *Operating technique:*

□ *Monitoring of the first insulation fault*

□ *Mandatory location and clearing of the fault*

□ *Interruption for two simultaneous insulation faults*

IT system (see **Fig. E15**)

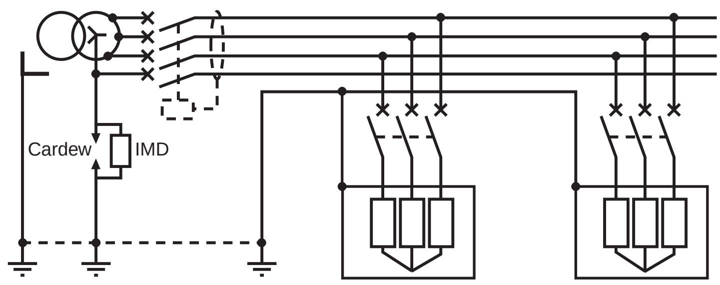


Fig. E15: IT system

Main characteristics

■ Solution offering the best continuity of service during operation

■ Indication of the first insulation fault, followed by mandatory location and clearing, ensures systematic prevention of supply outages

■ Generally used in installations supplied by a private MV/LV or LV/LV transformer

■ Requires maintenance personnel for monitoring and operation

■ Requires a high level of insulation in the network (implies breaking up the network if it is very large and the use of circuit-separation transformers to supply loads with high leakage currents)

■ The check on effective tripping for two simultaneous faults must be carried out by calculations during the design stage, followed by mandatory measurements during commissioning on each group of interconnected exposed conductive parts

■ Protection of the neutral conductor must be ensured as indicated in section 7.2 of Chapter G.

Selection does not depend on safety criteria. The three systems are equivalent in terms of protection of persons if all installation and operating rules are correctly followed. The selection criteria for the best system(s) depend on the regulatory requirements, the required continuity of service, operating conditions and the types of network and loads.

1.4 Selection criteria for the TT, TN and IT systems

In terms of the protection of persons, the three system earthing arrangements (SEA) are equivalent if all installation and operating rules are correctly followed. Consequently, selection does not depend on safety criteria.

It is by combining all requirements in terms of regulations, continuity of service, operating conditions and the types of network and loads that it is possible to determine the best system(s) (see **Fig. E16**).
Selection is determined by the following factors:
■ Above all, the applicable regulations which in some cases impose certain types of SEA
■ Secondly, the decision of the owner if supply is via a private MV/LV transformer (MV subscription) or the owner has a private energy source (or a separate-winding transformer).

If the owner effectively has a choice, the decision on the SEA is taken following discussions with the network designer (design office, contractor).
The discussions must cover:
■ First of all, the operating requirements (the required level of continuity of service) and the operating conditions (maintenance ensured by electrical personnel or not, in-house personnel or outsourced, etc.)
■ Secondly, the particular characteristics of the network and the loads (see **Fig. E17** next page).

	TT	TN-S	TN-C	IT1 (a)	IT2 (b)	Comments
Electrical characteristics						
Fault current	-	- -	- -	+	- -	Only the IT system offers virtually negligible first-fault currents
Fault voltage	-	-	-	+	-	In the IT system, the touch voltage is very low for the first fault, but is considerable for the second
Touch voltage	+/- -	-	-	+	-	In the TT system, the touch voltage is very low if system is equipotential, otherwise it is high
Protection						
Protection of persons against indirect contact	+	+	+	+	+	All SEAs (system earthing arrangement) are equivalent, if the rules are followed
Protection of persons with emergency generating sets	+	-	-	+	-	Systems where protection is ensured by RCDs are not sensitive to a change in the internal impedance of the source
Protection against fire (with an RCD)	+	+	Not allowed	+	+	All SEAs in which RCDs can be used are equivalent. The TN-C system is forbidden on premises where there is a risk of fire
Overvoltages						
Continuous overvoltage	+	+	+	-	+	A phase-to-earth overvoltage is continuous in the IT system if there is a first insulation fault
Transient overvoltage	+	-	-	+	-	Systems with high fault currents may cause transient overvoltages
Overvoltage if transformer breakdown (primary/secondary)	-	+	+	+	+	In the TT system, there is a voltage imbalance between the different earth electrodes. The other systems are interconnected to a single earth electrode
Electromagnetic compatibility						
Immunity to nearby lightning strikes	-	+	+	+	+	In the TT system, there may be voltage imbalances between the earth electrodes. In the TT system, there is a significant current loop between the two separate earth electrodes
Immunity to lightning strikes on MV lines	-	-	-	-	-	All SEAs are equivalent when a MV line takes a direct lightning strike
Continuous emission of an electromagnetic field	+	+	-	+	+	Connection of the PEN to the metal structures of the building is conducive to the continuous generation of electromagnetic fields
Transient non-equipotentiality of the PE	+	-	-	+	-	The PE is no longer equipotential if there is a high fault current
Continuity of service						
Interruption for first fault	-	-	-	+	+	Only the IT system avoids tripping for the first insulation fault
Voltage dip during insulation fault	+	-	-	+	-	The TN-S, TNC and IT (2nd fault) systems generate high fault currents which may cause phase voltage dips
Installation						
Special devices	-	+	+	-	-	The TT system requires the use of RCDs. The IT system requires the use of IMDs
Number of earth electrodes	-	+	+	-/+	-/+	The TT system requires two distinct earth electrodes. The IT system offers a choice between one or two earth electrodes
Number of cables	-	-	+	-	-	Only the TN-C system offers, in certain cases, a reduction in the number of cables
Maintenance						
Cost of repairs	-	- -	- -	-	- -	The cost of repairs depends on the damage caused by the amplitude of the fault currents
Installation damage	+	-	-	++	-	Systems causing high fault currents require a check on the installation after clearing the fault

(a) IT-net when a first fault occurs.
(b) IT-net when a second fault occurs.

Fig. E16: Comparison of system earthing arrangements

Type of network	Advised	Possible	Not advised
Very large network with high-quality earth electrodes for exposed conductive parts (10 Ω max.)		TT, TN, IT (1) or mixed	
Very large network with low-quality earth electrodes for exposed conductive parts (> 30 Ω)	TN	TN-S	IT (1) TN-C
Disturbed area (storms) (e.g. television or radio transmitter)	TN	TT	IT (2)
Network with high leakage currents (> 500 mA)	TN (4)	IT (4) TT (3) (4)	
Network with outdoor overhead lines	TT (5)	TN (5) (6)	IT (6)
Emergency standby generator set	IT	TT	TN (7)
Type of loads			
Loads sensitive to high fault currents (motors, etc.)	IT	TT	TN (8)
Loads with a low insulation level (electric furnaces, welding machines, heating elements, immersion heaters, equipment in large kitchens)	TN (9)	TT (9)	IT
Numerous phase-neutral single-phase loads (mobile, semi-fixed, portable)	TT (10) TN-S		IT (10) TN-C (10)
Loads with sizeable risks (hoists, conveyers, etc.)	TN (11)	TT (11)	IT (11)
Numerous auxiliaries (machine tools)	TN-S	TN-C IT (12 bis)	TT (12)
Miscellaneous			
Supply via star-star connected power transformer (13)	TT	IT without neutral	IT (13) with neutral
Premises with risk of fire	IT (15)	TN-S (15) TT (15)	TN-C (14)
Increase in power level of LV utility subscription, requiring a private substation	TT (16)		
Installation with frequent modifications	TT (17)		TN (18) IT (18)
Installation where the continuity of earth circuits is uncertain (work sites, old installations)	TT (19)	TN-S	TN-C IT (19)
Electronic equipment (computers, PLCs)	TN-S	TT	TN-C
Machine control-monitoring network, PLC sensors and actuators	IT (20)	TN-S, TT	

(1) When the SEA is not imposed by regulations, it is selected according to the level of operating characteristics (continuity of service that is mandatory for safety reasons or desired to enhance productivity, etc.)
Whatever the SEA, the probability of an insulation failure increases with the length of the network. It may be a good idea to break up the network, which facilitates fault location and makes it possible to implement the system advised above for each type of application.
(2) The risk of flashover on the surge limiter turns the isolated neutral into an earthed neutral. These risks are high for regions with frequent thunder storms or installations supplied by overhead lines. If the IT system is selected to ensure a higher level of continuity of service, the system designer must precisely calculate the tripping conditions for a second fault.
(3) Risk of RCD nuisance tripping.
(4) Whatever the SEA, the ideal solution is to isolate the disturbing section if it can be easily identified.
(5) Risks of phase-to-earth faults affecting equipotentiality.
(6) Insulation is uncertain due to humidity and conducting dust.
(7) The TN system is not advised due to the risk of damage to the generator in the case of an internal fault. What is more, when generator sets supply safety equipment, the system must not trip for the first fault.
(8) The phase-to-earth current may be several times higher than In, with the risk of damaging or accelerating the ageing of motor windings, or of destroying magnetic circuits.
(9) To combine continuity of service and safety, it is necessary and highly advised, whatever the SEA, to separate these loads from the rest of the installation (transformers with local neutral connection).
(10) When load equipment quality is not a design priority, there is a risk that the insulation resistance will fall rapidly. The TT system with RCDs is the best means to avoid problems.
(11) The mobility of this type of load causes frequent faults (sliding contact for bonding of exposed conductive parts) that must be countered. Whatever the SEA, it is advised to supply these circuits using transformers with a local neutral connection.
(12) Requires the use of transformers with a local TN system to avoid operating risks and nuisance tripping at the first fault (TT) or a double fault (IT).
(12 bis) With a double break in the control circuit.
(13) Excessive limitation of the phase-to-neutral current due to the high value of the zero-phase impedance (at least 4 to 5 times the direct impedance). This system must be replaced by a star-delta arrangement.
(14) The high fault currents make the TN system dangerous. The TN-C system is forbidden.
(15) Whatever the system, the RCD must be set to $\Delta n \leq 500$ mA.
(16) An installation supplied with LV energy must use the TT system. Maintaining this SEA means the least amount of modifications on the existing network (no cables to be run, no protection devices to be modified).
(17) Possible without highly competent maintenance personnel.
(18) This type of installation requires particular attention in maintaining safety. The absence of preventive measures in the TN system means highly qualified personnel are required to ensure safety over time.
(19) The risks of breaks in conductors (supply, protection) may cause the loss of equipotentiality for exposed conductive parts. A TT system or a TN-S system with 30 mA RCDs is advised and is often mandatory. The IT system may be used in very specific cases.
(20) This solution avoids nuisance tripping for unexpected earth leakage.

Fig. E17: Influence of networks and loads on the selection of system earthing arrangements

1.5 Choice of earthing method - implementation

After consulting applicable regulations, **Figures E16** and **E17** can be used as an aid in deciding on divisions and possible galvanic isolation of appropriate sections of a proposed installation.

Division of source

This technique concerns the use of several transformers instead of employing one high-rated unit. In this way, a load that is a source of network disturbances (large motors, furnaces, etc.) can be supplied by its own transformer.
The quality and continuity of supply to the whole installation are thereby improved.
The cost of switchgear is reduced (short-circuit current level is lower).
The cost-effectiveness of separate transformers must be determined on a case by case basis.

Network islands

The creation of galvanically-separated "islands" by means of LV/LV transformers makes it possible to optimise the choice of earthing methods to meet specific requirements (see **Fig. E18** and **Fig. E19**).

