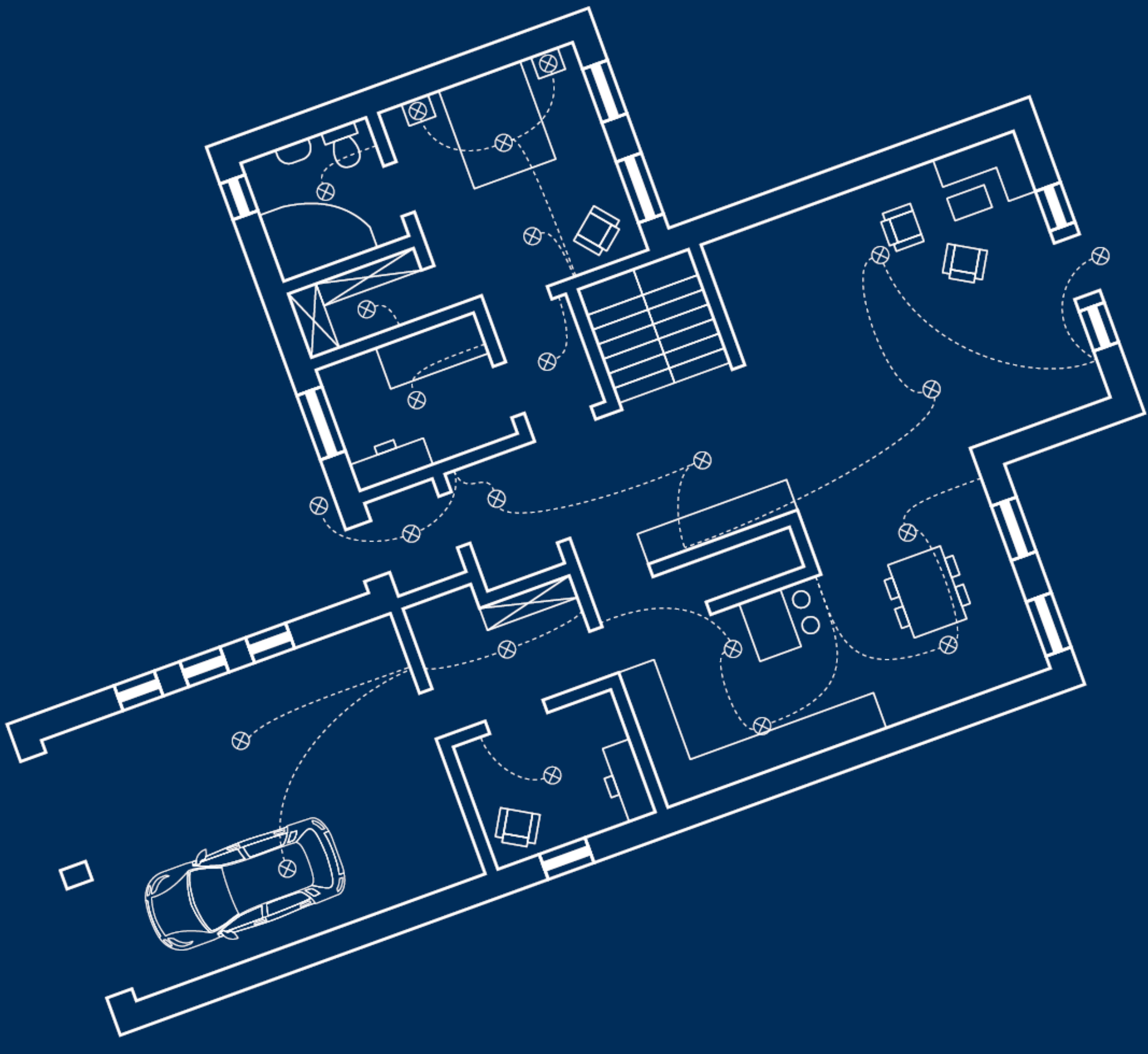
ELECTRICAL INSTALLATIONS IN THE BUILDING

DESIGNING

Helena RUSAK • Joanna NAZARKO • Jarosław MAKAL • Marcin SULKOWSKI



Politechnika Białostocka

Electrical Installations in the Building – Designing

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Bialystok University of Technology
Bialystok 2023

The elaboration of this student textbook has been funded by the ICT_EDUPAND Project
2020-1-PL01-KA226-HE-096196 financed by ERASMUS+ Programme

Holistic approach towards problem-based ICT education based on international cooperation in pandemic conditions.

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ISBN 978-83-67185-65-3 (eBook)
DOI: 10.24427/978-83-67185-65-3

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Preface

This book has been written for foreign students designing lighting installations as part of the Electrical-Equipment-and-Installations course. Since the projects of these installations require knowledge of Polish regulations and international standards, it is very helpful to describe them and provide appropriate sources/links. It can be as an introduction for the reader to electrical installations in the building designing. This book can also be used by everyone who want to deepen the knowledge of electrical terminology in English. The online availability of this book in the OER (Open Educational Resources) hopes that many students will benefit from it.

1. Introduction

The equivalent circuit of the supplying line can be presented as connection of Two-Port Networks (Fig. 1 1). The resistors R and inductors L represent the resistance and inductance of the wires from which the transmission line is built. In air lines with the length over 60 km and voltages more than 35 kV we cannot neglect the capacitance currents (between two wires and/or between one wire and the ground).

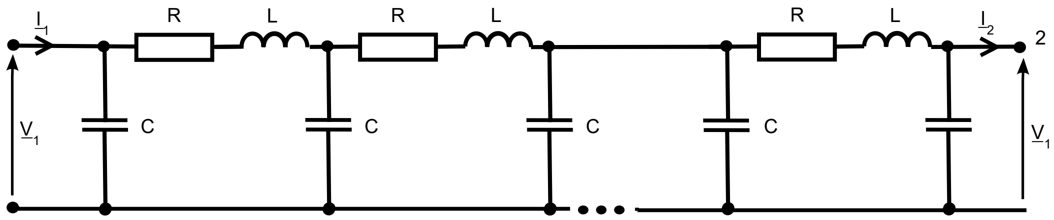
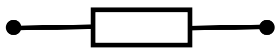


Fig. 1_1 Model of supplying AC line.

The elements that model the real physical phenomena in supplying line are as following.

1.1. Elements

1.1.1. Resistor



It is an element that resist the flow of current and converts electrical energy to heat. Also we use resistor for modelling a phenomenon in the circuit even there is not any resistor (i.e. internal resistance of DC battery).

The ability of a material to resist the flow of charge is called *resistivity*. Materials that have low values of resistivity called *conductors* (of electric current). The high value of resistivity is characteristic for *insulators*. Electrical *conductivity* is the reciprocal quantity of resistivity. Conductivity describes the ability of material of well conducting an electric current. In the Table 1.1 the resistivity and conductivity values of some well-known materials are presented.

Table 1.1. Resistivity and conductivity of selected materials at 20°C

Material	Resistivity, ρ (Ω•m)	Conductivity, σ (S/m)
Silver	1.59×10^{-8}	6.30×10^{7}
Copper	1.68×10^{-8}	5.96×10^{7}
Gold	2.44×10^{-8}	4.10×10^{7}
Aluminum	2.82×10^{-8}	3.5×10^{7}
Iron	1.0×10^{-7}	1.00×10^{7}
Platinum	1.06×10^{-7}	9.43×10^{6}
Constantan	4.9×10^{-7}	2.04×10^{6}
Carbon (diamond)	1×10^{12}	$\sim10^{-13}$
Sea water	2×10^{-1}	4.8
Drinking water	20 to 2000	5×10^{-4} to 5×10^{-2}
Wood (damp)	10^{3} to 10^{4}	10^{-4} to 10^{-3}
Glass	10×10^{10} to 10×10^{14}	10^{-11} to 10^{-15}
Hard rubber	1×10^{13}	10^{-14}
Air	1.3×10^{16} to 3.3×10^{16}	3×10^{-15} to 8×10^{-15}
Paraffin wax	1×10^{17}	10^{-18}
PET	10×10^{20}	10^{-21}

The resistance of a wire (use for supply an electric load) depends mainly on three factors: what material it is made of, its shape and its length (Eq.1.1). The resistance R of a conductor of uniform cross section can be computed as

$$R = \rho \cdot \frac{l}{S} \tag{1.1}$$

where: l – is the length of the conductor, measured in metres (m), S – is the cross-sectional area of the conductor measured in square metres (m^2), and ρ (rho) – is the electrical resistivity of the material, measured in ohm-metres (Ω·m).

The resistivity and conductivity are proportionality constants, and therefore depend only on the material the wire is made of, not the geometry of the wire.

Worth remembering

Formula (1.1) is not exact, as it assumes the current density is totally uniform in the conductor, which is not always true in practical situations. However, this formula still provides a good approximation for long thin conductors such as wires.

Another situation for which this formula is with alternating current (AC), because the skin effect inhibits current flow near the centre of the conductor. For this reason, the geometrical cross-section is different from the effective cross-section in which current actually flows, so resistance is higher than expected.

Similarly, if two near each other conductors carry AC current, their resistances increase due to the proximity effect. At commercial network frequency these effects are significant only for large conductors carrying large currents, such as busbars in an electrical substations or large power cables carrying more than a few hundred amperes

The relation of the voltage and current was published in 1827 by Georg Simon Ohm (1789-1854) as so called Ohm's law (Eq.1.2)

$$i = \frac{v}{R} \tag{1.2}$$

where: v – is the voltage, measured in Volt (V), i – is the current, measured in Amper (A)

The higher the resistance, the lower the current flow. If it is abnormally high, the conductor could be damaged due to burning or corrosion. All conductors give off some degree of heat, so overheating is an issue often associated with resistance.

The lower the resistance, the higher the current flow. Possible causes: insulators damaged by moisture or overheating.

Many components, such as heating elements and resistors, have a fixed-resistance value. These values and the permissible power value are often printed on the components' nameplates or in manuals for reference.

The power delivered to a resistor is (Eq. 1.3 and 1.4)

$$p = v \cdot i = v \cdot \left(\frac{v}{R}\right) = \frac{v^2}{R} \tag{1.3}$$

$$p = v \cdot i = (i \cdot R) \cdot i = i^2 R \tag{1.4}$$

The energy delivered to resistor at time t is always nonnegative (Eq.1.5)

$$w_R = i^2 R \cdot t \tag{1.5}$$

Worth remembering

Resistance cannot be measured in an operating circuit. This is due to the way in which the ohmmeter measures the resistance value. If you measure the resistance of an element in an operating circuit, you will either get an incorrect result or damage the instrument. Accordingly, troubleshooting technicians often determine resistance by taking voltage and current measurements and applying Ohm's Law:

$$v = i \cdot R$$

If resistance is unknown, the formula can be converted to $R = \frac{v}{i}$. In AC circuits the multimeter indicates the effective value (called also as rms value) of voltage (current) and the resistance value can be received as

$$R = \frac{V_{rms}}{I_{rms}}$$

The resistance of metal film resistors depends on temperature because the resistivity of metals typically increases as temperature is increased. The resistivity of insulators and electrolytes may increase or decrease depending on the system.

The dependence of resistance in the term of temperature is expressed in equation (1.6)

$$R(T) = R_0\big(1 + \alpha \cdot (T - T_0)\big) \tag{1.6}$$

where: R_0 – resistance at reference temperature (usually the room temperature), T_0 – the reference temperature, α – the temperature coefficient of resistance (TCR).

The values of TCR of some typical materials at 20°C are presented in Table 1.2.

Table 1.2. The temperature coefficient of resistance of some materials at 20°C.

Materials	Temperature coefficient of resistance (at 20°C), 1/°C
Silver	0.0038
Copper	0.00386
Gold	0.0034
Aluminum	0.00429
Tungsten	0.0045
Iron	0.00651
Platinum	0.003927
Manganin	0.000002

Example 1.1.

Calculate the change of the resistance of a 200 m long air power connection made with a 16 mm^2 aluminum cable when the external temperature is 40°C in summer and –30°C in winter.

The resistance of this connection (1 wire) is

$$R = \rho\frac{l}{S} = 2{,}82 \cdot 10^{-8}\frac{200}{16 \cdot 10^{-6}} = 0{,}353\ \Omega$$

Assuming that it is the resistance at 20°C we can calculate its values at 40°C and –30°C

$$R_{40} = 0{,}353 \cdot \big(1 + 0{,}00429 \cdot (40 - 20)\big) = 0{,}383\ \Omega$$

$$R_{-30} = 0{,}353 \cdot \big(1 + 0{,}00429 \cdot (-30 - 20)\big) = 0{,}277\ \Omega$$

The changes from reference resistance (at 20°C) to higher one is up to 10% and to lower one is more than 20% (is decreasing).

We see that the resistance of wires, resistors, and other components often change with temperature. This effect is used in temperature sensors that call thermoresistors. They are made of metal, usually Platinum (i.e. Pt100, Pt500, Pt1000) or of ceramic or polimer (thermistors).

1.1.2. Inductor (magnetic coil)

https://youtu.be/uW-M8eBHq9U

An inductor is an element which stores electrical energy in a magnetic field. An inductor can be constructed by winding coils of wire around a magnetic core. *Inductivity L* (in H) is a parameter that represents the inductor and it depends of its construction i.e. number of turns (of wire around the core), cross-section of the core and its magnetic property µ (permeability). The more turns, the higher the inductivity. The inductivity also depends on the shape of the coil, separation of the turns, and many other factors.

The current flowing in a circuit produces an associated magnetic flux (Eq.1.7).

$$\Phi = L \cdot i \tag{1.7}$$

The energy stored in inductor is expressed as

$$w_L = \frac{L \cdot i^2}{2} \tag{1.8}$$

The change in the current through an inductor creates a changing flux, inducing a voltage across the inductor (Faraday's law). The voltage ε induced by any change in magnetic flux through the circuit is given by

$$\varepsilon = -\frac{d\Phi}{dt}$$

and

$$\varepsilon = -\frac{d\Phi}{dt} = -L\frac{di}{dt} \tag{1.9}$$

for L independent of time, current and magnetic flux linkage.

