Chapter A
General rules of electrical installation design

Contents

1 Methodology

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

Listing of power demands

A - General rules of electrical installation design

The study of a proposed electrical installation requires an adequate understanding of all governing rules and regulations.

The total 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.)

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 are 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.

Service connection

This connection can be made at:

B – Connection to the MV utility distribution network

- Medium Voltage level

A consumer-type substation will then 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

- Low Voltage level

The installation will be connected to the local power network and will (necessarily) be metered according to LV tariffs.

Electrical Distribution architecture

D - MV & LV architecture selection guide

The whole installation distribution network is studied as a complete system.

A selection guide is proposed for determination of the most suitable architecture. MV/LV main distribution and LV power distribution levels are covered.

E - LV Distribution

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.

Protection against electric shocks

F - Protection against electric shocks

The earthing system (TT, IT or TN) having been previously determined, then the appropriate protective devices must be implemented in order to achieve protection against hazards of direct or indirect contact.

Circuits and switchgear

G - Sizing and protection of conductors

Each circuit is then studied in detail. From the rated currents of the loads, the level of short-circuit current, and the type of protective device, the cross-sectional area of circuit conductors can be determined, taking into account the nature of the cableways and their influence on the current rating of conductors.

Before adopting the conductor size indicated above, the following requirements must be satisfied:

- The voltage drop complies with the relevant standard
- Motor starting is satisfactory
- Protection against electric shock is assured

The short-circuit current Isc is then determined, and the thermal and electrodynamic withstand capability of the circuit is checked.

These calculations may indicate that it is necessary to use a conductor size larger than the size originally chosen.

H - LV switchgear: functions & selection

The performance required by the switchgear will determine its type and characteristics.

The use of cascading techniques and the discriminative operation of fuses and tripping of circuit breakers are examined.

J – Protection against voltage surges in LV

Protection against overvoltages

Direct or indirect lightning strokes can damage electrical equipment at a distance of several kilometers. Operating voltage surges, transient and industrial frequency over-voltage can also produce the same consequences.The effects are examined and solutions are proposed.

K – Energy efficiency in electrical distribution

Energy efficiency in electrial distribution

Implementation of measuring devices with an adequate communication system 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.

L - Power factor correction and harmonic filtering

Reactive energy

The power factor correction within electrical installations is carried out locally, globally or as a combination of both methods.

M - Harmonic management

Harmonics

Harmonics 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 - Residential and other special locations

Generic applications

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

Q - EMC guideline

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.

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
- Calculation of voltage drops
- Optimization of cable sizes
- Required ratings of switchgear and fusegear
- Discrimination of protective devices
- Recommendations for cascading schemes
- Verification of the protection of people
- Comprehensive print-out of the foregoing calculated design data

(1) Ecodial is a Merlin Gerin product and is available in French and English versions.

2 Rules and statutory regulations

Low-voltage installations are 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
–	240	–
230/400(1)	277/480	–
400/690(1)	480	–
–	347/600	–
1000	600	–

(1) The nominal voltage of existing 220/380 V and 240/415 V systems shall evolve toward the recommended value of 230/400 V. The transition period should be as short as possible and should not exceed the year 2003. During this period, as a first step, the electricity supply authorities of countries having 220/380 V systems should bring the voltage within the range 230/400 V +6 %, -10 % and those of countries having 240/415 V systems should bring the voltage within the range 230/400 V +10 %, -6 %. At the end of this transition period, the tolerance of 230/400 V ± 10 % should have been achieved; after this the reduction of this range will be considered. All the above considerations apply also to the present 380/660 V value with respect to the recommended value 400/690 V.

Fig. A1 : Standard voltages between 100 V and 1000 V (IEC 60038 Edition 6.2 2002-07)

Series I Highest voltage for equipment (kV)	Series I Nominal system voltage (kV)		Series II Highest voltage for equipment (kV)	Series II Nominal system voltage (kV)
3.6(1)	3.3(1)	3(1)	4.40(1)	4.16(1)
7.2(1)	6.6(1)	6(1)	–	–
12	11	10	–	–
–	–	–	13.2(2)	12.47(2)
–	–	–	13.97(2)	13.2(2)
–	–	–	14.52(1)	13.8(1)
(17.5)	–	(15)	–	–
24	22	20	–	–
–	–	–	26.4(2)	24.94(2)
36(3)	33(3)	–	–	–
–	–	–	36.5	34.5
40.5(3)	–	35(3)	–	–

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.
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 then +5 % and the lowest voltage by more than -10 % from the nominal voltage of the system.