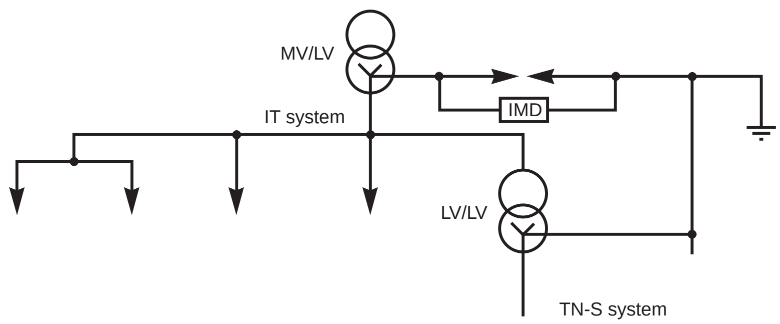


Fig. E18: TN-S island within an IT system

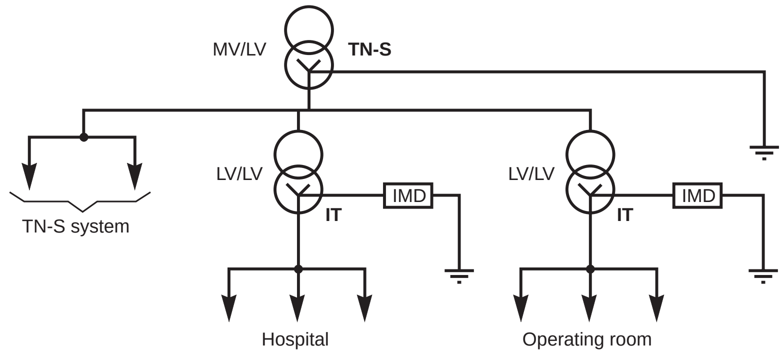


Fig. E19: IT islands within a TN-S system

Conclusion

The optimisation of the performance of the whole installation governs the choice of earthing system.

Including:

- Initial investments, and
- Future operational expenditures, hard to assess, that can arise from insufficient reliability, quality of equipment, safety, continuity of service, etc.

An ideal structure would comprise normal power supply sources, local reserve power supply sources (see section 1.4 of Chapter E) and the appropriate earthing arrangements.

A very effective method of obtaining a low-resistance earth connection is to bury a conductor in the form of a closed loop in the soil at the bottom of the excavation for building foundations.
The resistance R of such an electrode (in homogeneous soil) is given (approximately) in ohms by: $R = \frac{2\rho}{L}$ *where*
L = length of the buried conductor in metres
ρ = soil resistivity in ohm-metres

For n rods: $R = \frac{1}{n}\frac{\rho}{L}$

1.6 Installation and measurements of earth electrodes

The quality of an earth electrode (resistance as low as possible) depends essentially on two factors:

- Installation method
- Type of soil.

Installation methods

Three common types of installation will be discussed:

Buried ring (see **Fig. E20**)

This solution is strongly recommended, particularly in the case of a new building. The electrode should be buried around the perimeter of the excavation made for the foundations. It is important that the bare conductor be in intimate contact with the soil (and not placed in the gravel or aggregate hard-core, often forming a base for concrete). At least four (widely-spaced) vertically arranged conductors from the electrode should be provided for the installation connections and, where possible, any reinforcing rods in concrete work should be connected to the electrode.

The conductor forming the earth electrode, particularly when it is laid in an excavation for foundations, must be in the earth, at least 50 cm below the hard-core or aggregate base for the concrete foundation. Neither the electrode nor the vertical rising conductors to the ground floor, should ever be in contact with the foundation concrete.

For existing buildings, the electrode conductor should be buried around the outside wall of the premises to a depth of at least 1 metre. As a general rule, all vertical connections from an electrode to above-ground level should be insulated for the nominal LV voltage (600-1000 V).

The conductors may be:

- Copper: Bare cable (⩾ 25 mm^2) or multiple-strip (⩾ 25 mm^2 and ⩾ 2 mm thick)
- Aluminium with lead jacket: Cable (⩾ 35 mm^2)
- Galvanised-steel cable: Bare cable (⩾ 95 mm^2)
or multiple-strip (⩾ 100 mm^2 and ⩾ 3 mm thick).

The approximate resistance R of the electrode in ohms:

$$R = \frac{2\rho}{L}$$

where
L = length of conductor in metres
ρ = resistivity of the soil in ohm-metres (see “Influence of the type of soil” next page).

Earthing rods (see **Fig. E21**)

Vertically driven earthing rods are often used for existing buildings, and for improving (i.e. reducing the resistance of) existing earth electrodes.

The rods may be:

- Copper or (more commonly) copper-clad steel. The latter are generally 1 or 2 metres long and provided with screwed ends and sockets in order to reach considerable depths, if necessary (for instance, the water-table level in areas of high soil resistivity)
- Galvanised (see note (1) next page) steel pipe ⩾ 25 mm diameter or rod ⩾ 15 mm diameter, ⩾ 2 metres long in each case.

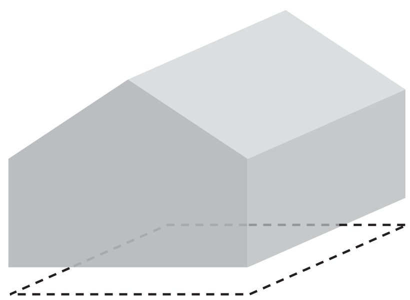


Fig. E20: Conductor buried below the level of the foundations, i.e. not in the concrete

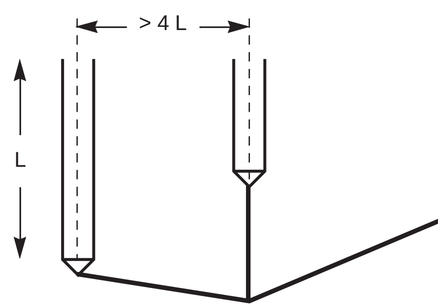


Fig. E21: Earthing rods

It is often necessary to use more than one rod, in which case the spacing between them should exceed the depth to which they are driven, by a factor of 2 to 3.

The total resistance (in homogeneous soil) is then equal to the resistance of one rod, divided by the number of rods in question. The approximate resistance R obtained is:

$R = \frac{1}{n}\frac{\rho}{L}$ if the distance separating the rods > 4 L

where
L = the length of the rod in metres
ρ = resistivity of the soil in ohm-metres (see “Influence of the type of soil” below)
n = the number of rods.

For a vertical plate electrode: $R = \frac{0.8\ \rho}{L}$

Vertical plates (see **Fig. E22**)
Rectangular plates, each side of which must be ⩾ 0.5 metres, are commonly used as earth electrodes, being buried in a vertical plane such that the centre of the plate is at least 1 metre below the surface of the soil.

The plates may be:
- Copper of 2 mm thickness
- Galvanised [(1)] steel of 3 mm thickness

The resistance R in ohms is given (approximately), by:

$R = \frac{0.8\ \rho}{L}$

L = the perimeter of the plate in metres
ρ = resistivity of the soil in ohm-metres (see “Influence of the type of soil” below).

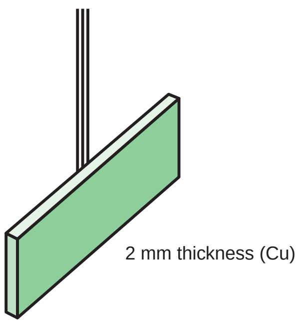


Fig. E22: Vertical plate

Influence of the type of soil

Measurements on earth electrodes in similar soils are useful to determine the resistivity value to be applied for the design of an earth-electrode system

Type of soil	Mean value of resistivity in Ωm
Swampy soil, bogs	1 - 30
Silt alluvium	20 - 100
Humus, leaf mould	10 - 150
Peat, turf	5 - 100
Soft clay	50
Marl and compacted clay	100 - 200
Jurassic marl	30 - 40
Clayey sand	50 - 500
Siliceous sand	200 - 300
Stoney ground	1500 - 3000
Grass-covered-stoney sub-soil	300 - 500
Chalky soil	100 - 300
Limestone	1000 - 5000
Fissured limestone	500 - 1000
Schist, shale	50 - 300
Mica schist	800
Granite and sandstone	1500 - 10000
Modified granite and sandstone	100 - 600

Fig. E23: Resistivity (Ωm) for different types of soil

Type of soil	Average value of resistivity in Ωm
Fertile soil, compacted damp fill	50
Arid soil, gravel, uncompacted non-uniform fill	500
Stoney soil, bare, dry sand, fissured rocks	3000

Fig. E24: Average resistivity (Ωm) values for approximate earth-elect

(1) Where galvanised conducting materials are used for earth electrodes, sacrificial cathodic protection anodes may be necessary to avoid rapid corrosion of the electrodes where the soil is aggressive. Specially prepared magnesium anodes (in a porous sack filled with a suitable “soil”) are available for direct connection to the electrodes. In such circumstances, a specialist should be consulted

Measurement and constancy of the resistance between an earth electrode and the earth

The resistance of the electrode/earth interface rarely remains constant

Among the principal factors affecting this resistance are the following:

- Humidity of the soil

The seasonal changes in the moisture content of the soil can be significant at depths of up to 2 meters.

At a depth of 1 metre the resistivity and therefore the resistance can vary by a ratio of 1 to 3 between a wet winter and a dry summer in temperate regions

- Frost

Frozen earth can increase the resistivity of the soil by several orders of magnitude. This is one reason for recommending the installation of deep electrodes, in particular in cold climates

- Ageing

The materials used for electrodes will generally deteriorate to some extent for various reasons, for example:

- Chemical reactions (in acidic or alkaline soils)
- Galvanic: due to stray DC currents in the earth, for example from electric railways, etc. or due to dissimilar metals forming primary cells. Different soils acting on sections of the same conductor can also form cathodic and anodic areas with consequent loss of surface metal from the latter areas. Unfortunately, the most favourable conditions for low earth-electrode resistance (i.e. low soil resistivity) are also those in which galvanic currents can most easily flow.

- Oxidation

Brazed and welded joints and connections are the points most sensitive to oxidation. Thorough cleaning of a newly made joint or connection and wrapping with a suitable greased-tape binding is a commonly used preventive measure.

Measurement of the earth-electrode resistance

There must always be one or more removable links to isolate an earth electrode so that it can be tested.

There must always be removable links which allow the earth electrode to be isolated from the installation, so that periodic tests of the earthing resistance can be carried out. To make such tests, two auxiliary electrodes are required, each consisting of a vertically driven rod.

- Ammeter method (see **Fig. E25**).

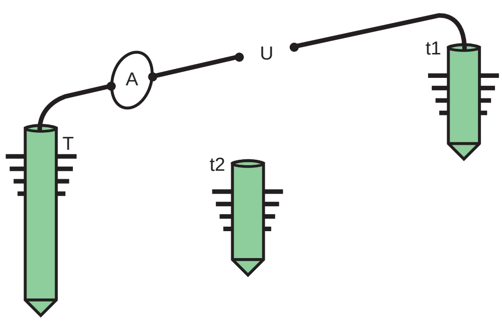


Fig. E25: Measurement of the resistance to earth of the earth electrode of an installation by means of an ammeter

$$A = R_T + R_{t1} = \frac{U_{Tt1}}{i_1}$$

$$B = R_{t1} + R_{t2} = \frac{U_{t1t2}}{i_2}$$

$$C = R_{t2} + R_T = \frac{U_{t2T}}{i_3}$$

When the source voltage U is constant (adjusted to be the same value for each test) then:

$$R_T = \frac{U}{2}\left(\frac{1}{i_1} + \frac{1}{i_3} - \frac{1}{i_2}\right)$$

1 Earthing schemes

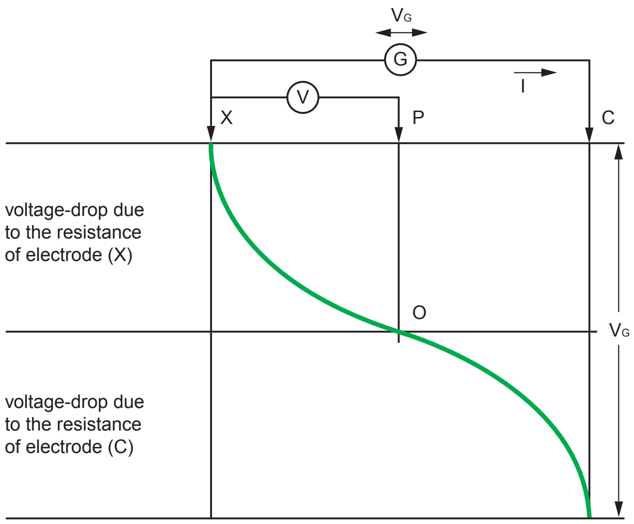
In order to avoid errors due to stray earth currents (galvanic -DC- or leakage currents from power and communication networks and so on) the test current should be AC, but at a different frequency to that of the power system or any of its harmonics. Instruments using hand-driven generators to make these measurements usually produce an AC voltage at a frequency of between 85 Hz and 135 Hz.