The negative polarity (direction) of the induced voltage is given by Lenz's law, which states that the induced voltage will be such as to oppose the change in current.

Inductors store energy in the form of a magnetic field; this mechanism results in an opposition to AC current known as inductive reactance X_L.

$$I_{eff} = \frac{V_{eff}}{X_L} \tag{1.10}$$

$$X_L = \omega L = 2\pi f L$$

where: f – frequency of sinusoidal current, L – inductivity.

For AC signals with low frequency the influence of an inductor can be neglected. In DC circuit (in steady state) inductor behaves as short circuit.

The difference between inductance and inductivity is that inductance is the property of an electric circuit by which a voltage is induced in it by a changing magnetic field while inductivity is a measure of the capacity for magnetic inductance (also measure of ability to store the energy in magnetic field and also the ability to create the magnetic flux).

In the medium and long transmission lines reactance is more significant than resistance. When sinusoidal current flows within a conductor, the numbers of magnetic flux lines changes and an electromagnetics force is induced in it (Faraday's Law).

The magnetic flux linking with the conductor consist of two parts: the internal and the external flux. The internal flux is induced due to the current flow in the conductor. The external flux produced around the conductor is due to its own current and the current of the other conductors place around it. The total inductance of the conductor is determined by the calculation of the internal and external flux. In home and industry installations the wires of transmission lines are very close to each other and we must consider this effect especially if there are large currents flowing in the wires or the signal frequency is high (i.e. Internet connections).

Worth remembering
In practice inductors have a measurable resistance due to the resistance of used wire and losses of energy in the core. The equivalent circuit of a real inductor is presented at Fig. 1.2

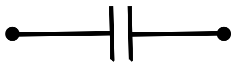
Fig. 1.2. The real inductor's equivalent circuit.

The R_L presents the active energy losses and is mainly referred to as DC resistance. The quality factor (Q) of an inductor is the ratio of its inductive reactance to its resistance at a given frequency, and is a measure of its efficiency. The higher the Q factor of the inductor, the closer it approaches the behavior of an ideal inductor. High Q inductors are used with capacitors to make resonant circuits in radio transmitters and receivers.
The Q factor of an inductor is defined as

$$Q = \frac{\omega L}{R_L}$$

Inductors with ferromagnetic cores experience additional energy losses due to hysteresis and eddy currents in the core, which increase with frequency. At high currents, magnetic core inductors also show significant difference from ideal behavior because of nonlinearity caused by magnetic saturation of the core.

1.1.3. Capacitor



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A capacitor is a circuit element that stores electrical energy in an electric field. A typical capacitor is constructed with two parallel separated conducting plates. Capacitor are represented by a parameter called *capacitance* (in F – farads). Its value depends on the construction of an element in particularly on surface of the plates, the distance between them and dielectric property of the medium (Eq. 1.11).

$$C = \varepsilon \frac{S}{d} \tag{1.11}$$

where: ε – dielectric constant of medium which is between the plates, S – area of the plates, d – the distance between plates.

The charge *q(t)* stored by a capacitor is proportional to the capacitor voltage *v(t)* (Eq. 1.12)

$$q(t) = C \cdot v(t) \tag{1.12}$$

In general, the voltage *v(t)* can vary in a time and consequently, the charge *q(t)* also varies as a function of time. This fact means that there is a current, which is a natural consequence of the change in the amount of charge (Eq. 1.13)

$$i(t) = \frac{dq(t)}{dt} = \frac{d}{dt}(C \cdot v(t)) = C\frac{dv(t)}{dt} \tag{1.13}$$

when the capacitance C does not change in a time.

The energy stored in capacitor is expressed as

$$w_C = \frac{Cv^2}{2} \tag{1.14}$$

Worth remembering
Understand that capacitance is not a physical device. It is capability of any material/body to held charge over itself. Even human body has capacitance. The moment that material/body receive some charge in actual, it becomes capacitor. Now in case of transmission line, it has lot of charge running in the form of current.

From (1.13) it is easy to see that for the DC current the capacitor behaves as a break in the circuit. Thanks to this property, it is used as a DC filter in power grids.

The flow of electrons through a capacitor is directly proportional to the rate of change of voltage across the capacitor. In AC circuits the current flow is also proportional to voltage at capacitor when it varies with frequency *f*:

$$I_{eff} = 2\pi f C \cdot V_{eff}$$

Capacitive reactance X_C in a purely capacitive circuit is the opposition to current flow (1.15).

$$\begin{cases} X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C} \\ I_{eff} = \frac{V_{eff}}{X_C} \end{cases} \tag{1.15}$$

The formula proves that if either the frequency or capacitance is to be increased, the overall capacitive reactance would decrease. Similar to a perfect conductor, the capacitor reactance would reduce to zero as the frequency approaches infinity.

1.2. R-L-C circuit in Sinusoidal Steady-State Analysis

1.2.1. Phasor representation

Lets consider the circuit consisting of R, L and C connected in series and supplied by a voltage source of V_{eff} (volts). The resulting current I_{eff} is flowing in the circuit. Since the elements are connected in series, thus current is same through all of them.

We can describe this circuit using (voltage) Kirchhof's law

$$v(t) = v_R(t) + v_L(t) + v_C(t) \tag{1.16}$$

and regarding dependences (1.2), (1.9), (1.13)

$$v(t) = R \cdot i(t) + L\frac{di(t)}{dt} + \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau \tag{1.17}$$

Solving this equation is very complicated in time domain (even for a simple one-loop containing these three elements) so we employ to establish a relationship between time-varying sinusoidal signal and its representation as a phasor in complex numbers domain, i.e.

$$i(t) = I_{eff}\sqrt{2}\sin(\omega t + \varphi_i) = \mathrm{Im}\left[I_{eff}\sqrt{2}\,e^{j(\omega t + \varphi_i)}\right] = \mathrm{Im}\left[I_{eff}\sqrt{2}\,e^{j\varphi_i}e^{j\omega t)}\right] \tag{1.18}$$

$$i(t) = I_{eff}\sqrt{2}\sin(\omega t + \varphi_i) \Longrightarrow \boldsymbol{I} = \boldsymbol{I_{eff}} = I_{eff}e^{j\varphi_i} \tag{1.19}$$

and

$$\boldsymbol{V} = \boldsymbol{V_{eff}} = V_{eff}e^{j\varphi_v}$$

The equation (1.17) may be written with the use of phasor representation

$$\boldsymbol{V} = R \cdot \boldsymbol{I} + jX_L\boldsymbol{I} - jX_C\boldsymbol{I} \tag{1.20}$$

And the current is easy to determine

$$\boldsymbol{I} = \boldsymbol{I_{eff}} = \frac{\boldsymbol{V_{eff}}}{R + j(X_L - X_C)} = \frac{V_{eff}}{\sqrt{R^2 + (X_L - X_C)^2}}e^{j(\varphi_v - arc\,tg\frac{X_L - X_C}{R})} \tag{1.21}$$

$$i(t) = \frac{V_{eff}}{\sqrt{R^2 + (X_L - X_C)^2}}\sqrt{2}\sin\left(\omega t + \varphi_v - arc\,tg\,\frac{X_L - X_C}{R}\right) \tag{1.22}$$

This technique converts the differential equation to an algebraic equation that is easier to solve in spite of components consisting with complex numbers.

For the convenience of the analysis, the current can be taken as reference phasor. Therefore, the phasor diagram for current and voltages is presented below (Fig.1.3)

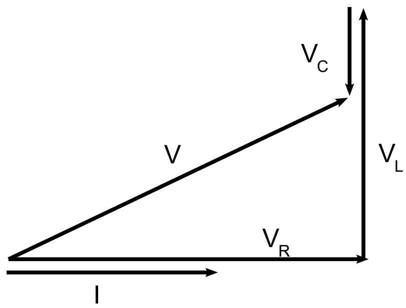

Fig. 1.3. The phasor diagram of voltages and current in RLC serie circuit

where: $\boldsymbol{V_R}$ is in phase with ***I***, $\boldsymbol{V_L}$ is leading the current ***I*** by 90° and $\boldsymbol{V_C}$ is lagging the current ***I*** by 90°.

and the lengths of phasors are the effective (rms) values of

$V_R = R \cdot I_{eff}$ – voltage across resistor,

$V_L = X_L \cdot I_{eff}$ – voltage across magnetic coil,

$V_C = X_C \cdot I_{eff}$ – voltage across capacitor.

1.2.2. Impedance and admittance of RLC circuit

The expressions below are used to describe the elements in a complex domain

– impedance of magnetic coil $\boldsymbol{Z}_L = j\omega L = jX_L$

– impedance of capacitor $\boldsymbol{Z}_C = \frac{1}{j\omega C} = -j\frac{1}{\omega C} = -jX_C$

– impedance of resistor $\boldsymbol{Z}_R = R$.

This RLC circuit can be presented as at Fig. 1.4

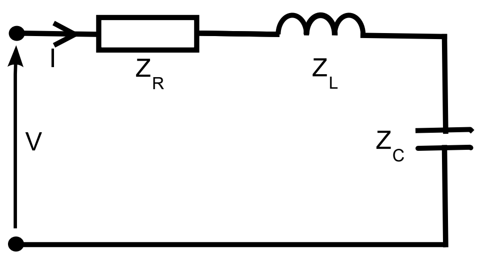

Fig. 1.4. The RLC series circuit

The equivalent impedance of this circuit is

$$\boldsymbol{Z} = \boldsymbol{Z}_R + \boldsymbol{Z}_L + \boldsymbol{Z}_C = R + jX_L - jX_C = Z \cdot e^{j\varphi} \tag{1.23}$$

where:

$Z = \sqrt{R^2 + (X_L - X_C)^2}$, – modul of impedance,

$$\varphi = arc\ tan \frac{X_L - X_C}{R}$$ – argument of impedance (1.24)

The inverse of the impedance is called admittance

$$\boldsymbol{Y} = \frac{1}{\boldsymbol{Z}} = \frac{1}{Z \cdot e^{j\varphi}} = Y \cdot e^{-j\varphi} \quad (25)$$

In general, in AC circuit, the impedance is made up of two parts so is the admittance. The real and imaginary parts of these parameters are presented below

$\boldsymbol{Z} = R + jX$,

$R = Re[\boldsymbol{Z}]$ – resistance,

$X = Im[\boldsymbol{Z}]$ – reactance,

$\boldsymbol{Y} = G + jB$,

$G = Re[\boldsymbol{Y}]$ – conductance,

$B = Im[\boldsymbol{Y}]$ – susceptance.

Resistance, reactance and impedance respectively in a geometrical representation compose **right angled triangle** (Fig.1.5).

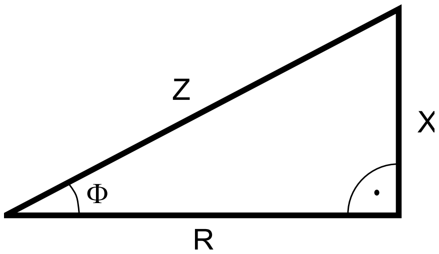

Fig.1.5. The triangle of impedance of AC circuit.

1.2.3. Power and power factor in AC network

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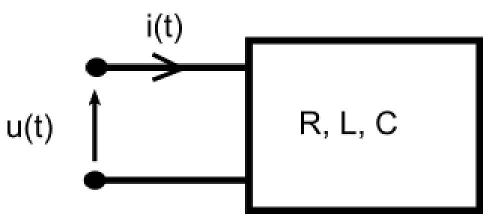


Fig.1.6 A simple AC network

Lets consider the simple circuit shown in Fig.6 and assume the steady-state voltage and current in this network as

$$v(t) = V_{rms}\sqrt{2}\sin(\omega t + \varphi_v)$$
$$i(t) = I_{rms}\sqrt{2}\sin(\omega t + \varphi_i)$$

The instantaneous power is

$$p(t) = v(t) \cdot i(t) =$$
$$= 2V_{rms}I_{rms}\sin(\omega t + \varphi_v)\sin(\omega t + \varphi_i) =$$
$$= V_{rms}I_{rms}\cos(\varphi_v - \varphi_i) + V_{rms}I_{rms}\ \cos(2\omega t + \varphi_v + \varphi_i) \tag{1.26}$$

It consists of two terms: the first one is constant (in term of time) and the second term is a cosine wave of twice frequency of voltage/current signal.

The first term is defined as *active power* expressed in watts (W)

$$P = V_{rms}I_{rms}\cos(\varphi_v - \varphi_i) = V_{rms}I_{rms}\cos(\varphi) \tag{1.27}$$

where $\varphi = \varphi_v - \varphi_i$ is a displacement between voltage and current.

This displacement is caused by the presence of capacitance and inductance in RLC circuit. If there are only resistors then $\varphi_v = \varphi_i$ and the voltage and current are in phase. When if there are only capacitors or inductors (the pure theoretical case) then $\varphi = +90^o$ or $\varphi = -90^o$. The active power is a mean value of instantaneous power and can be expressed as an average value of $p(t)$

$$P = \frac{1}{T}\int_0^T p(t)dt = V_{rms}I_{rms}\cos(\varphi_v - \varphi_i) \tag{1.28}$$

The product $V_{rms}I_{rms} = S$ is named as the *apparent power*. It present the maximum average power that can be transferred with the voltage and current values V_{rms}, I_{rms}. Its unit is called VA (Volt Amper) and has the same physical size as Watt.

The ***reactive power*** is given by

$$Q = V_{rms}I_{rms}\sin(\varphi_v - \varphi_i) = V_{rms}I_{rms}\sin(\varphi) \tag{1.29}$$

The physical unit of reactive power is watt. However, to emphasize the fact that *Q* does not represent the flow of active energy, its unit is usually given as VAR (*V*olt *A*mpere *R*eactive).