(1) These values should not be used for public distribution systems.
(2) These systems are generally four-wire systems.
(3) The unification of these values is under consideration.

Fig. A2 : Standard voltages above 1 kV and not exceeding 35 kV (IEC 60038 Edition 6.2 2002-07)

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.

2.3 Standards

This Guide is based on relevant IEC standards, in particular IEC 60364. IEC 60364 has been established by medical and engineering experts of all countries in the world comparing their experience at an international level. Currently, the safety principles of IEC 60364 and 60479-1 are the fundamentals of most electrical standards in the world (see table below and next page).

IEC 60038	Standard voltages
IEC 60076-2	Power transformers - Temperature rise
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 60076-10	Power transformers - Determination of sound levels
IEC 60146	Semiconductor convertors - General requirements and line commutated convertors
IEC 60255	Electrical relays
IEC 60265-1	High-voltage switches - High-voltage switches for rated voltages above 1 kV and less than 52 kV
IEC 60269-1	Low-voltage fuses - General requirements
IEC 60269-2	Low-voltage fuses - Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications)
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	Electrical installations of buildings
IEC 60364-1	Electrical installations of buildings - Fundamental principles
IEC 60364-4-41	Electrical installations of buildings - Protection for safety - Protection against electric shock
IEC 60364-4-42	Electrical installations of buildings - Protection for safety - Protection against thermal effects
IEC 60364-4-43	Electrical installations of buildings - Protection for safety - Protection against overcurrent
IEC 60364-4-44	Electrical installations of buildings - Protection for safety - Protection against electromagnetic and voltage disrurbance
IEC 60364-5-51	Electrical installations of buildings - Selection and erection of electrical equipment - Common rules
IEC 60364-5-52	Electrical installations of buildings - Selection and erection of electrical equipment - Wiring systems
IEC 60364-5-53	Electrical installations of buildings - Selection and erection of electrical equipment - Isolation, switching and control
IEC 60364-5-54	Electrical installations of buildings - Selection and erection of electrical equipment - Earthing arrangements
IEC 60364-5-55	Electrical installations of buildings - Selection and erection of electrical equipment - Other equipments
IEC 60364-6-61	Electrical installations of buildings - Verification and testing - Initial verification
IEC 60364-7-701	Electrical installations of buildings - Requirements for special installations or locations - Locations containing a bath tub or shower basin
IEC 60364-7-702	Electrical installations of buildings - Requirements for special installations or locations - Swimming pools and other basins
IEC 60364-7-703	Electrical installations of buildings - Requirements for special installations or locations - Locations containing sauna heaters
IEC 60364-7-704	Electrical installations of buildings - Requirements for special installations or locations - Construction and demolition site installations
IEC 60364-7-705	Electrical installations of buildings - Requirements for special installations or locations - Electrical installations of agricultural and horticultural premises
IEC 60364-7-706	Electrical installations of buildings - Requirements for special installations or locations - Restrictive conducting locations
IEC 60364-7-707	Electrical installations of buildings - Requirements for special installations or locations - Earthing requirements for the installation of data processing equipment
IEC 60364-7-708	Electrical installations of buildings - Requirements for special installations or locations - Electrical installations in caravan parks and caravans
IEC 60364-7-709	Electrical installations of buildings - Requirements for special installations or locations - Marinas and pleasure craft
IEC 60364-7-710	Electrical installations of buildings - Requirements for special installations or locations - Medical locations
IEC 60364-7-711	Electrical installations of buildings - Requirements for special installations or locations - Exhibitions, shows and stands
IEC 60364-7-712	Electrical installations of buildings - Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
IEC 60364-7-713	Electrical installations of buildings - Requirements for special installations or locations - Furniture
IEC 60364-7-714	Electrical installations of buildings - Requirements for special installations or locations - External lighting installations
IEC 60364-7-715	Electrical installations of buildings - Requirements for special installations or locations - Extra-low-voltage lighting installations
IEC 60364-7-717	Electrical installations of buildings - Requirements for special installations or locations - Mobile or transportable units
IEC 60364-7-740	Electrical installations of buildings - Requirements for special installations or locations - Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses
IEC 60427	High-voltage alternating current circuit-breakers
IEC 60439-1	Low-voltage switchgear and controlgear assemblies - Type-tested and partially type-tested assemblies
IEC 60439-2	Low-voltage switchgear and controlgear assemblies - Particular requirements for busbar trunking systems (busways)
IEC 60439-3	Low-voltage switchgear and controlgear assemblies - Particular requirements for low-voltage switchgear and controlgear assemblies intended to be installed in places where unskilled persons have access for their use - Distribution boards
IEC 60439-4	Low-voltage switchgear and controlgear assemblies - Particular requirements for assemblies for construction sites (ACS)
IEC 60446	Basic and safety principles for man-machine interface, marking and identification - Identification of conductors by colours or numerals
IEC 60439-5	Low-voltage switchgear and controlgear assemblies - Particular requirements for assemblies intended to be installed outdoors in public places - Cable distribution cabinets (CDCs)
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