The distances between the electrodes are not critical and may be in different directions from the electrode being tested, according to site conditions. A number of tests at different spacings and directions are generally made to cross-check the test results.

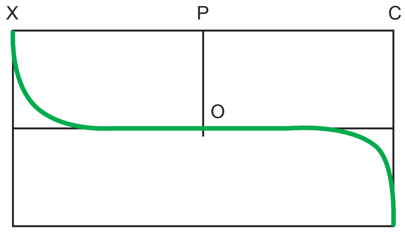
■ Use of a direct-reading earthing-resistance ohmmeter

These instruments use a hand-driven or electronic-type AC generator, together with two auxiliary electrodes, the spacing of which must be such that the zone of influence of the electrode being tested should not overlap that of the test electrode (C). The test electrode (C) furthest from the electrode (X) under test, passes a current through the earth and the electrode under test, while the second test electrode (P) picks up a voltage. This voltage, measured between (X) and (P), is due to the test current and is a measure of the contact resistance (of the electrode under test) with earth. It is clear that the distance (X) to (P) must be carefully chosen to give accurate results. If the distance (X) to (C) is increased, however, the zones of resistance of electrodes (X) and (C) become more remote, one from the other, and the curve of potential (voltage) becomes more nearly horizontal about the point (O).

In practical tests, therefore, the distance (X) to (C) is increased until readings taken with electrode (P) at three different points, i.e. at (P) and at approximately 5 metres on either side of (P), give similar values. The distance (X) to (P) is generally about 0.68 of the distance (X) to (C).



a) the principle of measurement is based on assumed homogeneous soil conditions. Where the zones of influence of electrodes C and X overlap, the location of test electrode P is difficult to determine for satisfactory results.



b) showing the effect on the potential gradient when (X) and (C) are widely spaced. The location of test electrode P is not critical and can be easily determined.

Fig. E26: Measurement of the resistance to the mass of earth of electrode (X) using an earth-electrode-testing ohmmeter

2 The installation system

Distribution switchboards, including the main LV switchboard (MLVS), are critical to the dependability of an electrical installation. They must comply with well-defined standards governing the design and construction of LV switchgear assemblies

2.1 Distribution switchboards

A distribution switchboard is the point at which an incoming-power supply divides into separate circuits, each of which is controlled and protected by the fuses or switchgear of the switchboard. A distribution switchboard is divided into a number of functional units, each comprising all the electrical and mechanical elements that contribute to the fulfilment of a given function. It represents a key link in the dependability chain.

Consequently, the type of distribution switchboard must be perfectly adapted to its application. Its design and construction must comply with applicable standards and working practises.

The distribution switchboard enclosure provides dual protection:

- Protection of switchgear, indicating instruments, relays, fusegear, etc. against mechanical impacts, vibrations and other external influences likely to interfere with operational integrity (EMI, dust, moisture, vermin, etc.)
- The protection of human life against the possibility of direct and indirect electric shock (see degree of protection IP and the IK index in section 3.3 of Chapter E).

2.1.1 Types of distribution switchboards

The load requirements dictate the type of distribution switchboard to be installed

Distribution switchboards may differ according to the kind of application and the design principle adopted (notably in the arrangement of the busbars).

Distribution switchboards according to specific applications

The principal types of distribution switchboards are:

- The main LV switchboard - MLVS - (see **Fig. E27a**)
- Motor control centres - MCC - (see **Fig. E27b**)
- Sub-distribution switchboards (see **Fig. E28**)
- Final distribution switchboards (see **Fig. E29**).

Distribution switchboards for specific applications (e.g. heating, lifts, industrial processes) can be located:

- Adjacent to the main LV switchboard, or
- Near the application concerned.

Sub-distribution and final distribution switchboards are generally distributed throughout the site.

a b

*Fig. E27: **[a]** A main LV switchboard - MLVS - (Prisma Plus P) with incoming circuits in the form of busways - **[b]** A LV motor control centre - MCC - (Okken)*

Fig. E28: A sub-distribution switchboard (Prisma Plus G)

a b c

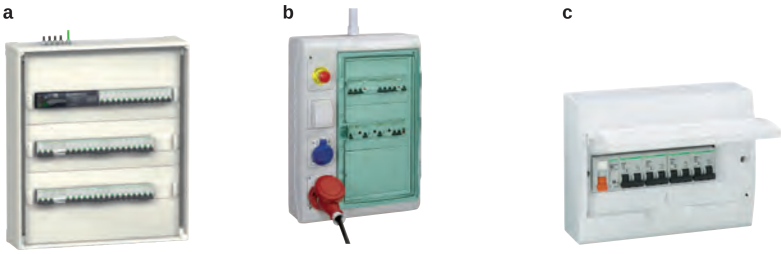


*Fig. E29: Final distribution switchboards **[a]** Prisma Plus G Pack; **[b]** Kaedra; **[c]** mini-Pragma*

A distinction is made between:
■ Traditional distribution switchboards in which switchgear and fusegear, etc. are fixed to a chassis at the rear of an enclosure
■ Functional distribution switchboards for specific applications, based on modular and standardised design.

Fig. E30: Assembly of a final distribution switchboard with fixed functional units (Prisma Plus G)

Fig. E31: Distribution switchboard with disconnectable functional units

Fig. E32: Distribution switchboard with withdrawable functional units in drawers

2.1.2 Two technologies of distribution switchboards

Traditional distribution switchboards

Switchgear and fusegear, etc. are normally located on a chassis at the rear of the enclosure. Indications and control devices (meters, lamps, pushbuttons, etc.) are mounted on the front face of the switchboard.
The placement of the components within the enclosure requires very careful study, taking into account the dimensions of each item, the connections to be made to it, and the clearances necessary to ensure safe and trouble-free operation.

Functional distribution switchboards

Generally dedicated to specific applications, these distribution switchboards are made up of functional modules that include switchgear devices together with standardised accessories for mounting and connections, ensuring a high level of reliability and a great capacity for last-minute and future changes.

■ Many advantages
The use of functional distribution switchboards has spread to all levels of LV electrical distribution, from the main LV switchboard (MLVS) to final distribution switchboards, due to their many advantages:
□ System modularity that makes it possible to integrate numerous functions in a single distribution switchboard, including protection, control, technical management and monitoring of electrical installations. Modular design also enhances distribution switchboard maintenance, operation and upgrades
□ Distribution switchboard design is fast because it simply involves adding functional modules
□ Prefabricated components can be mounted faster
□ Finally, these distribution switchboards are subjected to type tests that ensure a high degree of dependability.

The new Prisma Plus G and P ranges of functional distribution switchboards from Schneider Electric cover needs up to 3200 A and offer:
□ Flexibility and ease in building distribution switchboards
□ Certification of a distribution switchboard complying with standard IEC 61439 and the assurance of servicing under safe conditions
□ Time savings at all stages, from design to installation, operation and modifications or upgrades
□ Easy adaptation, for example to meet the specific work habits and standards in different countries
Figures E27a, **E28** and **E29** show examples of functional distribution switchboards ranging for all power ratings and **Figure E27b** shows a high-power industrial functional distribution switchboard.

■ Main types of functional units
Three basic technologies are used in functional distribution switchboards.
□ Fixed functional units (see **Fig. E30**)
These units cannot be isolated from the supply so that any intervention for maintenance, modifications and so on, requires the shutdown of the entire distribution switchboard. Plug-in or withdrawable devices can however be used to minimise shutdown times and improve the availability of the rest of the installation.
□ Disconnectable functional units (see **Fig. E31**)
Each functional unit is mounted on a removable mounting plate and provided with a means of isolation on the upstream side (busbars) and disconnecting facilities on the downstream (outgoing circuit) side. The complete unit can therefore be removed for servicing, without requiring a general shutdown.
□ Drawer-type withdrawable functional units (see **Fig. E32**)
The switchgear and associated accessories for a complete function are mounted on a drawer-type horizontally withdrawable chassis. The function is generally complex and often concerns motor control.
Isolation is possible on both the upstream and downstream sides by the complete withdrawal of the drawer, allowing fast replacement of a faulty unit without de-energising the rest of the distribution switchboard.

Compliance with applicable standards is essential in order to ensure an adequate degree of dependability

Three elements of standards IEC 61439-1 & 2 contribute significantly to dependability:
■ Clear definition of functional units
■ Forms of separation between adjacent functional units in accordance with user requirements
■ Clearly defined verification tests and routine verification

2.1.3 Standards IEC 61439

The IEC standard series 61439 ("Low-voltage switchgear and controlgear assemblies") have been developed in order to provide to the End-Users of switchboards a high level of confidence in terms of **safety** and **power availability**.

Safety aspects include:
■ Safety of people (risk of electrocution),
■ Risk of fire,
■ Risk of explosion.

Power availability is a major issue in many activity sectors, with high possible economical impact in case of long interruption consecutive to a switchboard failure.

The standards give the design and verification requirements so that no failure should be expected in case of fault, disturbance, or operation in severe environment conditions.

Compliance to the standards shall ensure that the switchboard will operate correctly not only in normal conditions, but also in difficult conditions.

Standard structure

The IEC 61439 standard series consist in one basic standard giving the general rules, and several other standards referring to different types of assemblies.

■ IEC/TR 61439-1: General rules
■ IEC 61439-2: Power switchgear and controlgear assemblies
■ IEC 61439-3: Distribution boards intended to be operated by ordinary persons (DBO)
■ IEC 61439-4: Particular requirements for assemblies for construction sites (ACS)
■ IEC 61439-5: Assemblies for power distribution in public networks
■ IEC 61439-6: Busbar trunking systems (busways)
■ IEC/TS 61439-7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations.

The first edition (IEC 61439-1 and 2) of these documents has been published in 2009, with a revision in 2011.

Major improvements with IEC61439 standard

Compared to the previous series IEC60439, several major improvements have been introduced, for the benefit of the End-User.

Requirements based on End-User expectations

The different requirements included in the standards have been introduced in order to fulfil the End-User expectations:
■ Capability to operate the electrical installation,
■ Voltage stress withstand capability,
■ Current carrying capability,
■ Short-circuit withstand capability,
■ Electro-Magnetic Compatibility,
■ Protection against electric shock,
■ Maintenance and modifying capabilities,
■ Ability to be installed on site,
■ Protection against risk of fire,
■ Protection against environmental conditions.

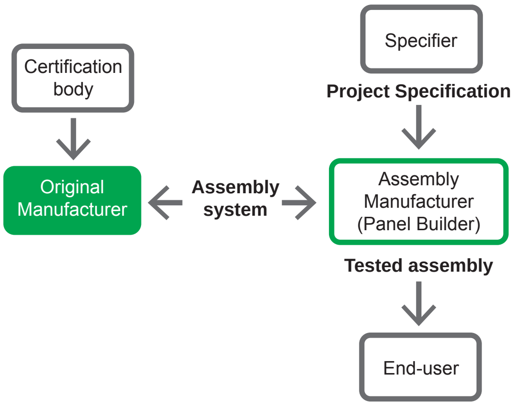


Fig. E32b: Main actors and responsibilities, as defined by the IEC 61439-1&2 standard

Clear definition of responsibilities

The role of the different actors has been clearly defined, and can be summarized by the following **Figure E32b.**

Switchboards are qualified as **Assembly**, including switching devices, control, measuring, protective, regulating equipment, with all the internal electrical and mechanical interconnections and structural parts. **Assembly systems** include mechanical and electrical components (enclosures, busbars, functional units, etc.).