The *power factor* (*pf*) is defined as the ratio of the average power to the apparent power

$$pf = \frac{P}{S} = cos(\varphi_v - \varphi_i) \tag{1.30}$$

https://youtu.be/TdwNLcdnR58

https://youtu.be/2mD3UbSW7ho

Worth remembering

The companies that deliver the electrical energy very often define the power factor as

$$pf = tan(\varphi_v - \varphi_i) = \frac{Q}{P}$$

Note that regardless of the sign of the displacement the $cos(\varphi_v - \varphi_i) \geq 0$. It causes that we must give the *pf* value with additional information about the character of a load (inductive or capacitive – leading or lagging). There is no need for this if you give the value as a tangent of displacement. The angle $(\varphi_v - \varphi_i)$ is the phase angle of the load impedance and is often referred to as the power factor angle.

1.2.4. Ohm's and Kirchhoff's laws in AC circuits

The well-known forms of basic formulas of electrical circuits in time domain (Eq. 1.30) will be presented in frequency domain by the following equations

$$\sum_k i_k(t) = 0, \sum_l v_l(t) = 0 \tag{1.31}$$

$$\sum_k \boldsymbol{I}_k = 0, \sum_l \boldsymbol{V}_l = 0 \tag{1.32}$$

where: $\boldsymbol{I}_k$ – phasors of all currents (rms) converging at a given node of the circuit,
$\boldsymbol{V}_l$ – phasors of all drops of voltage (rms) at a considered loop of circuit.

For an one-port network the Ohm's law is of the form

$$\boldsymbol{V}_{rms} = \boldsymbol{Z} \cdot \boldsymbol{I}_{rms} \text{ or } \boldsymbol{I}_{rms} = \frac{\boldsymbol{V}_{rms}}{\boldsymbol{Z}} \tag{1.33}$$

where: $\boldsymbol{Z}$ – (equivalent) complex input impedance of an one-port network,
$\boldsymbol{V}_k$, $\boldsymbol{I}_k$ – complex voltages and currents at the network nodes and loops.

1.2.5. Examples

A. Transmission line

For the general analysis the single Two-Port Network seems to be sufficient approach of the real line.

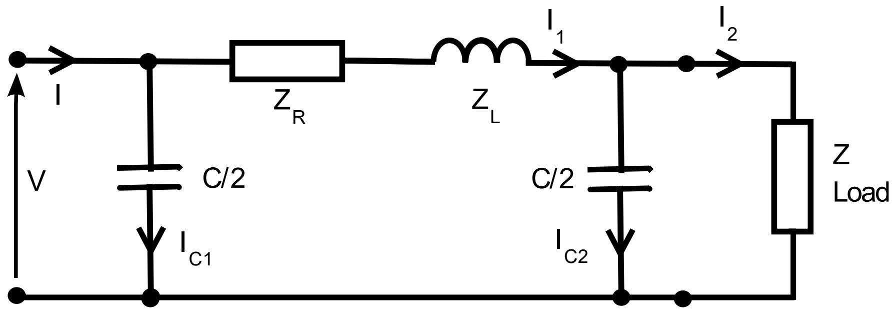


Fig. 1.7. Equivalent model of the real transmission line.

The losses of current can be define as $\Delta \underline{I} = \underline{I}_1 - \underline{I}_2$

The losses of active and reactive powers are

$$\Delta P = P_1 - P_2$$

$$\Delta Q = Q_1 - Q_2 \quad (1.34)$$

The drop of voltage $\Delta \boldsymbol{V}$ is a difference of effective values of voltages at the begin and end of the line.

$$\Delta \boldsymbol{V} = \boldsymbol{V}_1 - \boldsymbol{V}_2$$

The analysis of work of this line can be presented with relevant calculations or with the use of phasor diagrams. Fig. 8 presents the phasors for the line loaded by an inductive load (i.e. RL circuit).

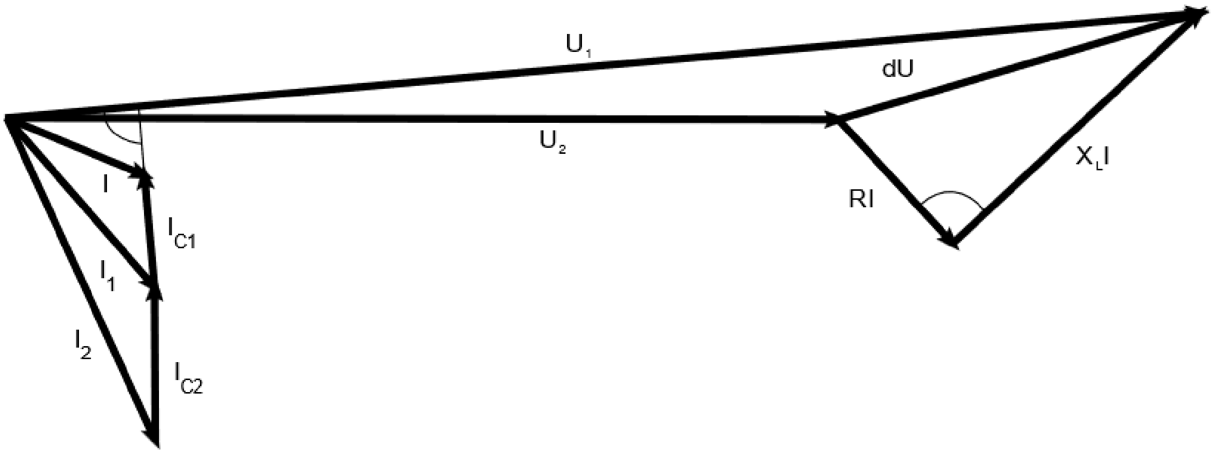


Fig. 1.8. Phasor diagram for R-L load of the line.

B. The home electric installation (1-phase)

Typically, in a home electrical system, there are R and R-L loads on a single phase of power supply. Since the lengths of the wires are not very long, with the 1.5 mm^2 and 2.5 mm^2 copper wires used, their resistances are small and are, for example, for l=10 m respectively

$$R_{1,5} = 1{,}68 \cdot 10^{-8} \frac{10}{1{,}5 \cdot (10^{-3})^2} \frac{\Omega \cdot m \cdot m}{m^2} = 0{,}112\ \Omega$$

$$R_{2,5} = 1{,}68 \cdot 10^{-8} \frac{10}{2{,}5 \cdot (10^{-3})^2} \frac{\Omega \cdot m \cdot m}{m^2} = 0{,}07\ \Omega$$

These resistance values, combined with the values of the currents flowing through them (up to 10–16 A), mean that the voltage drop on the supply line will be less than 2,2 V (10 A at two wires line 1,5 mm^2 and 16 A at 2,5 mm^2).

Because of this fact the diagram of an example load of such a line can be shown in the Fig. 1.9.

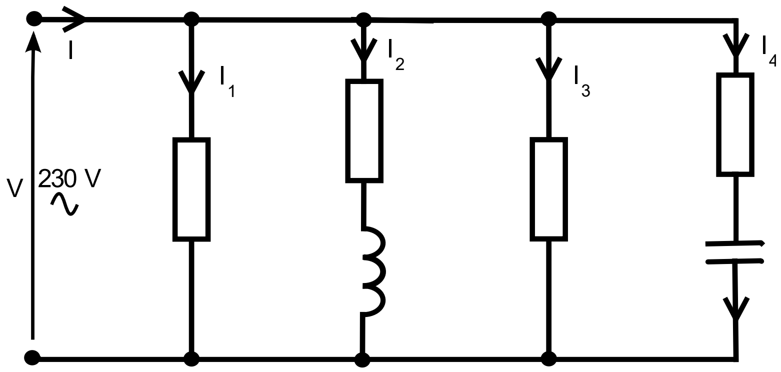


Fig.1. 9. Schematic diagram for a typical home one-phase section of installation.

Manufacturers of household electric equipment do not specify the value of their resistance or inductance, but only the nominal power that these devices have when supplied with their nominal voltage, in this case 230 V.

Lets assume that devices presented at Fig.9 have respectively the power:

$P_1 = 500\ W$, $P_2 = 1500\ W$ with *pf*=0,8 (lagging), $P_3 = 100\ W$, $P_4 = 400\ W$ with *pf*=0,6 (leading). In this section the installer placed a 16 A fuse. Check that the total current supplied to these loads does not exceed the current of this overcurrent circuit breaker.

Solution:

Since the active power is $P = V_{rms} I_{rms} \cos(\varphi)$, the current can be calculated from the relationship

$$I_{rms} = \frac{P}{V_{rms}\cos(\varphi)}, \boldsymbol{I} = I_{rms} e^{-j\varphi} \tag{1.35}$$

$\boldsymbol{I_1} = \frac{500}{230} e^{j0} = 2{,}17\ A$; $\boldsymbol{I_2} = \frac{1500}{230 \cdot 0{,}8} e^{-jarc\cos(0{,}8)} = 8{,}15\ e^{-j37^o} A$;

$\boldsymbol{I_3} = \frac{100}{230} e^{j0} = 0{,}44\ A$;

$$I_4 = \frac{400}{230 \cdot 0{,}6} e^{jarc\cos(0{,}6)} = 2{,}9\ e^{j53^o} A$$

The total current in this section is

$$\boldsymbol{I} = \boldsymbol{I_1} + \boldsymbol{I_2} + \boldsymbol{I_3} + \boldsymbol{I_4} =$$

$$= \left(2{,}17 + 8{,}15\ e^{-j37^o} + 0{,}44 + 2{,}9\ e^{j53^o}\right) = (10{,}9 - j2{,}6) = 11{,}2e^{-j13^o} A$$

Its rms value does not exceed the value of 16 A.

The phasor diagram of these currents and voltage is presented below (Fig.1.10)

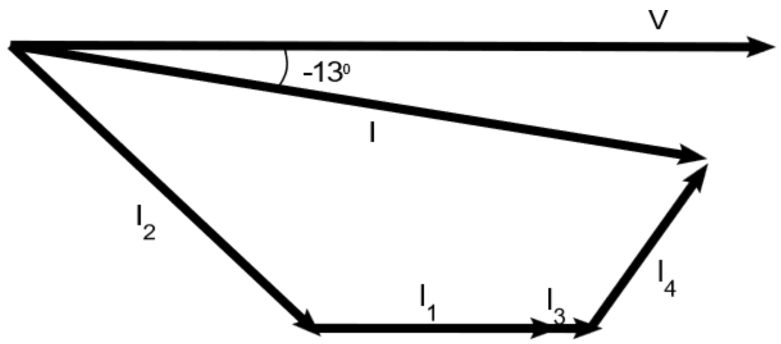


Fig. 1. 10. The phasor diagram for currents and voltage of an example of a loaded section of a home electrical system.

2. Lighting design

Lighting design is a comprehensive process aimed at achieving high-quality lighting that meets the user's expectations and also complies with current lighting standards, requirements and recommendations.

The primary objective of the lighting design is to determine the types of luminaires, the types of light sources, the number of luminaires and their optimum positioning, as well as how the lighting is to be maintained. Only the lighting designer's expertise in the field of lighting technology and his/her experience can guarantee the desired lighting effects of the designed object.

We start work on a lighting project from the planning phase, so we identify the main design objectives, the client's preferences, and analyze the facility and lighting needs. In the next stage, we formulate the design and lighting requirements. Based on the data obtained, we create a lighting concept and select the luminaires, their type, the power of the light sources, the method of light distribution and choose their optimal location.

The design of interior lighting is a rather complex procedure. On the one hand, it is necessary to comply with the lighting parameters defined by the lighting standard, but at the same time it is necessary to select lighting fittings that meet the requirements of the place where they are to be installed. On the one hand, the requirements relating to the aesthetics of the luminaire adapted to the type of room should be met, and on the other hand, the requirements relating to the environment in which the fixture will operate should be fulfilled. Installation requirements and possibilities can also be a limiting condition. When designing a lighting installation, it is also necessary to take into account the costs that the realization of our project will generate for the client. It is therefore necessary to develop an economically rational design.

2.1. Basic volumes used in the description of lighting in rooms.

Among the physical quantities necessary when describing lighting must be:

Luminous flux – symbol: Φ, unit – Lumen

Luminous flux Φ is a measure of the amount of light energy emitted per unit of time. Luminous flux is the portion of the optical radiation emitted by a light source that the human eye can see per unit of time, e.g. a light bulb emits, in addition to visible radiation, infrared radiation; the same is true of a halogen bulb, which emits both infrared and ultraviolet radiation – both invisible to the eye – in addition to visible radiation. A light source with luminous intensity I emits a luminous flux in an elementary solid angle $d\omega$

$$d\Phi = I \cdot d\omega \tag{2.1}$$

The unit of luminous flux is 1 lumen (1lm). This is the luminous flux of a point source of light with an intensity of *I*=1 cd, sent out at a solid angle ω=1 sr.

- Luminous intensity (or the intensity of a light source): symbol – *I*, unit – cd (candela)

  Luminous intensity is the angular (spatial) flux density in a given direction describing a light source. Luminous intensity is the quotient of the luminous flux emitted by a source in a given direction, in a cone with an infinitely small angle of dilation encompassing that direction, to the solid angle ω of that cone:

$$I_v = \frac{d\Phi_v}{d\omega} \tag{2.2}$$

Luminous intensity is a vector quantity, i.e. the same point of shining surface can have different directions.

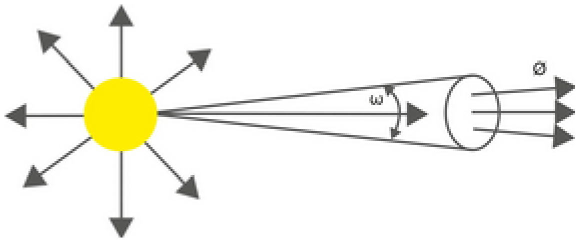


Fig. 2.1. Graphic interpretation of light [source: https://lenalighting.pl/o-nas/baza-wiedzy/937-swiatlosc/].