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IEC 60529	Degrees of protection provided by enclosures (IP code)
IEC 60644	Spécification for high-voltage fuse-links for motor circuit applications
IEC 60664	Insulation coordination for equipment within low-voltage systems
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 fuse-links of high-voltage fuses for transformer circuit application
IEC 60831	Shunt power capacitors of the self-healing type for AC systems having a rated voltage up to and including 1000 V - General - Performance, testing and rating - Safety requirements - Guide for installation and operation
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 - Automatic transfer switching equipment
IEC 61000	Electromagnetic compatibility (EMC)
IEC 61140	Protection against electric shocks - common aspects for installation and equipment
IEC 61557-1	Electrical safety in low-voltage distribution systems up to 1000 V AC and 1500 V DC - 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 AC and 1500 V DC - Equipment for testing, measuring or monitoring of protective measures
IEC 61557-9	Electrical safety in low-voltage distribution systems up to 1000 V AC and 1500 V DC - Equipment for insulation fault location in IT systems
IEC 61557-12	Electrical safety in low-voltage distribution systems up to 1000 V AC and 1500 V DC - Equipment for testing, measuring or monitoring of protective measures. Performance measuring and monitoring devices (PMD)
IEC 61558-2-6	Safety of power transformers, power supply units and similar - Particular requirements for safety isolating transformers for general use
IEC 62271-1	Common specifications for high-voltage switchgear and controlgear standards
IEC 62271-100	High-voltage switchgear and controlgear - High-voltage alternating-current circuit-breakers
IEC 62271-102	High-voltage switchgear and controlgear - Alternating current disconnectors and earthing switches
IEC 62271-105	High-voltage switchgear and controlgear - Alternating current switch-fuse combinations
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/low voltage prefabricated substations

(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 initial checking of conformity of the electrical installation with the standard and regulation has been achieved

■ The electrical equipment comply with standards

■ The periodic checking of the installation recommended by the equipment manufacturer 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 60364-6-61 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:

■ Insulation tests of all cable and wiring conductors of the fixed installation, between phases and between phases and earth

■ Continuity and conductivity tests of protective, equipotential and earth-bonding conductors

■ Resistance tests of earthing electrodes with respect to remote earth

■ Verification of the proper operation of the interlocks, if any

■ Check of allowable number of socket-outlets per circuit

■ Cross-sectional-area check of all conductors for adequacy at the short-circuit levels prevailing, taking account of the associated protective devices, materials and installation conditions (in air, conduit, etc.)
■ Verification that all exposed- and extraneous metallic parts are properly earthed (where appropriate)
■ Check of clearance distances in bathrooms, etc.

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: TN-, TT- or IT-earthed installations, installations based on class 2 insulation, SELV circuits, and 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.

2.6 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.
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	

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

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

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

Attestation of conformity

The conformity of equipment with the relevant standards can be attested:
■ By an official 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 from the manufacturer

The first two solutions are generally not available for high voltage equipment.

Declaration of conformity

Where the equipment is to be used by skilled or instructed persons, the manufacturer's declaration of conformity (included in the technical documentation), is generally recognized as a valid attestation. Where the competence of the manufacturer is in doubt, a certificate of conformity can reinforce the manufacturer's declaration.

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.

Mark of conformity

Marks of conformity are affixed on appliances and equipment generally used by ordinary non instructed people (e.g in the field of domestic appliances). A mark of conformity is delivered by certification body if the equipment meet the requirements from an applicable standard and after verification of the manufacturer's quality management system.