The **original manufacturer** is the organization that has carried out the original design and the associated verification of an assembly in accordance with the relevant standard. He is responsible for the **Design verifications** listed by IEC 61439-2 including many electrical tests.

The verification may be supervised by a **Certification body**, providing certificates to the Original Manufacturer. These certificates can be conveyed to the **Specifier** or End-User at their request.

The **assembly manufacturer**, generally a Panel Builder, is the organization taking responsibility for the completed assembly. The assembly must be completed according to the original manufacturer's instructions. If the assembly manufacturer derivates from the instructions of the original manufacturer he has to carry out again new design verifications.
Such deviations should also be submitted to the original manufacturer for validation.

At the end of assembly, **routine verifications** must be carried out by the assembly manufacturer (Panel-builder).

The result is a fully tested assembly, for which design verifications have been carried out by the original manufacturer, and routine verifications carried out by the assembly manufacturer.

This procedure gives a better visibility to the end-user, compared to the "Partially Type Tested" and "Totally Type Tested" approach proposed by the previous IEC60439 series.

Clarifications of design verification, new or updated design requirements and routine verifications

The new IEC61439 standards also include:
- updated or new **design requirements** (example: new lifting test)
- highly clarified **design verifications** to be made, and the acceptable methods which can be used (or not) to do these verifications, for each type of requirement. **See Fig. E32c** for more details
- a more detailed list of **routine verifications**, and more severe requirements for clearances.

The following paragraphs provide details on these evolutions.

Design requirements

For an Assembly System or switchboard to be compliant with the standards, different requirements are applicable. These requirements are of 2 types:
- **Constructional** requirements
- **Performance** requirements.

See **Fig. E32c** in “design verification” paragraph for the detailed list of requirements. The design of the assembly system must follow these requirements, under the responsibility of the **original manufacturer**.

Design verification

Design verification, under the responsibility of the **original manufacturer**, is intended to verify compliance of the design of an assembly or assembly system with the requirements of this series of standards.

Design verification can be carried out by:
- **Testing**, which should be done on the most onerous variant (worst-case)
- **Calculation**, including use of appropriate safety margins
- **Comparison** with a tested reference design.

The new IEC61439 standard have clarified a lot the definition of the different verification methods, and specifies very clearly which of these 3 methods can be used for each type of design verification, as shown in **Fig. E32c.**

No.	Characteristic to be verified	Clauses or subclauses	Verification options available		
			Testing	Comparison with a reference design	Assessment
1	Strength of material and parts:	10.2			
	Resistance to corrosion	10.2.2	YES	NO	NO
	Properties of insulatingmaterials:	10.2.3			
	Thermal stability	10.2.3.1	YES	NO	NO
	Resistance to abnormal heat and fire due to internal electric effects	10.2.3.2	YES	NO	YES
	Resistance to ultra-violet (UV) radiation	10.2.4	YES	NO	YES
	Lifting	10.2.5	YES	NO	NO
	Mechanical impact	10.2.6	YES	NO	NO
	Marking	10.2.7	YES	NO	NO
2	Degree of protection of enclosures	10.3	YES	NO	YES
3	Clearances	10.4	YES	NO	NO
4	Creepage distances	10.4	YES	NO	NO
5	Protection against electric shock and integrity of protective circuits:	10.5			
	Effective continuity between the exposed conductive parts of the ASSEMBLY and the protective circuit	10.5.2	YES	NO	NO
	Short-circuit withstand strength of the protective circuit	10.5.3	YES	YES	NO
6	Incorporation of switching devices and components	10.6	NO	NO	YES
7	Internal electrical circuits and connections	10.7	NO	NO	YES
8	Terminals for external conductors	10.8	NO	NO	YES
9	Dielectric properties:	10.9			
	Power-frequency withstand voltage	10.9.2	YES	NO	NO
	Impulse withstand voltage	10.9.3	YES	NO	YES
10	Temperature-rise limits	10.10	YES	YES	YES(1)
11	Short-circuit withstand strength	10.11	YES	YES(2)	NO
12	Electromagnetic compatibility (EMC)	10.12	YES	NO	YES
13	Mechanical operation	10.13	YES	NO	NO

(1) **Verification of temperature-rise limits by assessment** (e.g. calculation) has been restricted and clarified with IEC61439 standard. As a synthesis:
- For rated current > 1600 A, NO CALCULATION, ONLY TESTS PERMITTED
- For rated current < 1600 A, CALCULATION is permitted based on IEC60890, but with a mandatory 20 % de-rating of the components.

(2) **Verification of short-circuit withstand strength by comparison with a reference design** has been clarified with IEC61439 standard. In practice, in most cases it is mandatory to do this verification by testing (type-testing), and in any case **the comparison with a reference design is only possible for short-circuit protection devices of the same manufacturer**, and provided that all other elements of a very strict comparison checklist are verified (Table 13 – "Short-circuit verification by comparison with a reference design: check list" of IEC61439-1).

***Fig. E32c**: List of design verifications to be performed, and verification options available (table D.1 of Annex D of IEC61439-1)*

Routine verification

Routine verification is intended to detect faults in materials and workmanship and to ascertain proper functioning of the manufactured assemblies. It is under the responsibility of the **Assembly Manufacturer** or **Panel Builder**. Routine verification is performed on each manufactured assembly or assembly system.

Check to be carried out:

Routine verification	Visual inspection	Tests
Degree of protection of enclosures	■	
Clearances	■	- if D < minimum clearance: verification by an impulse voltage withstand test - if not evident by visual inspection to be larger than the minimum clearance (e.g. if D < 1.5 times minimum clearance), verification shall be by physical measurement or by an impulse voltage withstand test
Creepage distances	■	or measurement if visual inspection not applicable
Protection against electric shock and integrity of protective circuits	■	random verification of tightness of the connections of protective circuit
Incorporation of built-in components	■	
Internal electrical circuits and connections	■	or random verification of tightness
Terminals for external conductors		number, type and identification of terminals
Mechanical operation	■	effectiveness of mechanical actuating elements locks and interlocks, including those associated with removable parts
Dielectric properties		power-frequency dielectric test or verification of insulating resistance (from 250 A)
Wiring, operational performance and function	■	verification of completeness of information & markings, inspection of wiring and function test where relevant

Fig. E32d: List of routine verifications to be performed

A precise approach

The new IEC 61439 series introduces a precise approach, intended to give to switchboards the right level of quality and performance expected by End-Users.

Detailed design requirements are given, and a clear verification process is proposed, which differentiates design verification and routine verification.

Responsibilities are clearly defined between the original manufacturer, responsible for the design, and assembly manufacturer, responsible for assembly and delivery to the End-User.

Functional units

The same standard defines functional units:

■ Part of an assembly comprising all the electrical and mechanical elements that contribute to the fulfilment of the same function

■ The distribution switchboard includes an incoming functional unit and one or more functional units for outgoing circuits, depending on the operating requirements of the installation.

What is more, distribution switchboard technologies use functional units that may be fixed, disconnectable or withdrawable (see section 4.2 of Chapter D & **Fig. E30**, **E31**, **E32**).

Forms (see Fig. E33)

Separation of functional units within the assembly is provided by forms that are specified for different types of operation.

The various forms are numbered from 1 to 4 with variations labelled “a” or “b”. Each step up (from 1 to 4) is cumulative, i.e. a form with a higher number includes the characteristics of forms with lower numbers. The standard distinguishes:

■ Form 1: No separation

■ Form 2: Separation of busbars from the functional units

■ Form 3: Separation of busbars from the functional units and separation of all functional units, one from another, except at their output terminals

■ Form 4: As for Form 3, but including separation of the outgoing terminals of all functional units, one from another.

The decision on which form to implement results from an agreement between the manufacturer and the user.
The Prima Plus functional range offers solutions for forms 1, 2b, 3b, 4a, 4b.

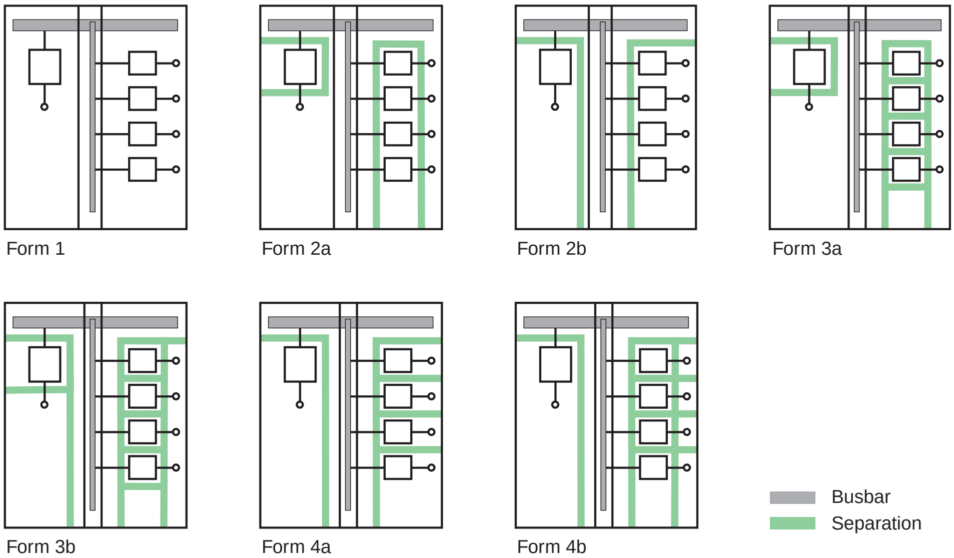


Fig. E33: Representation of different forms of LV functional distribution switchboards

Beyond the standard

In spite of the improvement provided by this new standard series, there are still some limitations. In particular, for an Assembly manufacturer or Panel Builder combining equipment and devices from different sources (manufacturers), the design verification cannot be complete. All the different combinations of equipment from different sources cannot be tested at the design stage. With this approach, the compliance with the standard cannot be obtained in all particular configurations. Compliance is limited to a reduced number of configurations.

In this situation, End-users are encouraged to ask for test certificates corresponding to their particular configuration, and not only valid for generic configurations.

On the other hand, IEC 61439 sets strict limitation to the device substitution by a device from another series, for temperature rise and short-circuit withstand verification in particular. Only substitution of devices of the same make and series, i.e. same manufacturer and with the same or better limitation characteristics (I^2t, Ipk), can guarantee that the level of performance is maintained. As a consequence, substitution by another device not of same manufacturer can only be verified by testing (e.g. “type-testing) to comply to IEC61439 standard and guarantee the safety of the Assembly.

By contrast, in addition to the requirements given by the IEC 61439 series, a **full system** approach as proposed by a manufacturer like Schneider Electric provides a maximum level of confidence. All the different parts of the assembly are provided by the Original Manufacturer. Not only generic combinations are tested, but all the possible combinations permitted by the Assembly design are tested and verified.

The high level of performance is obtained through **Protection Coordination**, where the combined operation of protective and switching devices with internal electrical and mechanical interconnections and structural parts is guaranteed. All these devices have been consistently designed with this objective in mind. All the relevant device combinations are tested. There is less risk left compared with assessment through calculations or based only on catalogued data. (Protection coordination is further explained in chapter H of this Guide.).

Only the full system approach can provide the necessary peace of mind to the End-user, whatever the possible disturbance in his electrical installation.