- Illuminance: symbol – *E*, unit – lx (lux)

  Illuminance *E* is the measure of the power of light energy per unit area illuminated.

$$E = \frac{d\phi_v}{dS} \tag{2.3}$$

where: *dS* is an element of the surface perpendicular to the incident luminous flux

- Luminance: symbol – *L*, unit – cd/m^2

  Luminance is a measure of brightness. It depends on the intensity of the illumination on the object under observation, the reflective properties of the object's surface (color, degree of roughness) and its apparent luminous surface area. The apparent luminous surface area is the size of the area of the luminous plane perceived by the observer depending on the direction of observation:

$$L_v = \frac{dI_v}{dS \cdot cos\theta} \tag{2.4}$$

The difference between the concepts of luminance is illustrated in Figure 2.2.

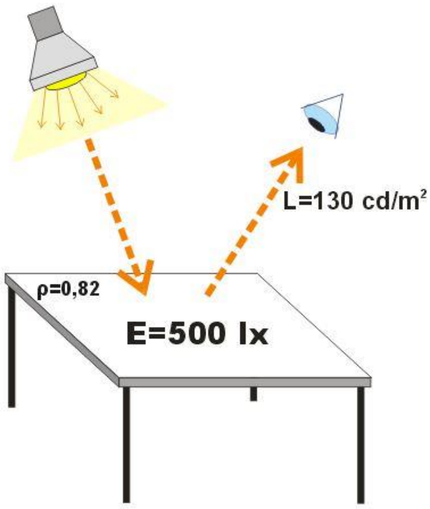


Fig. 2.2. The difference between illuminance and luminance [source: https://www.lampy-przemyslowe-led.eu/30-lampy-przemyslowe-podstawowe-parametry.php]

- Luminous efficacy – symbol: η, unit lm/W

Luminous efficacy (luminous efficiency) defines the quotient of the luminous flux emitted by a specific light source to the energy consumed by it per unit of time (electrical power) and characterizes the efficiency of light production; it makes as much physical sense as the efficiency of other electrical consumers:

$$\eta = \frac{\Phi}{P} \tag{2.5}$$

Figure 2.3 shows the interrelationships between the different quantities used to describe lighting in rooms.

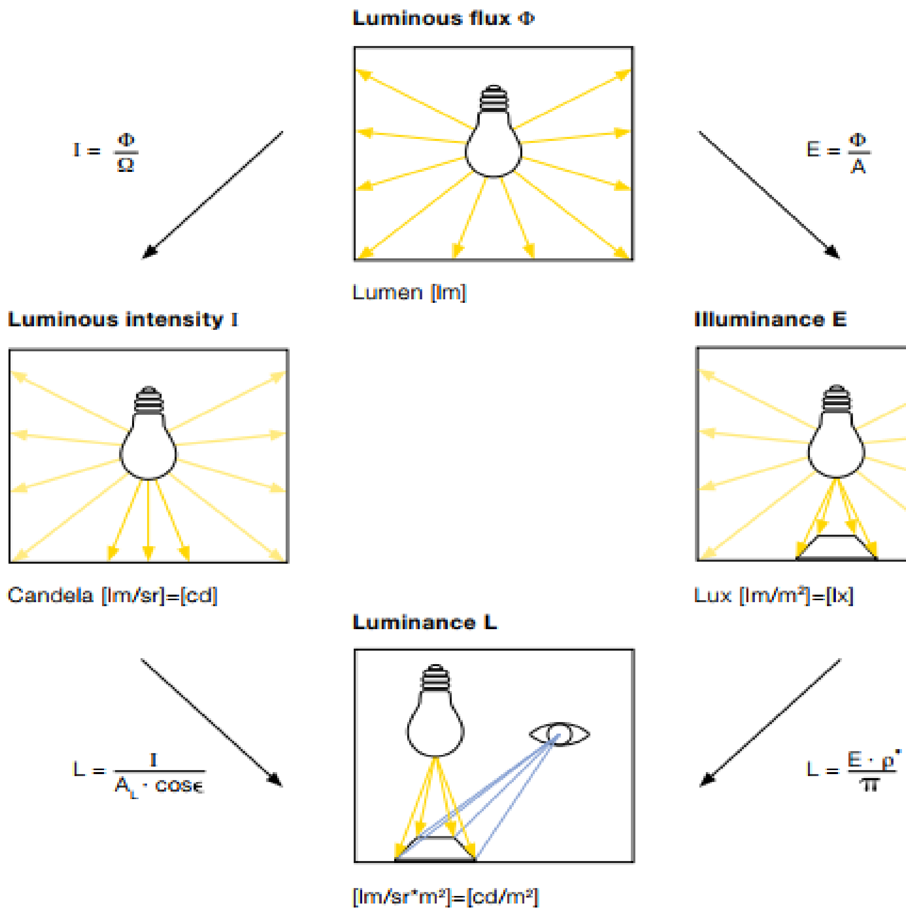


Fig. 2.3. Relationships between the basic quantities used to describe lighting [source: https://zumtobel.us/learn/knowledge-of-light/how-to-measure-light/].

2.2. Sources of light and luminaires

One of the important parameters of light sources, from the point of view of lighting design, is their luminous efficacy (Fig. 2.4), i.e. the number of lumens produced by the source from one watt of its power. From the point of view of the operating costs of designed lighting, it is advantageous to use light sources with the highest possible luminous efficacy.

Fig. 2.4. Luminous efficacy of light sources [source: https://cena-energii.pl/przelicznik_mocy_zarowek.html].

For technical reasons, light sources cannot operate independently. They must be placed in luminaries that serve one or more of the following purposes:

- fixing the light source
- connecting it to the supply system;
- · the right direction of light;
- · protecting the eyes from glare;
- · protecting the light source from external influences;
- · achieving a decorative effect.

Particularly noteworthy is the selection of luminaries as devices to protect light sources from external influences. The selection of lighting equipment for environmental conditions includes:

- chemical composition of the working atmosphere> chemical resistance of the luminaire construction
- ambient operating temperature of luminaires > Ta range dust, moisture > IP degree of protection
- mechanical resistance of luminaires> IK rating
- resistance to ambient corrosive conditions> corrosivity category C

Explosion hazard zones (EX- zones) of gas or dust are not only found in large industrial plants in the chemical and petrochemical industries or in mining, but also on the premises of small businesses such as paint shops, mills, sawmills or coal and coke boilers. In all these places, an explosive atmosphere may exist, i.e. a mixture of flammable substances in the form of gasses, vapors, mists or dusts with air, in which, once initiated by an ignition source, combustion spreads spontaneously. According to safety rules, equipment used in and EX zone must meet a number of requirements.

All explosion-proof luminaires must comply with parameters adapted to the type of explosion hazard zone and the properties of the mixture. Explosion hazard zones are classified according to the probability and duration of the explosive atmosphere. In zone 0, the explosive atmosphere is a mixture of air and gasses, liquids and their vapors (G), and the explosion hazard is present continuously, frequently or for long periods. In zone 1, characterized by the same atmosphere, an explosion may occur occasionally during normal operation, while in zone 2 the hazard does not occur during normal operation and when it does occur it is of short duration. An analogous classification regarding the probability and duration of explosive atmospheres applies to zones 20, 21 and 22, with the difference that they contain a mixture of air and combustible dust (D). Luminaires intended for use in explosive atmospheres are classified according to the danger zones in which they can operate: 0, 1, 2, 20, 21 and 22. All luminaires must have a document certifying that the product is approved for use in the specified conditions, i.e. a CE declaration of conformity or ATEX.

Luminaires for EX zones should be selected so that their maximum external surface temperature does not exceed the auto-ignition temperature of substances forming explosive atmospheres, and thus do not become a source of ignition.

Luminaires can be adapted for extremely high or low temperatures. Examples of luminaire operating temperature range values given in the data sheet are shown in Fig. 2.5.

a) b)

Fig. 2.5. Excerpts from the luminaire data sheets with the indicated operating temperature range [source: https://issuu.com/luglightfactory/docs/lug_into_led_07_2020_pl_web?fr=sYWUzMjE2MzMzODA].

The degree of protection against dust and moisture provided by various types of housing sealing systems is indicated by a special code made up of the letters IP (International Protection Rating) and two digits, the first of which indicates protection against solid objects and the second of which specifies protection against the ingress of water. In the case of luminaires for the EX area, the most common codes are IP 66, IP 67, IP 55, IP 65, IP 68. The number "5" in the first position indicates protection against the ingress of dust in quantities that interfere with the operation of the device, while "6" indicates complete protection against the ingress of dust. The second position specifies protection against the ingress of water. For example, a "5" guarantees protection against water jets from any direction, while a "6" indicates applied protection against strong water jets or wave flooding from any direction. A '7' in the second position, on the other hand, provides protection against submersion to a depth such that the lower surface of the enclosure is 1 m below the water surface and the upper surface is not less than 0.15 m for 30 minutes. The enclosures of explosion-proof electrical equipment must at least comply with protection class IP 54. Table 2.1 provides a summary of the protection classes of equipment.

Table 2.1. Impermeability classes of appliances [1].

FIRST DIGIT protection against ingress of solids		SECOND DIGIT protection against penetration of liquids	
0	no protection	0	no protection
1 (Ø 50 mm)	of diameter >= 50	1	dripping water (condensation)
2 (Ø 12,5mm)	of diameter >= 12,5	2 (15°)	dropping at an angle <= 15°
3 (Ø 2,5mm)	of diameter >= 2,5	3 (60°)	sprayed at an angle <= 60°
4 (Ø 1mm)	of diameter >= 1	4	falling from all directions
5	limited dust protection	5	poured from all directions
6	dustproof	6	poured with a strong stream from all directions
Example: IP 30.D	3 – protection against solid objects larger than 2,5mm; 0 – there is no liquid protection; D – protection against access by tools with dimensions 1mm (wire)	7	short-term immersion
		8	long-term immersion

Another parameter worth paying attention to, especially when designing lighting for public places or outdoor areas, is the mechanical resistance of the luminaires. The classification of mechanical resistance is shown in the following table (Table 2.2)

Table 2.2. Mechanical resistance classification of equipment [source: https://www.smd-led.pl/blog/odpornosc-na-upadki-i-zgniecenia/].

Classification level	Impact force	Example
00	lack of protection and impact resistance	lack of protection resistance
01	impact resistance to energy 0,15J	lightweight hammer blow
02	impact resistance to energy 0,20J	
03	impact resistance to energy 0,35J	
04	impact resistance to energy 0,50J	
05	impact resistance to energy 0,70J	
06	impact resistance to energy 1J	hammer blow with a mass 0,5kg from a high 20cm
07	impact resistance to energy 2J	hammer blow with a mass 0,5kg from a high 40cm
08	impact resistance to energy 5 J	hammer blow with a mass 1,7kg from high 29,5cm
09	impact resistance to energy 10J	hammer blow with a mass 5kg from high 20cm
10	impact resistance to energy 20J	hammer blow with a mass 5kg from high 40cm

From the point of view of the working environment of luminaires, corrosion resistance can also be important, especially if luminaires made of steel sheets operating in corrosively aggressive environments are used.

An important parameter characterizing luminaires as electrical appliances is the protection class, which states to what extent the users of the appliance are protected against electric shock. The standard defines the following classes:

class 0 – luminaire has only working insulation,

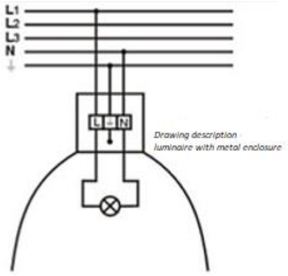
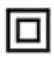
class I – luminaire with protective insulation and protective connection,

class II – luminaire with double reinforced insulation,

class III – luminaire with safe low voltage supply.

Below is a detailed description and graphic designations of the protection classes (Table 2.3)

Table 2.3. Protection classes of lighting equipment [1].

No.	Class	Symbol	Luminare
1	Class 0 working insulation		Protection against electric shock is provided only by basic insulation. The enclosure and other non-voltage parts of the luminaire are isolated from the live parts by means of working insulation. It is not possible to connect the luminaire to the protective conductor of the supply system. Luminaires with protection class 0 should be replaced by luminaires with protection class I or II.
2	Class I Working insulation together with protective bonding.		Protection against electric shock is not only achieved by basic insulation, additional means of protection are used. Accessible conductive parts (metal enclosure, etc.) are connected to the protective conductor of the permanent supply system in such a way that they cannot become active if the basic insulation is 
3	Class II Double or reinforced insulation		Protection against electric shock is achieved not only by using basic insulation, but also by using additional means of protection. Double insulation or reinforced insulation is used. The luminaire is not connected to the protective conductor. The luminaire may have a homogeneous housing of insulating material covering all metal parts, or it may have a metal enclosure and double insulation applied at all points, and reinforced insulation where this is not possible.
4	Class III safe low voltage		Protection against electric shock consists of supplying a very low, safe SELV voltage (up to 50V AC rms) from a protective transformer or inverter with separated windings. The luminaire should not have a protective terminal.

2.3. Volumes characterizing the quality of lighting and their standardization

Workplace lighting influences the quality of vision and thus not only productivity, but also safety. The aim of lighting is to create visual conditions in which people feel comfortable working visually. This is the case when the following conditions are met:

– it is possible to fully distinguish details,

– seeing is not unpleasant, does not cause undue fatigue or discomfort.

PN-EN-12646-1:2012 lists among the parameters affecting lighting quality:

- illumination intensity,
- uniformity of illumination,
- glare,
- color rendering and light color,
- flicker.

In addition, when selecting a luminaire for the room in which it is to be used, the environmental conditions in which the device will be used should be taken into account, such as humidity and dustiness of the air.