Certification of Quality

The standards define several methods of quality assurance which correspond to different situations rather than to different levels of 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).

2.8 Environment

Environmental management systems can be certified by an independent body if they meet requirements given in ISO 14001. This type of certification mainly concerns industrial settings but can also be granted to places where products are designed.

A product environmental design sometimes called "eco-design" is an approach of sustainable development with the objective of designing products/services best meeting the customers' requirements while reducing their environmental impact over their whole life cycle. The methodologies used for this purpose lead to choose equipment's architecture together with components and materials taking into account the influence of a product on the environment along its life cycle (from extraction of raw materials to scrap) i.e. production, transport, distribution, end of life etc.

In Europe two Directives have been published, they are called:

- RoHS Directive (Restriction of Hazardous Substances) coming into force on July 2006 (the coming into force was on February 13th, 2003, and the application date is July 1st, 2006) aims to eliminate from products six hazardous substances: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

- WEEE Directive (Waste of Electrical and Electronic Equipment) coming into force in August 2005 (the coming into force was on February 13th, 2003, and the application date is August 13th, 2005) in order to master the end of life and treatments for household and non household equipment.

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

In addition to manufacturers action in favour of products eco-design, 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)

See chapter D about location of the substation and the main LV switchboard.

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 full-load current Ia supplied to the motor is given by the following formulae:

- 3-phase motor: $Ia = Pn \times 1{,}000 / (\sqrt{3} \times U \times \eta \times \cos\varphi)$
- 1-phase motor: $Ia = Pn \times 1{,}000 / (U \times \eta \times \cos\varphi)$

where

Ia: current demand (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

$\cos\varphi$: 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 Inm. Sometimes this value can reach 25 times Inm.
- Merlin Gerin circuit-breakers, Telemecanique 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 Inm).
- 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.
- Merlin Gerin and Telemecanique 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 Ia instead of 7.5 Ia).

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 $\cos\varphi$.

3 Installed power loads - Characteristics

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.

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
3.7	-	-	-	-	-	-	-
4	-	15	9.7	8.5	7.6	6.8	4.9
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)*

3 Installed power loads - Characteristics

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
-	540	-	-	-	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)

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

3 Installed power loads - Characteristics

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.

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):

- $\cos \varphi$ = 0.6 with no power factor (PF) correction(2) capacitor
- $\cos \varphi$ = 0.86 with PF correction(2) (single or twin tubes)
- $\cos \varphi$ = 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 1,000

(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.

Discharge lamps

Figure A8 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	400 V	Current In(A) PF not corrected 230 V	400 V	PF corrected 230 V	400 V	Starting Ia/In	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
70	80		1		0.45						■ Outdoor spaces
100	115		1.2		0.65						■ Public lighting
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
36	46.5				0.22						■ Security lighting, station
66	80.5				0.39						■ Platform, storage areas
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)
80	90		0.8		0.45						■ Outdoor lighting
125	141		1.15		0.70						■ Low light output(1)
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. A8 : Current demands of discharge lamps

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:

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

for single phase-to-neutral connected load

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

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”.

When some or all of the load characteristics are not known, the values shown in **Figure A9** next page 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 m^2.

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

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.

Factor of simultaneity (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 simultaneity factor (ks).

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

Factor of simultaneity for an apartment block

Some typical values for this case are given in **Figure A10** opposite page, and are applicable to domestic consumers 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	Factor of simultaneity (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	0.40

Fig. A10 : Simultaneity factors in an apartment block

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 Figure A10, 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:

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

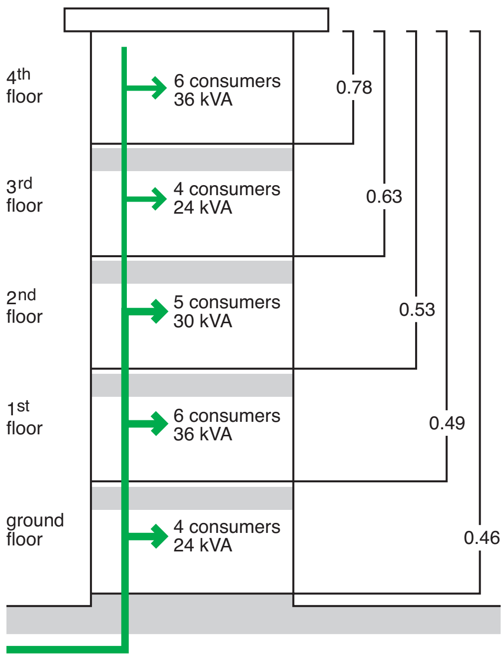

Fig. A11 : Application of the factor of simultaneity (ks) to an apartment block of 5 storeys

Factor of simultaneity for distribution boards

Figure A12 shows hypothetical values of ks for a distribution board supplying a number of circuits for which there is no indication of the manner in which the total load divides between them.