Total accessibility of electrical information and intelligent distribution switchboards are now a reality

2.1.4 Remote monitoring and control of the electrical installation

Remote monitoring and control are no longer limited to large installations.
These functions are increasingly used and provide considerable cost savings.
The main potential advantages are:

- Reductions in energy bills
- Reductions in structural costs to maintain the installation in running order
- Better use of the investment, notably concerning optimisation of the installation life cycle
- Greater satisfaction for energy users (in a building or in process industries) due to improved power availability and/or quality.

The above possibilities are all the more an option given the current deregulation of the electrical-energy sector.

Modbus is increasingly used as the open standard for communication within the distribution switchboard and between the distribution switchboard and customer power monitoring and control applications. Modbus exists in two forms, twisted pair (RS 485) and Ethernet-TCP/IP (IEEE 802.3).

The www.modbus.org site presents all bus specifications and constantly updates the list of products and companies using the open industrial standard.

The use of web technologies has largely contributed to wider use by drastically reducing the cost of accessing these functions through the use of an interface that is now universal (web pages) and a degree of openness and upgradeability that simply did not exist just a few years ago.

Two types of distribution are possible:
- *By insulated wires and cables*
- *By busbar trunking (busways)*

2.2 Cables and busways

Distribution by insulated conductors and cables

Definitions

- Conductor

A conductor comprises a single metallic core with or without an insulating envelope.

- Cable

A cable is made up of a number of conductors, electrically separated, but joined mechanically, generally enclosed in a protective flexible sheath.

- Cableway

The term cableway refers to conductors and/or cables together with the means of support and protection, etc. for example : cable trays, ladders, ducts, trenches, and so on… are all "cableways".

Conductor marking

Conductor identification must always respect the following three rules:

- Rule 1

The double colour green and yellow is strictly reserved for the PE and PEN protection conductors

- Rule 2

□ When a circuit comprises a neutral conductor, it must be light blue or marked "1" for cables with more than five conductors
□ When a circuit does not have a neutral conductor, the light blue conductor may be used as a phase conductor if it is part of a cable with more than one conductor

- Rule 3

Phase conductors may be any colour except:
□ Green and yellow
□ Green
□ Yellow
□ Light blue (see rule 2).

Conductors in a cable are identified either by their colour or by numbers (see **Fig. E34**).

Number of conductors in circuit	Circuit	Fixed cableways									
		Insulated conductors					Rigid and flexible multi-conductor cables				
		Ph	Ph	Pn	N	PE	Ph	Ph	Ph	N	PE
1	Protection or earth					G/Y					
2	Single-phase between phases	■	■				BL	LB			
	Single-phase between phase and neutral	■			LB		BL			LB	
	Single-phase between phase and neutral + protection conductor	■			G/Y		BL			G/Y	
3	Three-phase without neutral	■	■	■			BL	B	LB		
	2 phases + neutral	■	■		LB		BL	B		LB	
	2 phases + protection conductor	■	■			G/Y	BL	LB			G/Y
	Single-phase between phase and neutral + protection conductor	■			LB	G/Y	BL			LB	G/Y
4	Three-phase with neutral	■	■	■	LB		BL	B	BL	LB	
	Three-phase with neutral + protection conductor	■	■	■		G/Y	BL	B	LB		G/Y
	2 phases + neutral + protection conductor	■	■		LB	G/Y	BL	B		LB	G/Y
	Three-phase with PEN conductor	■	■	■	G/Y		BL	B	LB	G/Y	
5	Three-phase + neutral + protection conductor	■	■	■	LB	G/Y	BL	B	BL	LB	G/Y
> 5		Protection conductor: G/Y - Other conductors: BL: with numbering The number "1" is reserved for the neutral conductor if it exists									

G/Y: Green and yellow BL: Black ■: As indicated in rule 3 LB: Light blue B: Brown

Fig. E34: Conductor identification according to the type of circuit

Note: If the circuit includes a protection conductor and if the available cable does not have a green and yellow conductor, the protection conductor may be:
- A separate green and yellow conductor
- The blue conductor if the circuit does not have a neutral conductor
- A black conductor if the circuit has a neutral conductor.

In the last two cases, the conductor used must be marked by green and yellow bands or markings at the ends and on all visible lengths of the conductor.

Equipment power cords are marked similar to multi-conductor cables (see **Fig. E35**).

Distribution and installation methods (see **Fig. E36**)

Distribution takes place via cableways that carry single insulated conductors or cables and include a fixing system and mechanical protection.

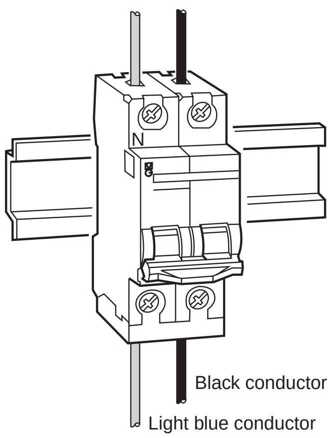


Fig. E35: Conductor identification on a circuit breaker with a phase and a neutral

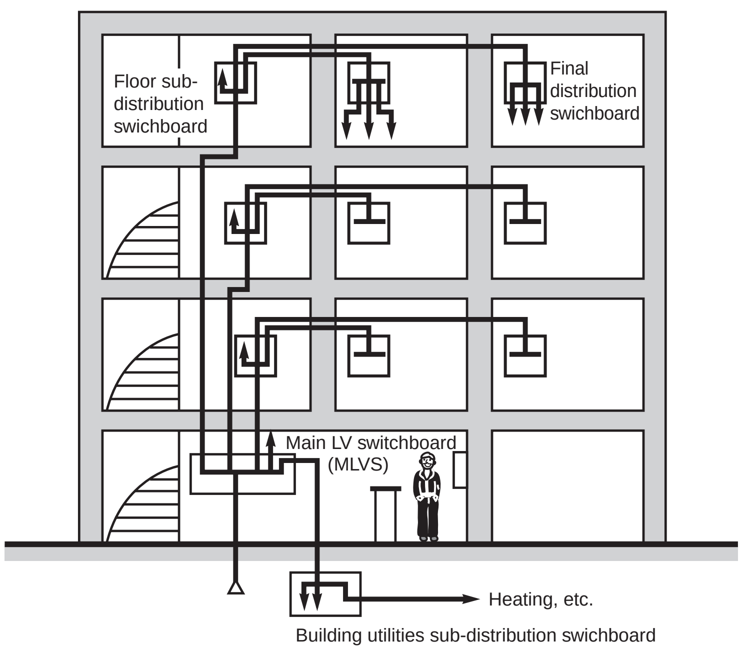


Fig. E36: Radial distribution using cables in a hotel

Busways, also referred to as busbar trunking systems, stand out for their ease of installation, flexibility and number of possible connection points

Busbar trunking (busways)

Busbar trunking is intended to distribute power (from 20 A to 5000 A) and lighting (in this application, the busbar trunking may play a dual role of supplying electrical power and physically holding the lights).

Busbar trunking system components

A **busbar trunking** system comprises a set of conductors protected by an enclosure (see **Fig. E37**). Used for the transmission and distribution of electrical power, busbar trunking systems have all the necessary features for fitting: connectors, straights, angles, fixings, etc. The tap-off points placed at regular intervals make power available at every point in the installation.

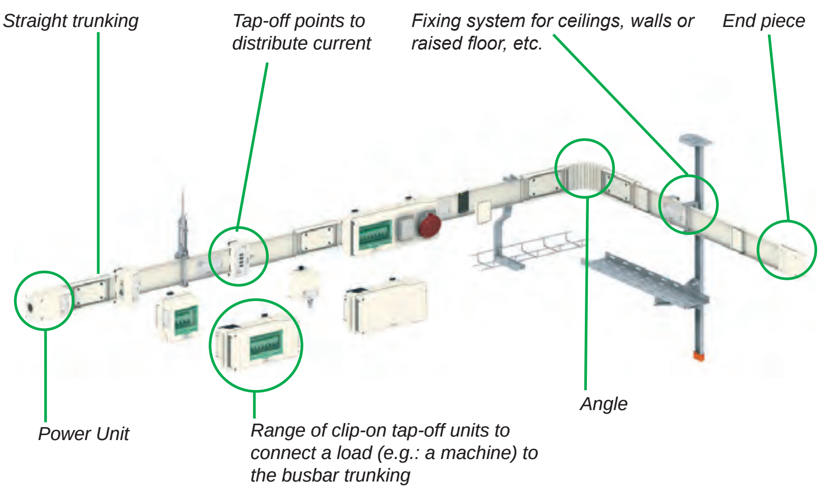


Fig. E37: Busbar trunking system design for distribution of currents from 25 to 4000 A

The various types of busbar trunking:

Busbar trunking systems are present at every level in electrical distribution: from the link between the transformer and the low voltage switch switchboard (MLVS) to the distribution of power sockets and lighting to offices, or power distribution to workshops.

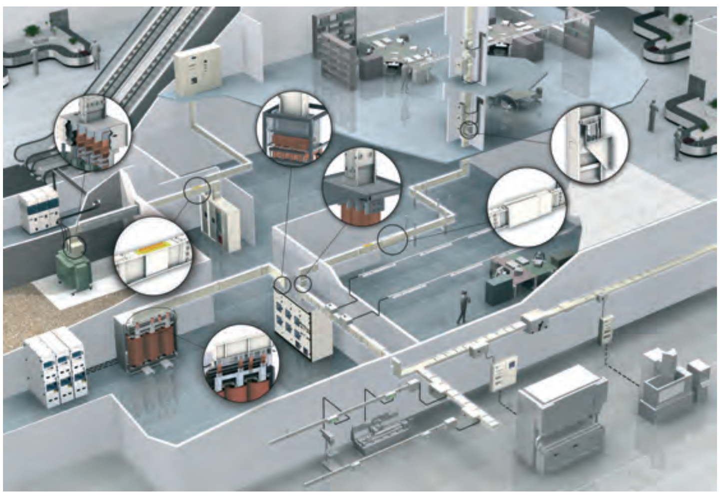


Fig. E38: Radial distribution using busways

We talk about a distributed network architecture.

There are essentially three categories of busways.

■ Transformer to MLVS busbar trunking

Installation of the busway may be considered as permanent and will most likely never be modified. There are no tap-off points.

Frequently used for short runs, it is almost always used for ratings above 1600 / 2000 A, i.e. when the use of parallel cables makes installation impossible. Busways are also used between the MLVS and downstream distribution switchboards.

The characteristics of main-distribution busways authorize operational currents from 1000 to 5000 A and short-circuit withstands up to 150 kA.

■ Sub-distribution busbar trunking with low or high tap-off densities

Downstream of main-distribution busbar trunking, two types of applications must be supplied:

□ Mid-sized premises (industrial workshops with injection presses and metalwork machines or large supermarkets with heavy loads). The short-circuit and currentlevels can be fairly high (respectively 20 to 70 kA and 100 to 1000 A)

□ Small sites (workshops with machine-tools, textile factories with small machines, supermarkets with small loads). The short-circuit and current levels are lower (respectively 10 to 40 kA and 40 to 400 A)

Sub-distribution using busbar trunking meets user needs in terms of:

□ Modifications and upgrades given the high number of tap-off points

□ Dependability and continuity of service because tap-off units can be connected under energized conditions in complete safety.

The sub-distribution concept is also valid for vertical distribution in the form of 100 to 5000 A risers in tall buildings.

■ Lighting distribution busbar trunking

Lighting circuits can be distributed using two types of busbar trunking according to whether the lighting fixtures are suspended from the busbar trunking or not.

□ busbar trunking designed for the suspension of lighting fixtures

These busways supply and support light fixtures (industrial reflectors, discharge lamps, etc.). They are used in industrial buildings, supermarkets, department stores and warehouses. The busbar trunkings are very rigid and are designed for one or two 25 A or 40 A circuits. They have tap-off outlets every 0.5 to 1 m.