Illumination intensity

In the lighting standard PN-EN-12464-1:2012, the specified values of required illuminance are adapted to the nature of the visual work performed in the room. An example of the values is shown in Figure 2.6. A full table of required room illuminance values can be found in Appendix 1.

Fig. 2.6. Examples of selected illuminance values according to the standard EN-12464 [7], [source:https://www.elektroklub.pl/aktualnosci/news,162,jakie-miary-opisuja-swiatlo.html].

Uniformity of lighting

Another standardized parameter for the quality of room lighting is uniformity. This indicator is defined as the ratio of the minimum illuminance to the average illuminance over a given area:

$$U_0 = \frac{E_{min}}{E_{śr}} \quad (2.6)$$

The minimum surface illuminance uniformities required by the standard are given in Table 2.4.

Table 2.4. Required values for uniformity of illumination on surfaces depending on the type of activity [7]

Type of activity performed	**Smallest acceptable uniformity of illumination**
Work surface on which long-term (casual) work is carried out	0,6
Work surface on which short-term (casual) work is carried out	0,4
Communication routes (corridors)	0,4

Uniformity of lighting is influenced by the parameters of the luminaires used and how they are positioned in the room. The luminaire’s light curve (photometric polar diagram) and light distribution angle are among the dimensions that characterize the luminaire and significantly influence uniformity.

In order to visualize the light distribution of a luminaire, its luminous intensity is measured in various directions. By converting the results into the values that would be obtained using light sources with a total luminous flux of 1000 lm, a curve is created which is called the luminaire luminosity diagram. The conversion to 1000 lm makes it possible to compare the luminosity curves produced for luminaires with different light sources. The angle of illuminance, is the angle of intersection of the curve of the luminaire's luminance diagram with the radial line defining half the value (50%) of the maximum luminous intensity (Imax – cd/1000lm) of that luminaire.

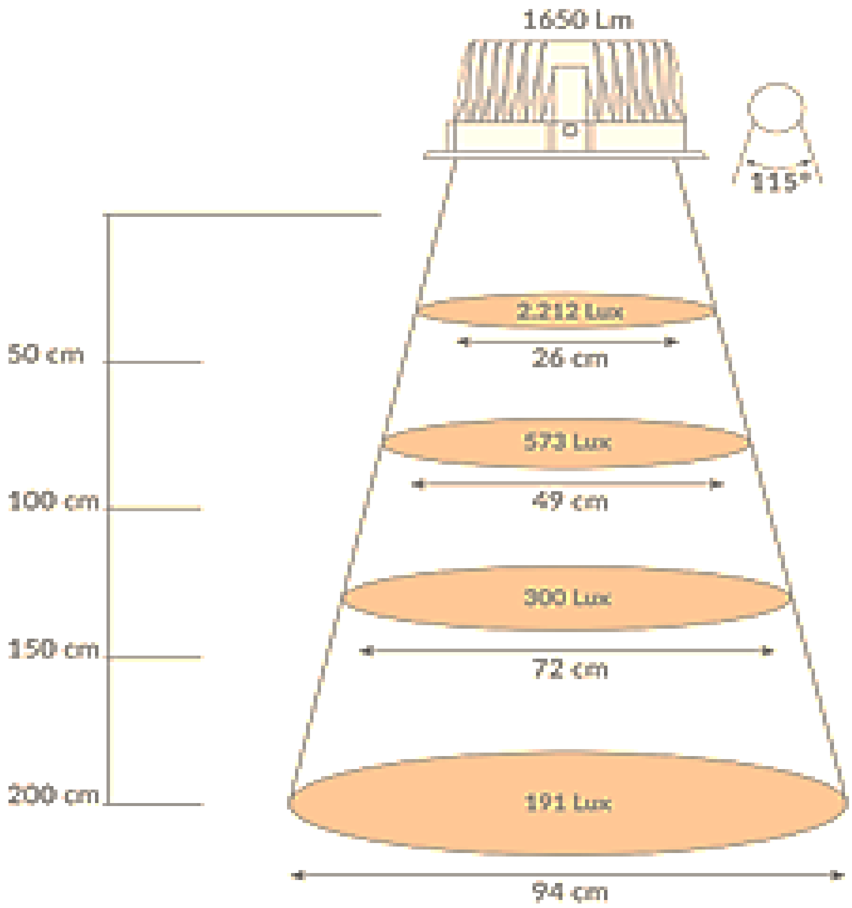


Fig. 2.7. Dependence of illuminated surface size and illuminance on luminaire distribution angle and distance of working surface from luminaire [source: https://luxon.pl/oswietlenie-stanowiska-pracy-jakie-normy-i-wymagania-musi-spelniac/]

Fig. 2.7 shows that if the distance between the work surface and the luminaire was 200 cm, the surface would be illuminated with an intensity of 191 lux, whereas if the distance was 150 cm, the intensity would increase to 300 lux, but the uniformity of illumination would decrease, as unlit areas would appear between the illuminated areas. If luminaires with a narrow light distribution are installed at a short distance above the working surface, very poor uniformity of illumination is obtained on the working surface, with alternating bright and dark areas visible.

Glare

The assessment of unpleasant glare in rooms and workplaces involves comparing the Uniform Glare Reduction Ratio (UGR) value determined in the lighting design with the limiting value (maximum acceptable value) of this parameter, in accordance with the EN-12464-1:2012 standard. The UGR glare index determines what the risk of glare is for a given lighting situation. The value of the glare index depends on, among other things, the photometric shape of the luminaires used, their positioning or the background luminance.

A distinction can be made between direct and indirect glare. Direct glare results from light rays falling directly from the luminaire, the light source, into the human eye, while indirect (reflected) glare results from light reflected from various obstacles (white walls, furniture, etc.). Direct glare is the main cause of discomfort, which at luminance values above 700 cd/m2 will cause unpleasant glare. Lighting should be selected and installed in relation to the workstation so as to offset the discomfort caused by glare. The standard gives, in tables of lighting requirements, UGR values for specific types of interiors, tasks or activities. The required UGR values should be taken into account at the design stage (Table 2.5)

Table 2.5. UGR values allowed at selected workplaces

Type work, premises	UGR logarithmic scale PN-EN 12464 [7]	UGR linear scale
Operating rooms	10	71
Quality control of microelectronics	13	169
Drawing, colour controls	16	200
Painting, sorting	19	948
Mechanical repairs	22	2249
Stairs, warehouses	25	5334
Corridors	28	12649

[source: https://www.elektro.info.pl/artykul/oswietlenie/159977,ocena-olsnienia-swietlnego-na-stanowiskach-pracy]

<u>Light color and color rendering</u>

The color of light is defined by the so-called color temperature (Tc) and is given in kelvin [K]. Light sources that emit white light can be classified according to their color temperature into three groups: warm (less than 3 000 K), neutral (intermediate) (3 300 to 5 300 K) and cool (cold) (above 5 300 K to 6 500 K). Warm-coloured lighting is ideal for rooms intended for relaxation: the bedroom, bathroom or living room. Cold lighting is more conducive to concentration, stimulation and learning. It is also more beneficial for work that requires visual effort. Cold-coloured bulbs work well in offices, production halls and can be used to illuminate the desk area, for example in a desk lamp. In hallways, vestibules and staircases, neutral-coloured light can be used, i.e. between warm and cold.

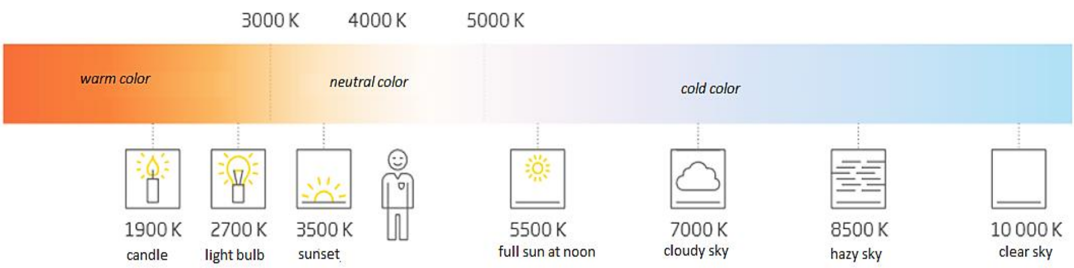


Fig. 2.8. Light color vs temperature
[source: http://www.swiatlo.tak.pl/1/index.php/wskaznik-oddawania-barw]

To ensure good color reproduction and proper color contrast, light sources with a high color rendering index should be used. Then the objects we observe appear in their natural, unadulterated colors. The color rendering index Ra (CRI) has a maximum value of 100 and corresponds to natural sunlight, which is the reference for other light sources. The Ra index carries information about the extent to which a light source allows colors to be observed.

Light sources with a color rendering index greater than 80 should be used in working rooms, while light sources with a color rendering index greater than 90 should be used in rooms where accurate color reproduction is particularly important, such as in school art classrooms, textile, meat and paint shops and dentists' surgeries. There are also light sources designed for color control workstations. Their color rendering index is as high as 98.

2.4. Methods of the lighting calculation

A widely used, free-of-charge programme for the calculation of both interior and exterior lighting is DIALUX.

The programme allows both the loading of a .dwg file and the creation of an object directly in the programme using the menu: Main menu > Constructions > Floor and building constructions. An example of the effect of a building floor created in DIALUX is shown in Figure 2. 9.

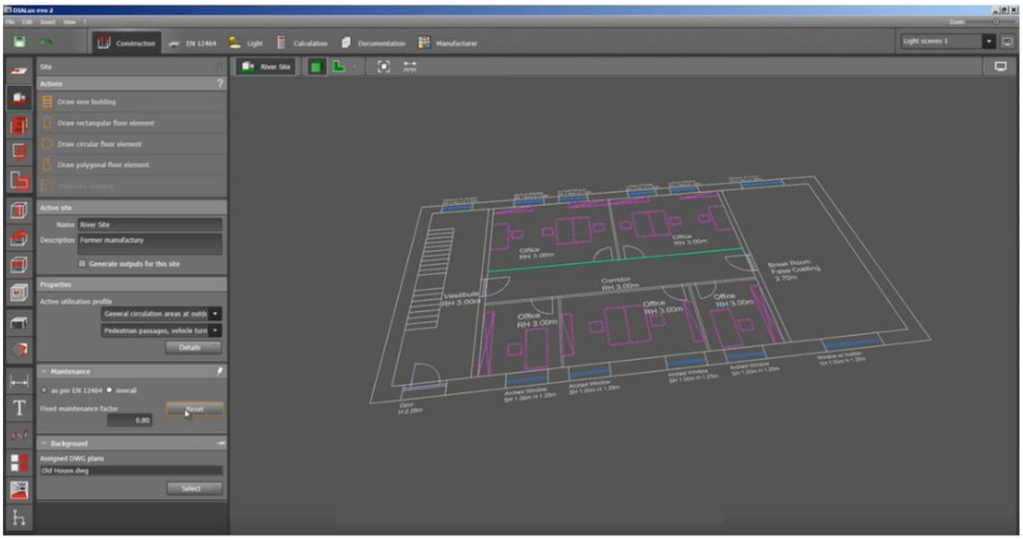


Fig. 2.9. Window for creating the object for which the lighting is to be calculated [source: software Dialux evo].

Once a building plan has been imported or plotted in Dialux (or an individual room), it is necessary to select the luminaire(s) to be used for the lighting design. Dialux has the ability to import the lighting fixture catalogs of a large number of lighting equipment manufacturers. A view of the programme window through which the selected luminaires can be imported into the programme is shown in Figure 2.10.

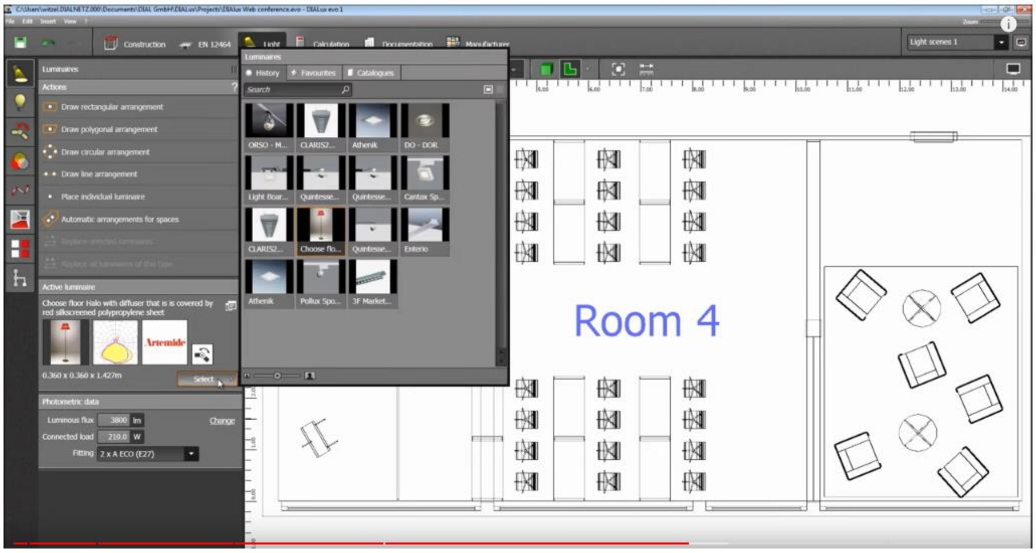


Fig. 2.10. Window for loading luminaire catalogs and their selection for use in the project [source: software Dialux evo].