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

Number of circuits	Factor of simultaneity (ks)
Assemblies entirely tested	0.9
2 and 3	
4 and 5	0.8
6 to 9	0.7
10 and more	0.6
Assemblies partially tested in every case choose	1.0

Fig. A12 : Factor of simultaneity for distribution boards (IEC 60439)

Factor of simultaneity according to circuit function

ks factors which may be used for circuits supplying commonly-occurring loads, are shown in **Figure A13**.

Circuit function		Factor of simultaneity (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 : Factor of simultaneity according to circuit function

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** (opposite page).

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).

4.5 Diversity factor

The term diversity factor, as defined in IEC standards, is identical to the factor of simultaneity (ks) used in this guide, as described in 4.3. In some English-speaking countries however (at the time of writing) diversity factor is the inverse of ks i.e. it is always ⩾ 1.

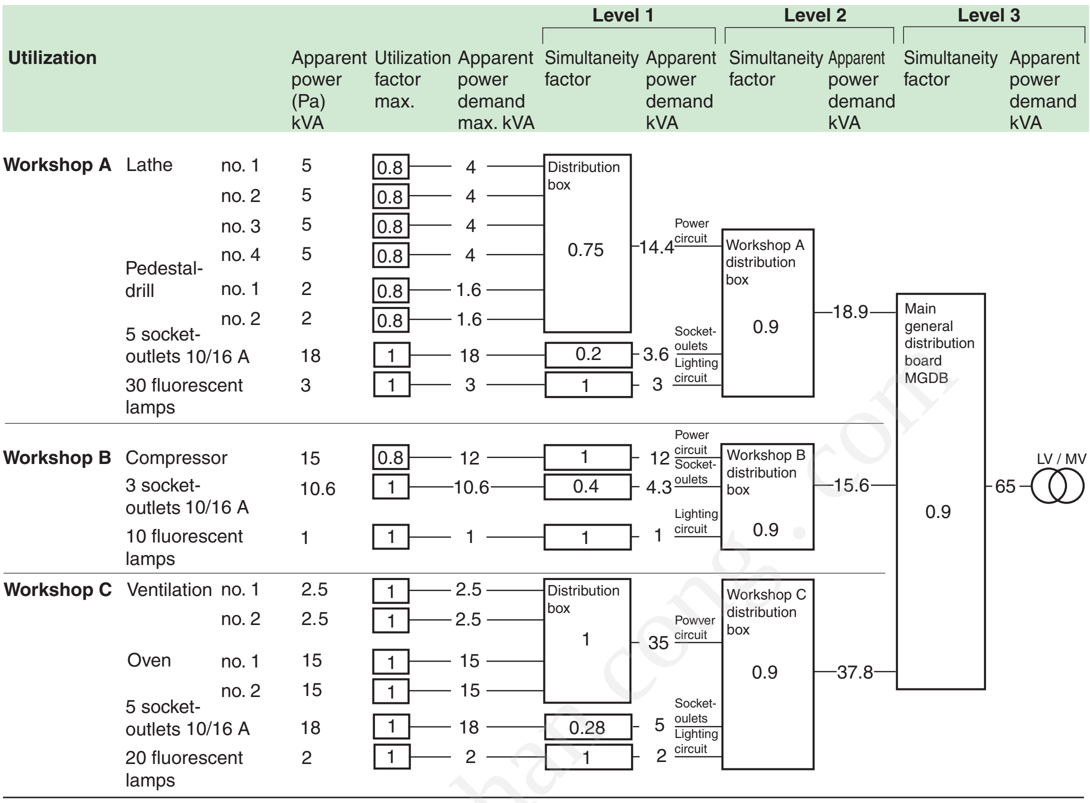

Fig A14 : An example in estimating the maximum predicted loading of an installation (the factor values used are for demonstration purposes only)

4.6 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

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

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.

4.7 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 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 and equip 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