□ busbar trunking not designed for the suspension of lighting fixtures

Similar to prefabricated cable systems, these busways are used to supply all types of lighting fixtures secured to the building structure. They are used in commercial buildings (offices, shops, restaurants, hotels, etc.), especially in false ceilings. The busbar trunking is flexible and designed for one 20 A circuit. It has tap-off outlets every 1.2 m to 3 m.

Busbar trunking systems are suited to the requirements of a large number of buildings.

■ Industrial buildings: garages, workshops, farm buildings, logistic centers, etc.

■ Commercial areas: stores, shopping malls, supermarkets, hotels, etc.

■ Tertiary buildings: offices, schools, hospitals, sports rooms, cruise liners, etc.

Standards

Busbar trunking systems must meet all rules stated in IEC 61439-6.

This defines the manufacturing arrangements to be complied with in the design of busbar trunking systems (e.g.: temperature rise characteristics, short-circuit withstand, mechanical strength, etc.) as well as test methods to check them.

The new standard IEC61439-6 describes in particular the design verifications and routine verifications required to ensure compliance.

By assembling the system components on the site according to the assembly instructions, the contractor benefits from conformity with the standard.

The advantages of busbar trunking systems

Flexibility

■ Easy to change configuration (on-site modification to change production line configuration or extend production areas).

■ Reusing components (components are kept intact): when an installation is subject to major modifications, the busbar trunking is easy to dismantle and reuse.

■ Power availability throughout the installation (possibility of having a tap-off point every meter).

■ Wide choice of tap-off units.

Simplicity

■ Design can be carried out independently from the distribution and layout of current consumers.
■ Performances are independent of implementation: the use of cables requires a lot of derating coefficients.
■ Clear distribution layout
■ Reduction of fitting time: the trunking system allows fitting times to be reduced by up to 50 % compared with a traditional cable installation.
■ Manufacturer’s guarantee.
■ Controlled execution times: the trunking system concept guarantees that there are no unexpected surprises when fitting. The fitting time is clearly known in advance and a quick solution can be provided to any problems on site with this adaptable and scalable equipment.
■ Easy to implement: modular components that are easy to handle, simple and quick to connect.

Dependability

■ Reliability guaranteed by being factory-built
■ Fool-proof units
■ Sequential assembly of straight components and tap-off units making it impossible to make any mistakes

Continuity of service

■ The large number of tap-off points makes it easy to supply power to any new current consumer. Connecting and disconnecting is quick and can be carried out in complete safety even when energized. These two operations (adding or modifying) take place without having to stop operations.
■ Quick and easy fault location since current consumers are near to the line
■ Maintenance is non existent or greatly reduced.

Major contribution to sustainable development

■ Busbar trunking systems allow circuits to be combined. Compared with a traditional cable distribution system, consumption of raw materials for insulators is divided by 4 due to the busbar trunking distributed network concept (see **Fig. E39**).
■ Reusable device and all of its components are fully recyclable.
■ Does not contain PVC and does not generate toxic gases or waste.
■ Reduction of risks due to exposure to electromagnetic fields.

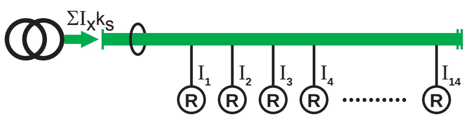
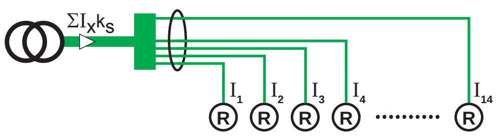
Distribution type	Insulation material	Power losses along life cycle
Decentralized		
 ks: diversity factor = 0.6	23 kg	1 600 Joules
Centralized		
 ks: diversity factor = 0.6	90 kg	2 000 Joules

Fig. E39: Example of a set of 14 x 25A loads distributed along 34 meters (for busway, Canalis KS 250A)

New functional features for Canalis

Busbar trunking systems are getting even better. Among the new features we can mention:
■ Increased performance with a IP55 protection index and new ratings of 160 A through to 1000 A (Ks).
■ New lighting offers with pre-cabled lights and new light ducts.
■ New fixing accessories. Quick fixing system, cable ducts, shared support with “VDI” (voice, data, images) circuits.

Busbar trunking systems are perfectly integrated with the environment:

- white color to enhance the working environment, naturally integrated in a range of electrical distribution products.
- conformity with European regulations on reducing hazardous materials (RoHS).

Examples of Canalis busbar trunking systems

Fig. E41: Rigid busbar trunking able to support light fittings: Canalis KBA or KBB (25 and 40 A)

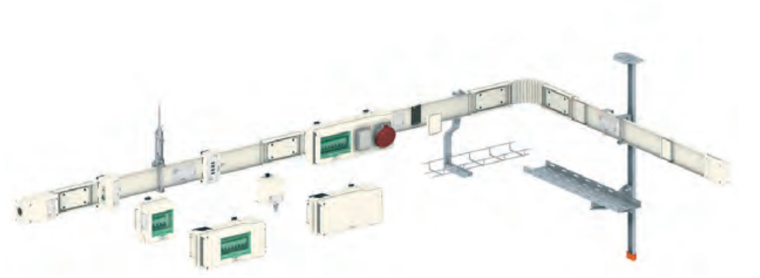


Fig. E43: A busway for medium power distribution: Canalis KN (40 up to 160 A)

Fig. E44: A busway for medium power distribution: Canalis KS (100 up to 1000 A)

Fig. E45: A busway for high power distribution: Canalis KT (800 up to 5000 A)

2.3 Harmonic currents in the selection of busbar trunking systems (busways)

2.3.1 Introduction

Harmonic current is generated by most modern electronic loads, which can be found in all sectors of Industrial, Commercial, and domestic facilities. These electronic loads use power electronic devices which are responsible for generating harmonic currents. Common non-linear loads:

- Industrial equipment (Soldering machines, Induction furnaces, bridge rectifiers and battery chargers)
- **V**ariable **S**peed **D**rives (VSDs) with AC or DC motors
- **U**ninterruptible **P**ower **S**upplies (UPS)
- Information Technology Equipment (computers, monitors, servers, copiers, printers, etc.)
- Domestic equipment (TV sets, microwave ovens, fluorescent lamps, light dimmers, etc.).

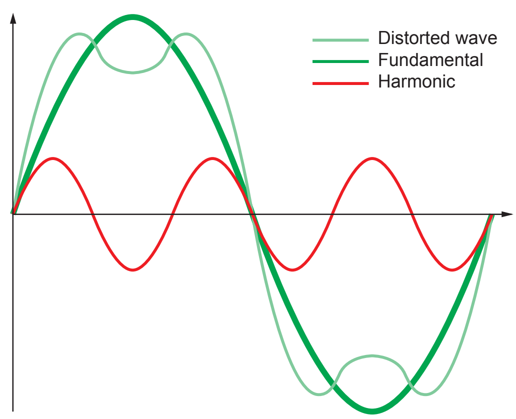


Fig. E46: Appearance of a distorted current waveform due to harmonics

Today's electronic loads share a common element: electronic power supplies. The benefits of the electronic power supply are its cost, efficiency and the ability to control its output. For this reason, they are found in a wide variety of common single and three-phase electrical equipment. Harmonic currents are a natural by-product of the manner in which electronic power supplies draw current. In order to be more efficient, these devices draw current for only a small portion of the electrical cycle.
Installations where these devices can be found in great number are computer centers, banks, Internet Data Centers etc.

Harmonic currents generated by these loads present some problems:

- Voltage distortion responsible for failure of some types of electrical equipment
- Increased losses, the rms current being higher than the fundamental design current
- Risk of resonance when power factor correction capacitors are present.

Third harmonic currents (150/180 Hz) or multiple of 3 (triple-n harmonics) are specifically responsible for increased neutral currents in three-phase, four-wire systems.
That the reason why it's important to select optimum busbar design for office buildings, where neutral conductor overload is a major concern.

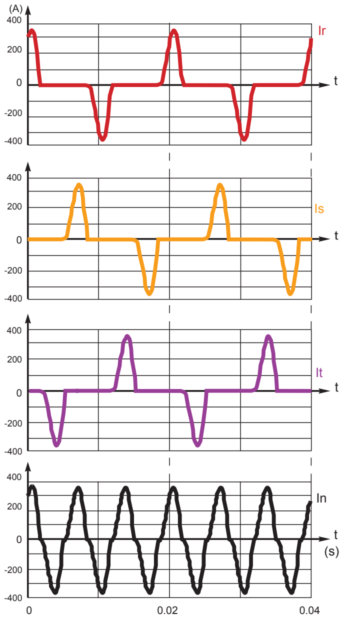


Fig. E47: Line and neutral currents absorbed by single-phase non-linear loads connected between phase and neutral.

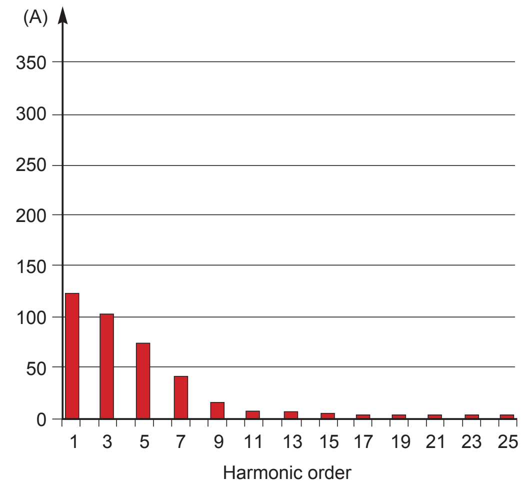


Fig. E49: Typical harmonic phase current spectrum for single-phase non-linear loads

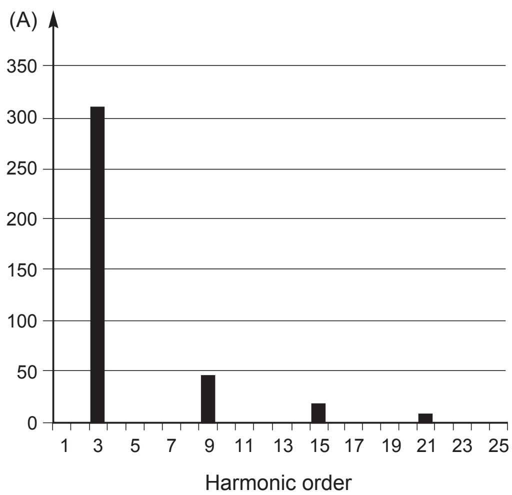


Fig. E50: Typical harmonic neutral current spectrum for single-phase non-linear loads

2.3.2 Neutral current in three-phase, four-wire systems

Figure E47 represents the non-linear phase currents and resulting non-linear neutral current, in a three-phase, four-wire system, supplying identical single phase loads.

Workshops supply:
- Mix polluting charges and clean charges (computer hardware, inverters, fluorescent lighting and motors, pumps, heaters, etc.).
- Little probability of harmonic's presence

THD < 33 %

Offices supply:
- A lot of polluting charges (computer hardware, inverters, fluorescent lighting, etc.).
- Strong probability of harmonic's presence

THD ⩾ 33 %

Fig. E48: Examples of applications where the level of harmonics (THD) is either negligible or high, depending on the proportion of loads generating harmonics versus classical loads.

The harmonic spectra of the phase and neutral currents are represented in **Figure E49** and **Figure E50**. It can be seen that the neutral current only includes third or triple-n harmonics (i.e. 3, 9, 15, etc). The amplitude of these currents are equal to three times the amplitude of the phase currents. In the neutral current measurements, third harmonic has the greatest magnitude and the other triple-n's (9, 15, 21, etc.) decrease significantly in magnitude so do not contribute significantly to the rms value.

In this example, the rms value of the neutral current is equal to 1.732 (√3) times the rms value of the line current. This theoretical value is only obtained with loads absorbing a current similar to the one represented on **Figure E47**.

When the loads include partially linear circuits (such as motors, heating devices, incandescent lamps), the rms value of the neutral current is strictly less than √3 times the rms value of the phase currents.