In the luminaire positioning menu (Figure 2.11), the positioning method is selected and the effect shown opposite is obtained. When the option Start calculation is selected, the programme calculates the lighting parameters in the object for the selected assumptions.

a)

b)

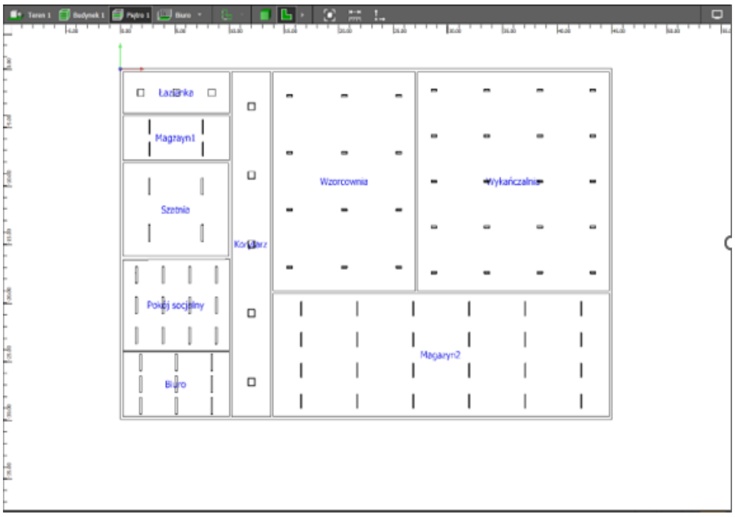
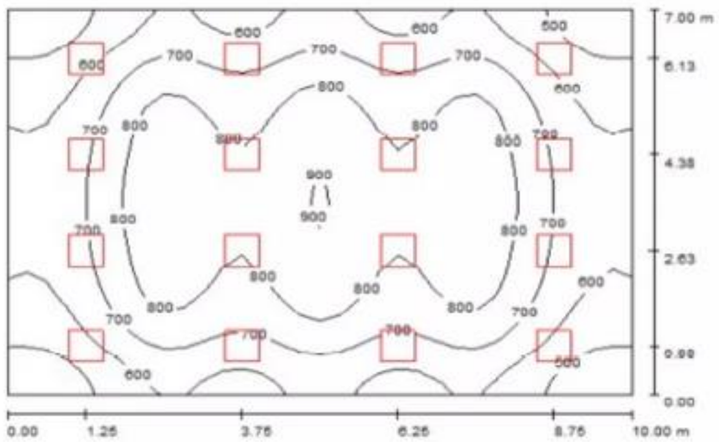


Fig. 2.11. View of the luminaire arrangement menu in the object (a)) and the effect of the selection made (b)) [source: software Dialux evo].

Once the calculations have been performed, it is possible to view the results and save them as a .pdf file. The content of the report is also up to the designer. The most important values to check and accept (or reject and run another simulation) are the average illuminance and the uniformity of illuminance. If difficulties arise in achieving the required uniformity of illumination, a margin of 0.5m from the wall can be used, which is not included in the uniformity calculation (it is assumed that visual work is not carried out right next to the wall).

How the results are derived is up to the user of the software. The most relevant information needed to assess whether the choice of luminaires and their positioning is correct can be found under Documentation>Building>Partment>Work plane (Fig. 2.12)

workstation / **Summary**



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:90

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	702	421	915	0.60
Floor	68	665	391	858	0.59
Ceiling	80	341	220	414	0.64
Walls (4)	50	420	233	647	/

Workplane:		UGR	Lengthways-	Across	to luminaire axis
Height:	0.560 m	Left Wall	14	15	
Grid:	32 x 32 Points	Lower Wall	14	15	
Boundary Zone:	0.000 m	(CIE, SHR = 0.25.)			

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.593, Ceiling / Working Plane: 0.485.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	16	TBS300/418,MIRROR-C6 (1.000)	5200	95.9
		Total:	83200	1534.4

Fig. 2.12. Results of room lighting calculations [source: software Dialux evo].

The most important parameters shown in Fig. 2.12 are E – average illuminance and g1 – illuminance uniformity (Emin/E). In addition, isolux (lines of constant illuminance values) and the position of the planned luminaires are plotted on the room drawing.

A more detailed description of the programme can be found in studies [2, 7].

2.5. Mistakes made in lighting design

Although the design of lighting in rooms, particularly with the use of appropriate software, appears to be a relatively straightforward task, several seemingly innocent mistakes can be made during the design process, which can lead to calculation results that are not in line with reality. Where do such errors come from, when the standard clearly and unambiguously defines the requirements for lighting? Sources of error can be:

- failure to take into account all the requirements contained in the standard,
- deliberate actions to achieve a satisfactory calculation result,
- a lack of complete knowledge on the part of the designer as to the parameters of the room or the type of pattern work to be performed there.

The last of the above-mentioned reasons deserves special attention. Lighting parameters should be calculated, and compared with the requirements, on a working plane. Usually the height of this plane is assumed to be 0.8m. However, it should be noted that this height will not be appropriate in all rooms, e.g. in passageways this surface will be the floor area. Incorrectly defining the height of the work surface may result in it failing to comply with the parameters defined by the regulations.

Another source of errors in the calculation and results of illuminance in rooms may be the incorrect assumption of floor, wall and ceiling reflectance coefficients (the values of reflectance for individual room surfaces can be determined in the Dialux programme or the default ones proposed by the programme can be adopted). It is not uncommon for the reflected light (indirect component) to account for more than half of the obtained illuminance value on the working plane. For calculations, standard values of reflectance are usually assumed (wall – 50%; ceiling – 70%; floor – 20%). However, if, for example, dark-coloured walls or a large area of glazing is involved, this should necessarily be taken into account in the calculation. Furthermore, the technical description of the lighting installation should provide information for which reflectance coefficients of the surfaces in the room were calculated.

Ignorance by the lighting designer of the environmental conditions in which the luminaires will operate can also result in incorrect luminaire selection. Also, a change in the intended use of the room after the lighting has been designed or during operation can lead to the lighting losing its proper function. Different luminaires should be chosen for a room in a bakery, where the luminaire is exposed to dust (flour), and others for a room in which, for example, cleaning takes place, causing water splashes.

In the design process, attention should also be paid, for example, to the temperature at which the lighting equipment will operate. When designing lighting for a cold store, luminaires should be chosen that will operate faultlessly at temperatures down to –50°C, whereas in the case of bakery lighting, the temperature may exceed 30°C.

An important influence on the result of the illuminance calculation is the maintenance factor adopted. Its value reflects the soiling of the luminaires during operation. In an ideally clean room, e.g. operating theaters, the maintenance factor can be set equal to 1. The dustier the room, the lower the factor should be. In moderately dusty facilities with a cleaning interval of approx. 2 years, this coefficient is assumed to be around 0.75–0.8. The Dialux software allows the designer to set the maintenance coefficient value freely for individual rooms in the building (Fig. 2.13).

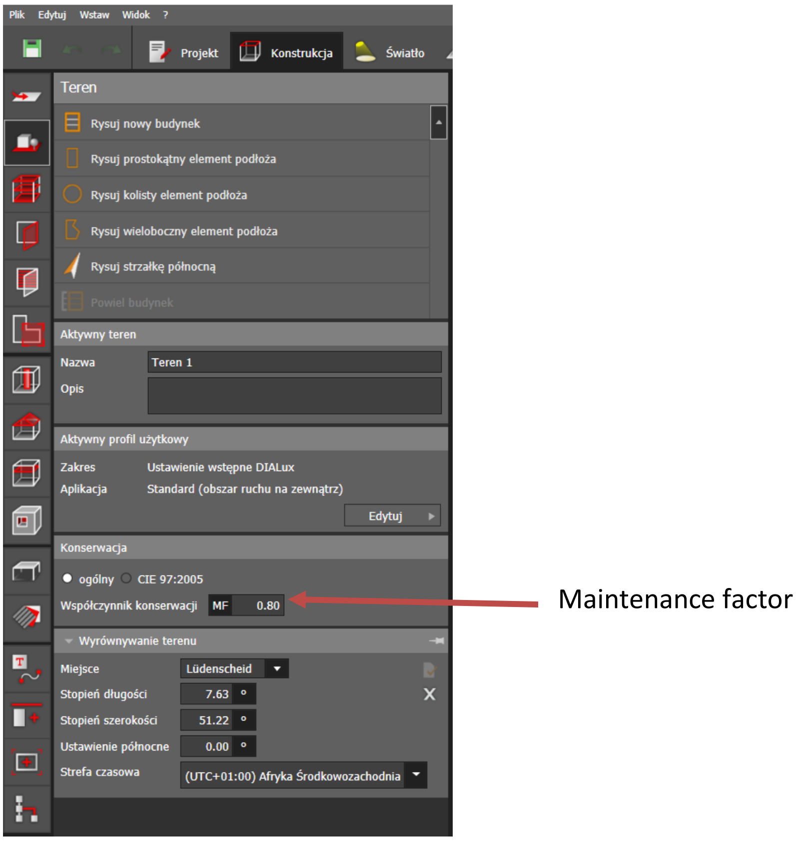


Fig. 2.13. Location where the maintenance factor is set in Dialux evo 10.1 [source: software Dialux evo].

3. Determination of loads on electrical installations

3.1. Determination of circuit loads

If we consider the types of final circuits we are dealing with in a building electrical installation project, these are:

a) Lighting circuits,

b) Socket circuits

c) Machine supply circuits on the production floor

The simultaneity factor k_j is used to determine the loads on both circuits and switchgear. The simultaneity factor is an estimate that takes into account the fact that it is rare in an installation that all equipment is switched on at full power simultaneously.

In the general case, the circuit load power can be calculated as:

$$P_o = \sum_{i=1}^{n} n_i . k_{ji} \cdot P_i \quad (3.1)$$

where:
n_i – the number of appliances with power P_i connected to the circuit under analysis
k_{ji} – simultaneity coefficient for equipment with power P_i
The simultaneity factor may have a value in the range $(0,1\rangle$

a. For lighting circuits, the factor $k_{ji} = 1$ because switching on a circuit switches on all n lamps of that circuit, which have equal power and operate at full power and the formula 3.1 takes the form:

$$P_o = n \cdot P_l \quad (3.2)$$

E.g. a circuit consists of 20 lamps of 12W each so the circuit load will be equal:

$$P_o = 20 \cdot 12W = 240W$$

b. for plug socket circuits, $k_j = 0{,}3$ is taken as the maximum load per socket, with a power of $P_g = 2000W$ and then equation 3.1 can be written as:

$$P_o = n \cdot k_j \cdot P_g \quad (3.3)$$

Suppose there are 4 single-phase sockets connected to a circuit, then the load power of the circuit will be calculated as:

$$P_o = 4 \cdot 0{,}3 \cdot 2000W = 2400W$$

c. For circuits feeding on the production floor, the following situations are potentially possible.

c.1 The circuit supplies only one appliance then the circuit load power P_o is equal to the appliance power i.e. $P_o = P_1$

c2. The circuit supplies several devices working together (e.g. successive process line devices with different capacities), then equation 3.1 can be written in the form:

$$P_o = (P_1 + P_2 + P_3 + \cdots + P_n) \cdot k_j \tag{3.4}$$

The power values substituted into the above formula are the electrical power of the equipment. In the case of motors, it must be remembered that the power given on the appliance nameplate is the rated power at the motor shaft. To obtain the electrical power value, the efficiency of the motor must be taken into account and the electrical power calculated as:

$$P = \frac{P_m}{\vartheta} \tag{3.5}$$

where: P_m means rated mechanical power, ϑ – motor efficiency.

The efficiency of the motor should be read off the appliance data sheet. This figure depends on the design of the appliance, the materials used in its construction and, finally, its power. In the absence of such information, the example values given in the table 3.1 can be used.

Table 3.1. Examples of motor efficiency ratios

Type of motor	Rated output P_n		Rated speed N_n	Rated Torque M_n	Efficiency η_n	Power factor cosφ	Full-load amps I_{ln} at U_N (nominal voltage)		
	[kW]	[HP]	[min^{-1}]	[Nm]	%	–	[A] 380V	[A] 400V	[A] 500V
2p=4						N=1500 min^{-1}			
Sg 80-4A	0,55	0,75	1430	3,7	74,4	0,76	1,5	1,4	1,1
Sg 80-4B	0,75	1,0	1425	5,0	75,4	0,77	2,0	1,9	1,5
Sh 90S-4	1,1	1,5	1405	7,5	76,7	0,80	2,7	2,6	2,1
Sh 90L-4	1,5	2,0	1410	10,2	79,0	0,78	3,7	3,5	2,8
Sg 100L-4A	2,2	3,0	1425	14,7	82,0	0,80	5,1	4,8	3,9
Sg 100L-4B	3,0	4,0	1415	20,2	82,7	0,81	6,8	6,5	5,2
Sg 112M-4	4,0	5,5	1435	26,6	85,1	0,82	8,7	8,3	6,6
Sg 132S-4	5,5	7,5	1450	36,2	85,9	0,84	11,6	11,0	8,8
Sg 132M-4	7,5	10,0	1450	49,4	87,0	0,85	15,4	14,6	11,7
Sg 160M-4	11,0	15,0	1460	72,0	89,0	0,85	22,1	21,0	16,8
Sg 160L-4	15,0	20,0	1460	98,1	89,5	0,87	29,3	27,8	22,2
Sg 180M-4	18,5	25,0	1470	120,2	90,5	0,90	34,5	32,8	26,2
Sg 180L-4	22,0	30,0	1465	143,4	91,0	0,90	40,8	38,8	31,0

The k_j factor is determined from the process line documentation or from information provided by the production technologist of the industrial plant.

EXAMPLE 3-1

If appliances with electrical powers of e.g. 11kW, 15kW and 7,5kW for which the simultaneity coefficient $k_j = 0{,}5$ has been specified work together, the circuit load is calculated as:

$$P_o = (11 + 15 + 7{,}5) \cdot 0{,}5 = 16{,}75kW$$

3.2. Determination of switchgear loads.

The value of the load on the switchgear that we determine during design determines the calculated current of the circuit feeding the switchgear, and thus the cross-section of the cable/supply cable. If we do not properly determine the load of the switchgear, e.g. by simply adding up the powers of all the devices connected to it, the result will be an oversizing of the cable feeding the switchgear, and thus the installation will be economically inefficient. Furthermore, for the selection of reactive power compensation devices we need information on the load of the switchgear in which we intend to place the compensator, both with active and reactive power. It should be added, however, that currently the selection of compensating devices takes place after the start-up of an industrial plant or other facility and the determination of the reactive load value.

Let's assume that our example installation has switchgear:

a) Lighting – to which the lighting and socket circuits are connected
b) Power – to which the production equipment circuits are connected
c) Main – through which lighting and power switchgear are supplied.

There may be more than one lighting and power distribution board in a large building.

a. **Lighting switchgear** – lighting circuits and socket circuits are connected to this. To draw up a balance sheet for the RO lighting distribution board, we need to to note that lighting lamps can have different wattages and power factors, i.e. light sources can be either inductive (e.g. fluorescent lamps) or capacitive (e.g. leds). The value of the power factor can be read from the data sheet of the device or, in the absence of such information, it can be assumed that for fluorescent luminaires $cos\varphi_{average} = 0{,}8$ (inductive), and for led luminaires $cos\varphi_{average} = -0{,}9$ (capacitive).

The simultaneity factor for all lighting in the building is also an important factor. This is a different coefficient this time than for a single circuit and is due to the fact that not all lighting circuits in the building are switched on at any given time, e.g. lighting in toilets, some storerooms and corridors etc. are used for a short period of time. From this it follows that the simultaneity coefficient for lighting $k_{jo} = 0{,}8$ (2) can be assumed in such buildings where the predominant room is a production hall in which the lighting equipment is fully used. The value of coefficient k_{jo} can be taken as less than 0.8 if there are many rooms in the building fulfilling different functions which are not used simultaneously or, e.g. in office buildings, higher than 0.8 as in these buildings the lighting is used in almost all rooms of the building simultaneously. Examples of simultaneity coefficients for lighting are shown in the table below.

Table 3.2. Examples of simultaneity coefficients for lighting in different types of buildings [2]

L.p.	Type of facility	k_{jo}
1	Industrial building with production hall	0,8
2	Public buildings	0,95
3	Hospitals	0,7–0,9

For sockets throughout the building, the simultaneity factor is usually taken as $k_{jg} = 0{,}15$.

The general formula for the design load of a lighting distribution board by active power can be written as:

$$P_{RO} = \sum_{i=1}^{N}(n_i \cdot P_i) \cdot k_{jo} + n_g \cdot P_g \cdot k_{jg} \tag{3.6}$$

where:

Similarly for reactive power:

$$Q_{RO} = \sum_{i=1}^{N}(n_i \cdot Q_i) \cdot k_{jo} + n_g \cdot Q_g \cdot k_{jg} \tag{3.7}$$

where:

$$Q_i = P_i \cdot tg\varphi_i \tag{3.8}$$

$$Q_g = P_g \cdot tg\varphi_g \tag{3.9}$$

whereby $tg\varphi_g$is the result of the $cos\varphi_g = 0{,}9$ assumed for sockets.

Based on the determined values of active and reactive power loading the switchgear, the apparent power can be calculated from the formula:

$$S_{RO} = \sqrt{P_{RO}^2 + Q_{RO}^2} \tag{3.10}$$

EXAMPLE 3-2

Suppose that a lighting switchgear is connected:

– 20 fluorescent luminaires of P_1=36 W,

– 30 fluorescent luminaires of P_2=58 W,

– 70 luminaires with led sources of P_3=12 W,

– 50 single-phase sockets for which the load power $P_g = 2000\ W$.

The active power load of the switchgear is then calculated according to formula 3.6 from the relationship:

$$P_{RO} = (20 \cdot 36 + 30 \cdot 58 + 70 \cdot 12) \cdot 0{,}8 + 50 \cdot 2000 \cdot 0{,}15 = 2640 + 15000 = 17640\ W$$
$$= 17{,}64\ kW$$

The apparent power load, on the other hand, is calculated according to formula 3.7 as:

$$Q_{RO} = (20 \cdot 36 \cdot 0{,}751 + 30 \cdot 58 \cdot 0{,}751 - 70 \cdot 12 \cdot 0{,}483) \cdot 0{,}8 + 50 \cdot 2000 \cdot 0{,}15 \cdot 0{,}483$$
$$= 1441{,}74 + 7245 = 8398{,}4\ var \approx 8{,}4\ kvar$$

Where:

$$cos\ \varphi = 0{,}9 \rightarrow\ tg\varphi = 0{,}483$$

$$cos\varphi = 0{,}8 \rightarrow\ tg\varphi = 0{,}751$$

The apparent power loading on the switchgear will be equal to:

$$S_{RO} = \sqrt{17640^2 + 8398{,}4^2} = 19537{,}2\ VA \approx 19{,}5\ kVA$$

b. **The power distribution board** – the circuits of the production machines are connected to it. The load on the power distribution board is most easily determined using simultaneity factors. Values for these coefficients are best obtained from equipment data sheets and/or from consultation with the production technologist. When such data is not available, statistical values should be used. The value of these coefficients will depend on the power of the individual pieces of equipment, their mode of operation and their number. In modern industry, the values of simultaneity coefficients for production equipment have increased, due to changes in the organisation of work and automation of production.

Table 3.3 Example simultaneity coefficients for machinery and equipment [2]

Lp.	**Device/machine**	$\boldsymbol{k_{jm}}$
1	Fans	1
2	Compressors	0,9
3	Lift motors	0,6–1
4	Lathes	0,6–0,7
5	Resistance furnaces	1

In the absence of further information on how the motors work, a simultaneity coefficient of 0.8 can be assumed for outputs below 100 kW and 1 above 100 kW.

EXAMPLE 3-3

1. The following equipment connected to the power distribution board was installed in the workshop:

   – 10 fans of P_w= 250 W,

   – 5 compressors of P_s=12 kW,

– 5 3f sockets with current *I*=16 A,

– 10 lathes of P_t=4 kW,

– resistance furnace of P_p=15 kW.

To be able to calculate the active, reactive and apparent power load on the switchgear, we need to assign power factors and simultaneity factors to the individual devices connected to the switchgear.

Table. 3.4 Power coefficients and simultaneity coefficients assigned to the equipment in the sample switchgear

Lp.	Device name	Power kW	Power factor $cos\varphi$	Simultaneity factor
1	Fan	0,25	0,75	1
2	Compressor	12	0,85	0,9
3	Socket	11	0,9	0,15
4	Lathe	4	0,82	0,65
5	Resistance furnace	15	1	1

In doing so, it is first necessary to calculate the power we can connect to a single three-phase 16 amp socket. We make the calculation using the known formula for power in a 3-phase system:

$$P_{g3f} = 3 \cdot I \cdot U = 3 \cdot 16 \cdot 230 = 11040\, W \approx 11\, kW$$

From the data collected, we can calculate the active power balance of the switchgear:

$$P_{RS} = 10 \cdot 0{,}25 \cdot 1 + 5 \cdot 12 \cdot 0{,}9 + 5 \cdot 11 \cdot 0{,}15 + 10 \cdot 4 \cdot 0{,}65 + 1 \cdot 15 \cdot 1 \approx 106\, kW$$

To determine the reactive power loading on the switchgear, we calculate the reactive powers of the equipment from the relationship e.g:

$$Q = P \cdot tg\varphi$$

Table 3.5 Calculated values of reactive power of devices installed in the power distribution board

Lp.	Device name	Power kW	Power factor $cos\varphi$	$tg\varphi$	Reactive power kvar
1	Fan	0,250	0,75	0,882	0,22
2	Compressor	12	0,85	0,620	7,44
3	Socket	11	0,9	0,483	5,313
4	Lathe	4	0,82	0,698	2,792
5	Resistance furnace	15	1	0	0

Using the data from the tables above, we calculate the reactive power loading on the power distribution board:

$$Q_{RS} = 10 \cdot 0{,}22 \cdot 1 + 5 \cdot 7{,}44 \cdot 0{,}9 + 5 \cdot 5{,}313 \cdot 0{,}15 + 10 \cdot 2{,}792 \cdot 0{,}65 + 1 \cdot 0 \cdot 1 \approx 57{,}8\, kvar$$

Apparent power loading of the power distribution board:

$$S_{RS} = \sqrt{105{,}75^2 + 57{,}813^2} \approx 120{,}5\, kVA$$

c. **Main switchgear** – Using simultaneity factors at the level of load calculation for the subordinate switchgear (lighting and power), the load on the main switchgear can be calculated as the sum of the loads on these switchgear:

$$P_{RG} = P_{RO} + P_{RS} \tag{3.11}$$

$$Q_{RG} = Q_{RO} + Q_{RS} \tag{3.12}$$

EXAMPLE 3-4

Let's assume that the lighting and power sub-districts are supplied from the main R_G switchgear. The load on these switchgear is equal to respectively:

– lighting switchgear: $P_{RO} = 17{,}64\ kW$, $Q_{RO} = 8{,}76\ kvar$

– power distribution board: $P_{RS} = 105{,}75\ kW$, $Q_{RS} = 57{,}81\ kvar$

The load on the power distribution board will then be:

$$P_G = 17{,}64 + 105{,}75 = 123{,}39\ kW$$

$$Q_G = 8{,}76 + 57{,}81 = 66{,}57\ kvar$$

$$S_G = \sqrt{123{,}39^2 + 66{,}577^2} = 140{,}2\ kVA$$

4. Definition and methodology of calculation cross sections and conductors and protective device

4.1. Definition

Maximum load current: I_B

At the final circuits level, this design current (according to IEV "**I**nternational **E**lectrotechnical **V**ocabulary" ref 826-11-10) corresponds to the rated kVA of the load.

Maximum permissible current: I_z

Current carrying capacity I_z is the maximum permissible that the cabling for the circuit can carry indefinitely, without reducing its normal life expectancy.

The current depends, for a given cross sectional area of conductors, on several parameters:

- Constitution of the cable and cable-way (Cu or Alu conductors; PVC or EPR etc. insulation; number of active conductors),
- Ambient temperature,
- Method of installation,
- Influence of neighbouring circuits.

Overcurrents

An overcurrent occurs each time the value of current exceeds the maximum load current I_B for the load concerned.

This current must be cut off with a rapidity that depends upon its magnitude, if permanent damage to the cabling (and appliance if the overcurrent is due to a defective load component) is to be avoided.

Overcurrents of relatively short duration can however, occur in normal operation;

two types of overcurrent are distinguished:

- Overloads

These overcurrents can occur in healthy electric circuits, for example, due to a number of small short-duration loads which occasionally occur co-incidentally: motor starting loads, and so on. If either of these conditions persists however beyond a given period (depending on protective-relay settings or fuse ratings) the circuit will be automatically cut off.

- Short-circuit currents

These currents result from the failure of insulation between live conductors or/and between live conductors and earth (on systems having low-impedance-earthed neutrals) in any combination.

4.2. Methodology of calculations cross sections conductors and protective device

4.2.1. Introduction

The cabling and its protection at each level must satisfy several conditions at the same time, in order to ensure a safe and reliable low-voltage installation, e.g. it must:

a) Carry the permanent full load current, and normal short-time overcurrents,

b) Not cause voltage drops likely to result in an inferior performance of certain loads, for example: an excessively long acceleration period when starting a motor, etc.

Moreover, the protective devices (circuit breakers or fuses) must:

a) Protect the cabling and busbars for all levels of overcurrent, up to and including short-circuit currents,

b) Ensure protection of persons against indirect contact hazards, particularly in TN- and IT- earthed systems, where the length of circuits may limit the magnitude of short-circuit currents, thereby delaying automatic disconnection (it may be remembered that TT- earthed installations are necessarily protected at the origin by a RCD, generally rated at 300 mA).

The cross-sectional areas of conductors are determined by the general method described in next part of this Chapter. Apart from this method some national standards may prescribe a minimum cross-sectional area to be observed for reasons of mechanical endurance.

4.2.2. Installation and dimensioning of cables

For a correct dimensioning of a cable, it is necessary to:

- choose the type of cable and installation according to the environment;
- choose the cross section according to the load current;
- verify the voltage drop.

Current carrying capacity and methods of installation

Selection of the cable

The international reference Standard ruling the installation and calculation of the current carrying capacity of cables in residential and industrial buildings is IEC 60364-5-52 "Electrical installations of buildings – Part 5-52 Selection and erection of electrical equipment- wiring systems".

The following parameters are used to select the cable type:

- conductive material (copper or aluminium): the choice depends on cost, dimension and weight requirements, resistance to corrosive environments (Chemical reagents or oxidizing elements). In general, the carrying capacity of a copper conductor is about 30% greater than the carrying capacity of an aluminium conductor of the same cross section. An aluminium conductor of the same cross section has an electrical resistance about 60% higher and a weight half to one third lower than a copper conductor.
- insulation material (none, PVC, XLPE-EPR): the insulation material affects the maximum temperature under normal and short-circuit conditions and therefore the exploitation of the conductor cross section.
- the type of conductor (bare conductor, single-core cable without sheath, single- core cable with sheath, multi-core cable) is selected according to mechanical resistance, degree of insulation and difficulty of installation (bends, joints along the route, barriers...) required by the method of installation.

Table 4.1. shows the types of conductors permitted by the different methods of installation.