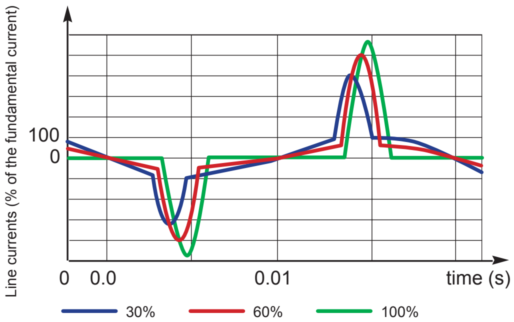


Fig. E51: Line current for different ratios of non-linear load

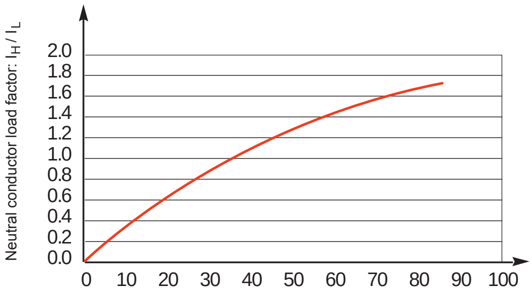


Fig. E52: Neutral conductor load factor as a function of the 3rd harmonic level.

2.3.3 Load factor of the neutral conductor

Simulations have been carried out to assess the influence of the 3rd harmonic level on the neutral conductor current. **Figure E51** represents different line current waveforms for different amounts of non-linear load. The same active power was maintained (linear loads are assumed purely resistive).

The neutral current is then calculated and compared to the line current for different levels of third harmonic. The load factor of the neutral conductor (ratio of the neutral current to the line current) is represented in **Figure E52**.

In installations where there are a large number of single-phase electronic non-linear loads connected to the same neutral, a high load factor can be found in that neutral.

In these installations the neutral current may exceed the phase current and a special attention must be given to sizing the neutral conductor. This prevents the installation of a reduced size neutral conductor, and the current in all four wires should be taken into account.

The diversified power absorbed by such a group of loads is generally limited, and even if the neutral current exceeds the line current, then the neutral conductor capacity is only exceeded in extreme circumstances if its size is equal to the line conductor's.

A common practice in these conditions is to use a 200 % neutral conductor. This does not form part of the electrical/ building regulations, but is encouraged by organizations such as the Copper Development Association.

In high power installations (>100 kVA or >150 A), various factors contribute to reduce the neutral conductor load factor:

- More and more high quality IT equipment (work stations, servers, routers, PC, UPS, etc.) include Power Factor Correction circuits, reducing considerably the generation of 3rd harmonic currents

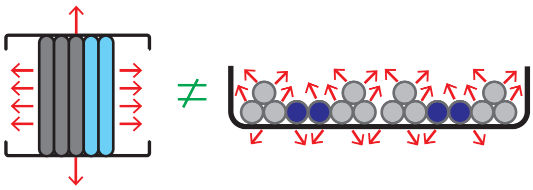


Fig. E53: Double-neutral installation for cable solution is not directly applicable for busway solution, due to their very different thermal dissipation behaviour.

- HVAC equipment in large buildings are supplied by a three-phase network, and as such do not produce triple-n harmonic currents
- Fluorescent lighting equipment (with magnetic or electronic ballast) generates triple-n harmonic currents which are phase shifted with harmonic currents generated by PCs, giving a partial vector cancellation.

Except in exceptional circumstances, the 3rd harmonic level in these installations does not exceed 33 %, so the neutral current does not exceed the line currents. It is not therefore necessary to use an oversized neutral conductor.

2.3.4 Effects of harmonic currents on circuit conductors

The circulation of harmonic currents produces additional heating within the conductors for several reasons:

- Heat is produced as a result of the additional high levels of triple-n harmonic currents, compared with the relatively minimal current flowing in the neutral for normal balanced linear loads.
- Additional heating of all conductors by increase of the skin effect and eddy current losses due to the circulation of all harmonic orders.

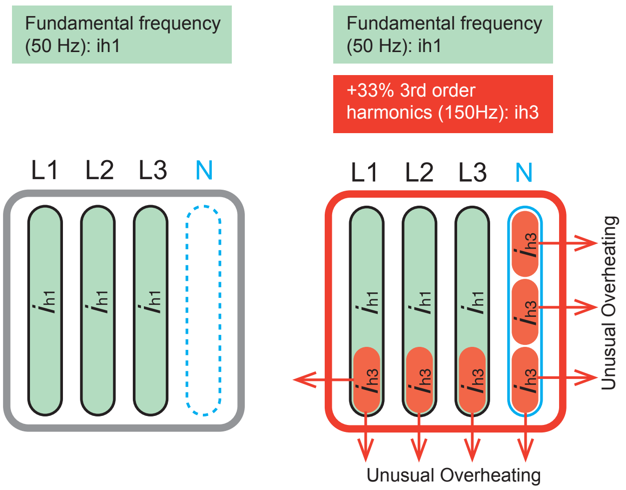


Fig. E54: Illustration of the overheating risk with standard busway sizing in presence of high level of 3rd harmonics

Modeling separately the power losses created by each harmonic order reveals the impact of harmonic currents in busbar trunking systems. Heat measurements performed on busbar trunking systems with circulation of harmonic currents of different frequencies has been also been considered.

The same approach has been used to compare two different type of busbar construction both with the same total cross sectional area (c.s.a.) of active conductors, a 200 % neutral and a standard 100 % neutral. This can be seen in **Figure E55**.

Placed in the same conditions, a busbar trunking system with 4 identical conductors will have a lower temperature rise than a 200 % busbar with the same total c.s.a. It is then perfectly adapted to this situation. Of course, the selection of the size of the conductors must take the possible current flowing through the neutral conductor into account.

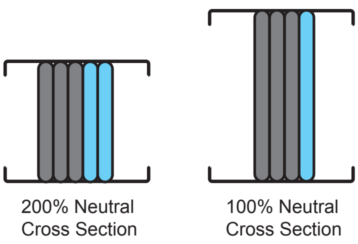


Fig. E55: Cross section architecture of 2 different busbar systems

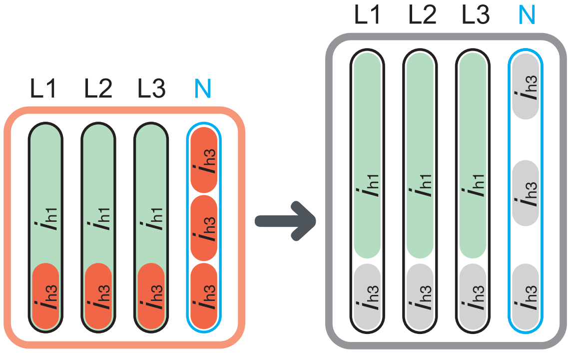


Fig. E56: The most effective solution = reduce the current density in ALL conductors, by selecting proper busway rating (single-neutral)

2.3.5 Simplified selection procedure

The first step in the selection procedure for busbar trunking systems is to assess the phase currents and 3rd harmonic current level.

Note: the 3rd harmonic current level has an impact on the neutral current, and consequently on the rating of all components in the installation:

- Switchboard,
- Protection and dispatching switchgear,
- Cables and busbar trunking systems.

Depending on the estimated 3rd harmonic level, 3 cases are possible:

A) 3rd harmonic level below 15 % (ih3 ≤ 15 %):

The neutral conductor is considered as not loaded. The size of the phase conductors is only dependant on the phase currents. According to IEC rules, the neutral conductor size may be smaller than the phase conductors', if the cross section area is higher than 16 mm² for copper, or 25 mm² for aluminum.

B) 3rd harmonic level between 15 and 33 % (15 < ih3 ≤ 33 %)
The neutral conductor is considered as current-carrying conductor.
The practical current shall be reduced by a factor equal to 84 % (or inversely, select a busbar with a practical current equal to the phase current divided by 0.84. Generally, this leads to the selection of a busbar trunking system, which the current rating is immediately superior to the requested capacity.
The size of the neutral conductor shall be equal to that of the phases.

C) 3rd harmonic level higher than 33 % (ih > 33 %)

The neutral conductor is considered as a current-carrying conductor.
The recommended approach is to adopt circuit conductors with equal size for phase and neutral. The neutral current is predominant in the selection of the size of conductor.
Generally, this leads to the selection of a busbar trunking system which current rating is higher than the requested capacity (generally by a factor of two).

Example for KT Schneider-Electric offer:

Rating (A)	No harmonic	Usual harmonic level	Very high level
1000	KTC1000	KTC1000HRB	KTC1350HRB
1350	KTC1350	KTC1350HRB	KTC1600HRB
1600	KTC1600	KTC1600HRB	KTC2000HRB
2000	KTC2000	KTC2000HRB	KTC2500HRB
2500	KTC2500	KTC2500HRB	KTC3200HRB
3200	KTC3200	KTC3200HRB	KTC4000HRB
4000	KTC4000	KTC4000HRB	
5000	KTC5000		

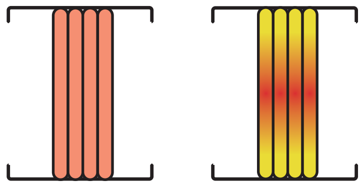


Fig. E57: Cross sectional view of a standard busway without and with harmonics

2.3.6 Conclusions

Office buildings are often subject to the circulation of high levels of triple-n harmonics in particular 3rd harmonic current. These are responsible for possible overload of the neutral conductor.

The performance of standard construction busbar trunking system with circulation of harmonic currents has been analyzed in depth.
A simplified procedure has been proposed for selection of busbar trunking systems adapted to the circulation of harmonic currents, and particularly in the neutral conductor.

A 200 % neutral conductor is not the optimum solution.

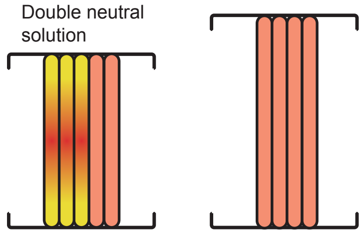
Busbar trunking systems with equal size for all conductors are perfectly adapted to harmonic distortion. The design is valid as long as the design for a realistic neutral overload is taken into consideration and is applied to the whole system.

The raw material and performance optimization for more guarantees

Figue E58 shows the comparison between 2 busway constructions. The test conditions are the same for both cases:

- Phase current: IL = 1600 A
- 3rd harmonic level: ih3 = 33%
- Neutral current: IN = 1520 A

Placed in the same conditions, a busbar trunking system with 4 identical conductors will have a lower temperature rise than a 200 % busbar with the same total c.s.a.
It is then perfectly adapted to this situation. Of course, the selection of the size of the conductors must take the possible current flowing through the neutral conductor into account.



Temperature rise (°K)	200 % Neutral	100 % Neutral
Phase conductor (average)	63.5	41.5
Neutral conductor	56	39
Casing (maximum)	55	39

The double neutral does not deal wih all the additionnal temperature rise

	200 % Neutral	100 % Neutral
Phase conductor c.s.a. (mm²)	960	1200
Neutral c.s.a. (mm²)	1920	1200
Total c.s.a. (mm²)	**4800**	**4800**

Even though the total cross-section for all conductors is exactly the same for the 2 busways solutions

Fig. E58: Comparison between double-neutral busway solution and properly selected single-neutral solution

Fig. E59: Coherent system approach for all components of the electrical installation

Coherent system approach

The approach on busway dedicated to harmonics network performance is a solution approach. The busway is optimized but completely in accordance with the electrical devices connected on it:
- Tap-off unit
- Circuit breakers
- Number of cables.

3 External influences (IEC 60364-5-51)

External influences shall be taken into account when choosing:
■ The appropriate measures to ensure the safety of persons (in particular in special locations or electrical installations)
■ The characteristics of electrical equipment, such as degree of protection (IP), mechanical withstand (IK), etc.

3.1 Definition and reference standards

Every electrical installation occupies an environment that presents a variable degree of risk:

- For people
- For the equipment constituting the installation.

Consequently, environmental conditions influence the definition and choice of appropriate installation equipment and the choice of protective measures for the safety of persons.

The environmental conditions are referred to collectively as "external influences". Many national standards concerned with external influences include a classification scheme which is based on, or which closely resembles, that of international standard IEC 60364-5-51.

If several external influences appear at the same time, they can have independent or mutual effects and the degree of protection must be chosen accordingly

3.2 Classification

Each condition of external influence is designated by a code comprising a group of two capital letters and a number as follows:

First letter (A, B or C)

The first letter relates to the general category of external influence:

- A = environment
- B = utilisation
- C = construction of buildings.

Second letter

The second letter relates to the nature of the external influence.

Number

The number relates to the class within each external influence.

Additional letter (optional)

Used only if the effective protection of persons is greater than that indicated by the first IP digit.
When only the protection of persons is to be specified, the two digits of the IP code are replaced by the X's.
Example: IP XXB.

Example

For example the code AC2 signifies:
A = environment
AC = environment-altitude
AC2 = environment-altitude > 2000 m.

3.3 List of external influences

Figure E60 below is from IEC 60364-5-51, which should be referred to if further details are required.

Code	External influences			Characteristics required for equipment
A - Environment				
AA	**Ambient temperature (°C)**			
	Low	High		Specially designed equipment or appropriate arrangements
AA1	-60 °C	+5 °C		
AA2	-40 °C	+5 °C		
AA3	-25 °C	+5 °C		
AA4	-5° C	+40 °C		Normal (special precautions in certain cases)
AA5	+5 °C	+40 °C		Normal
AA6	+5 °C	+60 °C		Specially designed equipment or appropriate arrangements
AA7	-25 °C	+55 °C		
AA8	-50 °C	+40 °C		

Fig. E60: List of external influences (taken from Appendix A of IEC 60364-5-51) *(continued on next page)*

3 External influences (IEC 60364-5-51)

Code	External influences						Characteristics required for equipment
A - Environment							
AB	**Atmospheric humidity**						
	Air temperature °C		Relative humidity %		Absolute humidity g/m^3		
	Low	High	Low	High	Low	High	
AB1	-60 °C	+5 °C	3	100	0.003	7	Appropriate arrangements shall be made
AB2	-40 °C	+5 °C	10	100	0.1	7	
AB3	-25 °C	+5 °C	10	100	0.5	7	
AB4	-5° C	+40 °C	5	95	1	29	Normal
AB5	+5 °C	+40 °C	5	85	1	25	Normal
AB6	+5 °C	+60 °C	10	100	1	35	Appropriate arrangements shall be made
AB7	-25 °C	+55 °C	10	100	0.5	29	
AB8	-50 °C	+40 °C	15	100	0.04	36	
AC	**Altitude**						
AC1	≤ 2000 m						Normal
AC2	> 2000 m						May necessitate precaution (derating factors)
AD	**Presence of water**						
AD1	Negligible		Probability of presence of water is negligible				IPX0
AD2	Free-falling drops		Probability of presence of water is negligible				IPX1 or IPX2
AD3	Sprays		Possibility of water falling as a spray at an angle up to 60° from the vertical				IPX3
AD4	Splashes		Possibility of splashes from any direction				IPX4
AD5	Jets		Possibility of jets of water from any direction				IPX5
AD6	Waves		Possibility of water waves (seashore locations)				IPX6
AD7	Immersion		Possibility of intermittent partial or total covering by water				IPX7
AD8	Submersion		Equipment is permanently and totally covered				IPX8
AE	**Presence of foreign solid bodies or dust**						
			Smallest dimension		Example		
AE1	Negligible						IP0X
AE2	Small objects		2.5 mm		Tools		IP3X
AE3	Very small objects		1 mm		Wire		IP4X
AE4	Light dust						IP5X if dust penetration is not harmful to functioning
AE5	Moderate dust						IP6X if dust should not penetrate
AE6	Heavy dust						IP6X
AF	**Presence of corrosive or polluting substances**						
AF1	Negligible						Normal
AF2	Atmospheric						According to the nature of the substance
AF3	Intermittent, accidental						Protection against corrosion
AF4	Continuous						Equipment specially designed
AG	**Mechanical shock**						
AG1	Low severity						Normal, e.g. household and similar equipment
AG2	Medium severity						Standard industrial equipment, where applicable, or reinforced protection
AG3	High severity						Reinforced protection
AH	**Vibrations**						
AH1	Low severity		Household or similar				Normal
AH2	Medium severity		Usual industrial conditions				Specially designed equipment or special arrangements
AH3	High severity		Severe industrial conditions				
AK	**Presence of flora and/or moulds growth**						
AK1	No hazard						Normal
AK2	Hazard						Special protection
AL	**Presence of fauna**						
AL1	No hazard						Normal
AL2	Hazard						Special protection
AM	**Electromagnetic, electrostatic or ionising influences / Low frequency electromagnetic phenomena / Harmonics**						
AM1	Harmonics, interharmonics						Refer to applicable IEC standards
AM2	Signalling voltage						
AM3	Voltage amplitude variations						
AM4	Voltage unbalance						
AM5	Power frequency variations						
AM6	Induced low-frequency voltages						
AM7	Direct current in a.c. networks						
AM8	Radiated magnetic fields						
AM9	Electric field						
AM21	Induced oscillatory voltages or currents						

Fig. E60: List of external influences (taken from Appendix A of IEC 60364-5-51) (continued on next page)

Code	External influences	Characteristics required for equipment
A - Environment		
AM22	Conducted unidirectional transients of the nanosecond time scale	Refer to applicable IEC standards
AM23	Conducted unidirectional transients of the microsecond to the millisecond time scale	
AM24	Conducted oscillatory transients	
AM25	Radiated high frequency phenomena	
AM31	Electrostatic discharges	
AM41	Ionisation	
AN	**Solar radiation**	
AN1	Low	Normal
AN2	Medium	
AN3	High	
AP	**Seismic effect**	
AP1	Negligible	Normal
AP2	Low severity	
AP3	Medium severity	
AP4	High severity	
AQ	**Lightning**	
AQ1	Negligible	Normal
AQ2	Indirect exposure	
AQ3	Direct exposure	
AR	**Movement of air**	
AR1	Low	Normal
AR2	Medium	
AR3	High	
AS	**Wind**	
AS1	Low	Normal
AS2	Medium	
AS3	High	
B - Utilization		
BA	**Capability of persons**	
BA1	Ordinary	Normal
BA2	Children	
BA3	Handicapped	
BA4	Instructed	
BA5	Skilled	
BB	**Electrical resistance of human body (under consideration)**	
BC	**Contact of persons with earth potential**	
BC1	None	Class of equipment according to IEC61140
BC2	Low	
BC3	Frequent	
BC4	Continuous	
BD	**Condition of evacuation in case of emergency**	
BD1	Low density / easy exit	Normal
BD2	Low density / difficult exit	
BD3	High density / easy exit	
BD4	High density / difficult exit	
BE	**Nature of processed or stored materials**	
BE1	No significant risks	Normal
BE2	Fire risks	
BE3	Explosion risks	
BE4	Contamination risks	
C - Construction of building		
CA	**Construction materials**	
CA1	Non combustible	Normal
CA2	Combustible	
CB	**Building design**	
CB1	Negligible risks	Normal
CB2	Propagation of fire	
CB3	Movement	
CB4	Lexible or unstable	

Fig. E60: List of external influences (taken from Appendix A of IEC 60364-5-51) (concluded)

3.4 Protection provided for enclosed equipment: codes IP and IK

IP code definition (see **Fig. E61**)

The degree of protection provided by an enclosure is indicated in the IP code, recommended in IEC 60529.

Protection is afforded against the following external influences:

- Penetration by solid bodies
- Protection of persons against access to live parts
- Protection against the ingress of dust
- Protection against the ingress of liquids.

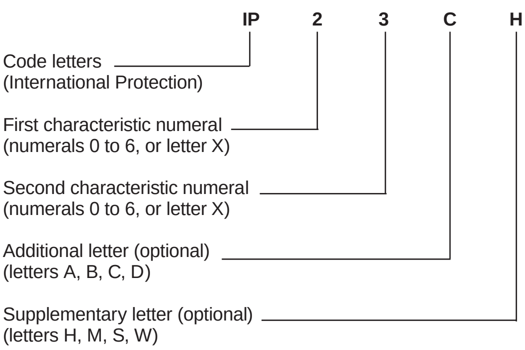
Note: the IP code applies to electrical equipment for voltages up to and including 72.5 kV.

Elements of the IP Code and their meanings

A brief description of the IP Code elements is given in the following chart (see **Fig. E62**).

Element	Numerals or letters	Meaning for the protection of equipment	Meaning for the protection of persons
Code letters	IP		
First characteristic numeral		**Against ingress of solid foreign objects**	**Against access to hazardous parts with**
	0	(non-protected)	(non-protected)
	1	⩾ 50 mm diameter	Back of hand
	2	⩾ 12.5 mm diameter	Finger
	3	⩾ 2.5 mm diameter	Tool
	4	⩾ 1.0 mm diameter	Wire
	5	Dust-protected	Wire
	6	Dust-tight	Wire
Second characteristic numeral		**Against ingress of water with harmful effects**	
	0	(non-protected)	
	1	Vertically dripping	
	2	Dripping (15° tilted)	
	3	Spraying	
	4	Splashing	
	5	Jetting	
	6	Powerful jetting	
	7	Temporary immersion	
	8	Continuous immersion	
	9	High pressure and temperature water jet	
Additional letter (optional)			**Against access to hazardous parts with**
	A		back of hand
	B		Finger
	C		Tool
	D		Wire
Supplementary letter (optional)		**Supplementary information specific to:**	
	H	High-voltage apparatus	
	M	Motion during water test	
	S	Stationary during water test	
	W	Weather conditions	

Fig. E62: Elements of the IP Code



Where a characteristic numeral is not required to be specified, it shall be replaced by the letter "X" ("XX" if both numerals are omitted). Additional letters and/or supplementary letters may be omitted without replacement.

Fig. E61: IP Code arrangement

3 External influences (IEC 60364-5-51)

IK Code definition

Standard IEC 62262 defines an IK code that characterises the aptitude of equipment to resist mechanical impacts on all sides (see **Fig. E63**).

IK code	Impact energy (in Joules)	AG code
00	0	
01	≤ 0.14	
02	≤ 0.20	AG1
03	≤ 0.35	
04	≤ 0.50	
05	≤ 0.70	
06	≤ 1	
07	≤ 2	AG2
08	≤ 5	AG3
09	≤ 10	
10	≤ 20	AG4

Fig. E63: Elements of the IK Code

IP and IK code specifications for distribution switchboards

The degrees of protection IP and IK of an enclosure must be specified as a function of the different external influences defined by standard IEC 60364-5-51, in particular:

- Presence of solid bodies (code AE)
- Presence of water (code AD)
- Mechanical stresses (no code)
- Capability of persons (code BA)
- …

Prisma Plus switchboards are designed for indoor installation.
Unless the rules, standards and regulations of a specific country stipulate otherwise, Schneider Electric recommends the following IP and IK values (see **Fig. E64** and **Fig. E65**)

IP recommendations

IP codes according to conditions		
Normal without risk of vertically falling water	Technical rooms	30
Normal with risk of vertically falling water	Hallways	31
Very severe with risk of splashing water from all directions	Workshops	54/55

Fig. E64: IP recommendations

IK recommendations

IK codes according to conditions		
No risk of major impact	Technical rooms	07
Significant risk of major impact that could damage devices	Hallways	08 (enclosure with door)
Maximum risk of impact that could damage the enclosure	Workshops	10

Fig. E65: IK recommendations