Table 4.1. Selection of wiring systems [8]

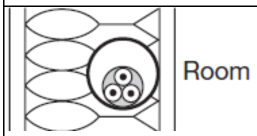
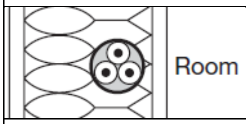
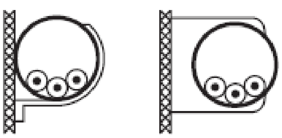
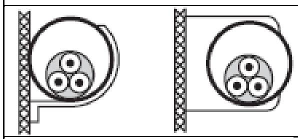
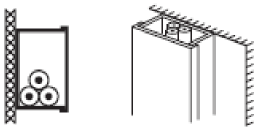
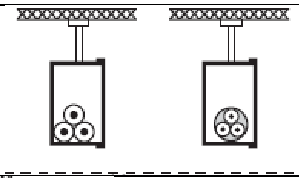
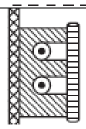
		Method of installation						
Conductors and cables		**Without faings**	**Clipped direct**	**Cable trunking (including skirting trunking, flush floor Conduit trunking)**	**Cable ducting**	**Cable ladder Cable tray Cable brackets**	**On insulators**	**Support wire**
Bare conductors		–	–	–	–	–	+	–
Insulated conductors		–	–	+ +	+	–	+	–
Sheathed cables (induding armoured and mineral insulated)	Multi-core	+	+	+ +	+	–	0	+
	Single-core	0	+	+ +	+	+	0	+
where: ++ Preferred + Permitted. – Not permitted. 0 Not applicable, or not normally used in practice.								

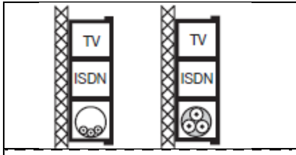
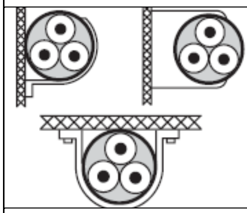
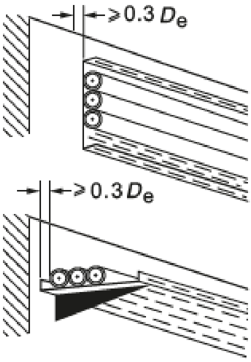
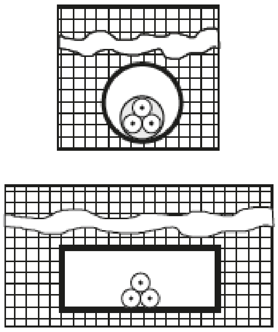
Methods of installation

To define the current carrying capacity of the conductor and therefore to identify the correct cross section for the load current, the standardized method of installation that better suits the actual installation situation must be identified among those described in the mentioned reference Standard.

From Table 4.2. it is possible to identify the installation identification number, the method of installation (A1, A2, B1, B2, C, D, E, F, G) and the tables to define the theoretical current carrying capacity of the conductor and any correction factors required to allow for particular environmental and installation situations.

Table 4.2. Examples of methods of installation (part of table A.52.3 of IEC 60364-5-52)[8]

Methods of installation	**Description**	**Reference method of installation to be used to obtain current-carrying capacity**
	Insulated conductors or single-core cables in conduit in a thermally insulated wall	A1
	Multi-core cables in conduit in a thermally insulated wall	A2
	Multi-core cable direct in a thermally insulated wall	A1
	Insulated conductors or single-core cables in conduit on a wooden, or masonry wall or spaced less than 0,3 times conduit diameter from it	B1
	Multi-core cable in conduit on a wooden, or masonry wali or spaced less than 0,3 times conduit diameter from it	B2
	Insulated conductors or single-core cables in cable trunking on a wooden wall – run horizontally – run vertically	B1
	Insulated conductors or single-core cable in suspended cable trunking (a) Multi-core cable in suspended cable trunking (b)	B1 (a) or B2 (b)
	Insulated conductors or single-core cable run in mouldings	A1

	Insulated conductors or single-core cables in skirting trunking (a) Multi-core cable in skirting trunking (b)	B1 (a) or B2 (b)
	Insulated conductors in conduit or single-core or multi-core cable in architrave	A1
	Insulated conductors in conduit or single-core or multi-core cable in window frames	A1
Methods of installation	**Description**	**Reference method of installation to be used to obtain current-carrying capacity**
	Single-core or multi-core cables: – fixed on, or spaced less than 0.3 times cable diameter from a wooden wall fixed directly under a wooden ceiling	C
	Single-core or multi-core cables: E or F on perforated tray run horizontally or vertically	E or F
	Bare or insulated conductors on insulators	G
	Multi-core cables in conduit or in cable ducting in the ground Single-core cable in conduit or in cable ducting in the ground	D1

Maximum operating temperature:

The current-carrying capacities given in the subsequent tables have been determined so that the maximum insulation temperature is not exceeded for sustained periods of time.
For different type of insulation material, the maximum admissible temperature
is given in Table 4.3.

Table 4.3. Maximum operating temperatures for types of insulation (table 52.1 of IEC 60364-5-52)

Type of insulation	**Temperature limit °C**
Polyvinyl-chloride (PVC)	70 at the conductor
Cross-linked polyethylene (XLPE) and ethylene propylene rubber (EPR)	90 at the conductor
Mineral (PVC covered or bare exposed to touch)	70 at the sheath
Mineral (bare not exposed to touch and not in contact with combustible material)	70 at the sheath

Admissible current as a function of nominal cross-sectional area of conductors

The current-carrying capacities of conductors in all different situations are given in international standard IEC 60364-5-52 in the form of tables giving the admissible currents as a function of cross-sectional area of cables. Many parameters are taken into account, such as the method of installation, type of insulation material, type of conductor material, number of loaded conductors.
As an example, Table 4.4 and 4.5 gives the current-carrying capacities for different methods of installation of PVC insulation, three loaded copper or aluminium conductors, free air or in ground.

Table 4.4. Current-carrying capacities in amperes for different methods of installation, PVC insulation, three loaded conductors, copper, conductor temperature: 70°C, ambient temperature: 30°C in air, 20°C in ground (table B.52.4 of IEC 60364-5-52) [8]

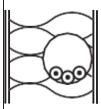
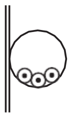
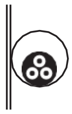
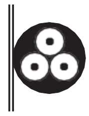
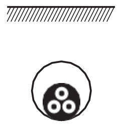
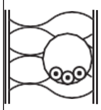
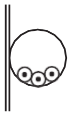
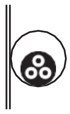
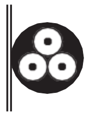
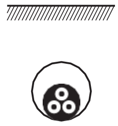
Nominal cross-sectional area of conductor mm2	Installation methods					
						
	A1	A2	B1	B2	C	D1
1,5	13,5	13	15,5	15	17,5	18
2,5	18	17,5	21	20	24	24
4,0	24	23	28	27	32	31
6	31	29	36	34	41	39
10	42	39	50	46	57	52
16	56	52	68	62	76	67
25	73	68	89	80	96	86
35	89	83	110	99	119	103
50	108	99	134	118	144	122
70	136	125	171	149	184	151
95	164	150	207	179	223	179
120	188	172	239	206	259	203
150	216	196	–	–	299	230
185	245	223	–	–	341	258
240	286	261	–	–	403	297
300	328	298	–	–	464	336

Table 4.5. Current-carrying capacities in amperes for different methods of installation, PVC insulation, three loaded conductors, aluminium, conductor temperature: 70°C, ambient temperature: 30°C in air, 20°C in ground (table B.52.4 of IEC 60364-5-52) [8]

Nominal cross-sectional area of conductor mm2	Installation methods					
						
	A1	A2	B1	B2	C	D1
1,5	17	16,5	20	19,5	22	22
2,5	23	22	28	26	30	29
4	31	30	37	35	40	37
6	40	38	48	44	52	46
10	54	51	66	60	71	61
16	73	68	88	80	96	79
25	95	89	117	105	119	101
35	117	109	144	128	147	122
50	141	130	175	154	179	144
70	179	164	222	194	229	178
95	216	197	269	233	278	211
120	249	227	312	268	322	240
150	285	259	–	–	371	271
185	324	295	–	–	424	304
240	380	346	–	–	500	351
300	435	396	–	–	576	396

4.3. Calculation of the cross-sectional areas of circuit live conductors and cables considering overcurrent protection of the cables

The following methods are based on rules laid down in the IEC standards, and are representative of the practices in many countries.

General rules

A protective device (circuit breaker or fuse) functions correctly if:

- Its nominal current or its setting current $\boldsymbol{I_n}$ is greater than the maximum load current $\boldsymbol{I_B}$ but less than the maximum permissible current $\boldsymbol{I_z}$ for the circuit, i.e.

$$I_B \leq I_n \leq I_Z \tag{4.1}$$

where: I_B –current for which the circuit is designed;
I_n – nominal current of the protective device;
I_Z–continuous current- carrying capacity of the cable;
I_2–current ensuring operation in conventional time of the protective device – tripping or fusing current corresponding to zone “a” in Figure 4.1.

- Its tripping current I_2 "conventional" setting is less than 1.45 I_z which corresponds to zone "b" in Figure 4.1

$$I_2 \leq 1{,}45 I_Z \qquad (4.2)$$

The "conventional" setting tripping time may be 1 hour or 2 hours according to local standards and the actual value selected for I_2. For fuses, I_2 is the current (denoted I_f) which will operate the fuse in the conventional time.

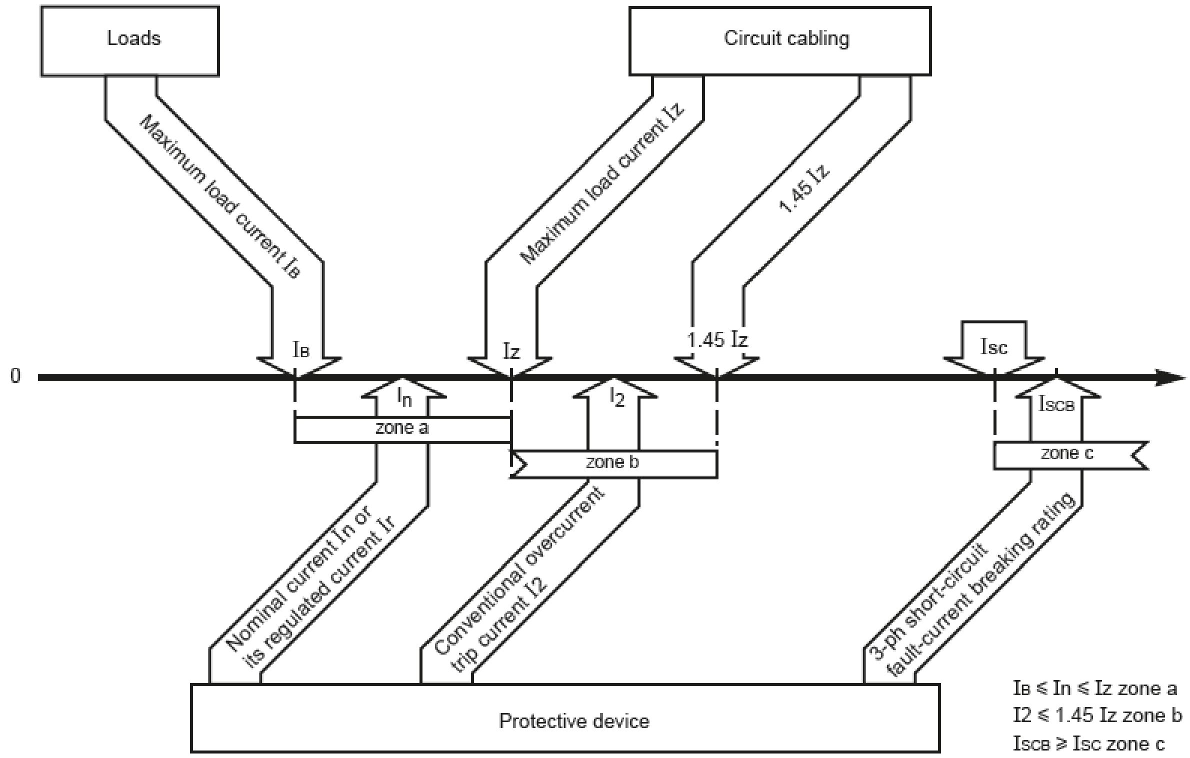


Fig. 4.1. Current levels for determining cross section of conductors, circuit breaker or fuse characteristics, where: I_{sc} – short-circuit current, I_{scb} – maximal short-circuit current of breaker [3].

Voltage drop

International standards (IEC 60364-5-52) [8] has specified voltage drop between the origin of an installation and any load point should not be greater below Table 4.6.

Table 4.6. Voltage drop in low voltage installation according to IEC 60364-5-52 [8]

Type of installation	**Lighting loads (%)**	**Other loads %**
A – Low voltage installations supplied directly from a public low voltage distribution system	3	5
B – Low voltage installation supplied from private LV supply (note 1)	6	8
Note 1 – As far as possible, it is recommended that voltage drop within the final circuits do not exceed those indicated in installation type A.		

Basic inputs to evaluate voltage drop calculation is:

- Data of cable (resistance R ohms, reactance X ohms, and cable length from power origin to loads),
- Consumer load (load rating power in kW and power factor).
- Voltage Drop Formulas:

a) Three-phase circuit voltage drop formula:

$$\Delta U = I(R\cos\varphi \pm X\sin\varphi)\sqrt{3} \tag{4.3}$$

Voltage drop in percentage:

$$\Delta U_{\%} = \frac{\Delta U}{U_n}100 \tag{4.4}$$

b) Single phase circuit voltage drop formula:

$$\Delta U = I(R\cos\varphi \pm X\sin\varphi)2 \tag{4.5}$$

Voltage drop in percentage:

$$\Delta U = \frac{\Delta U}{U_{nf}}100 \tag{4.6}$$

c) DC circuit voltage drop formula:

$$\Delta U = 2IR \tag{4.7}$$

Voltage drop in percentage:

$$\Delta U = \frac{\Delta U}{U_{n-}}100 \tag{4.8}$$

where:

ΔU – voltage drop, in volts; $\Delta U_{\%}$ – voltage drop, in percentage; $\cos\varphi$ – load power factor,

R – Resistance of cable, in ohms per phase, X – Reactance of cable, in ohms per phase; I – load current, in amperes

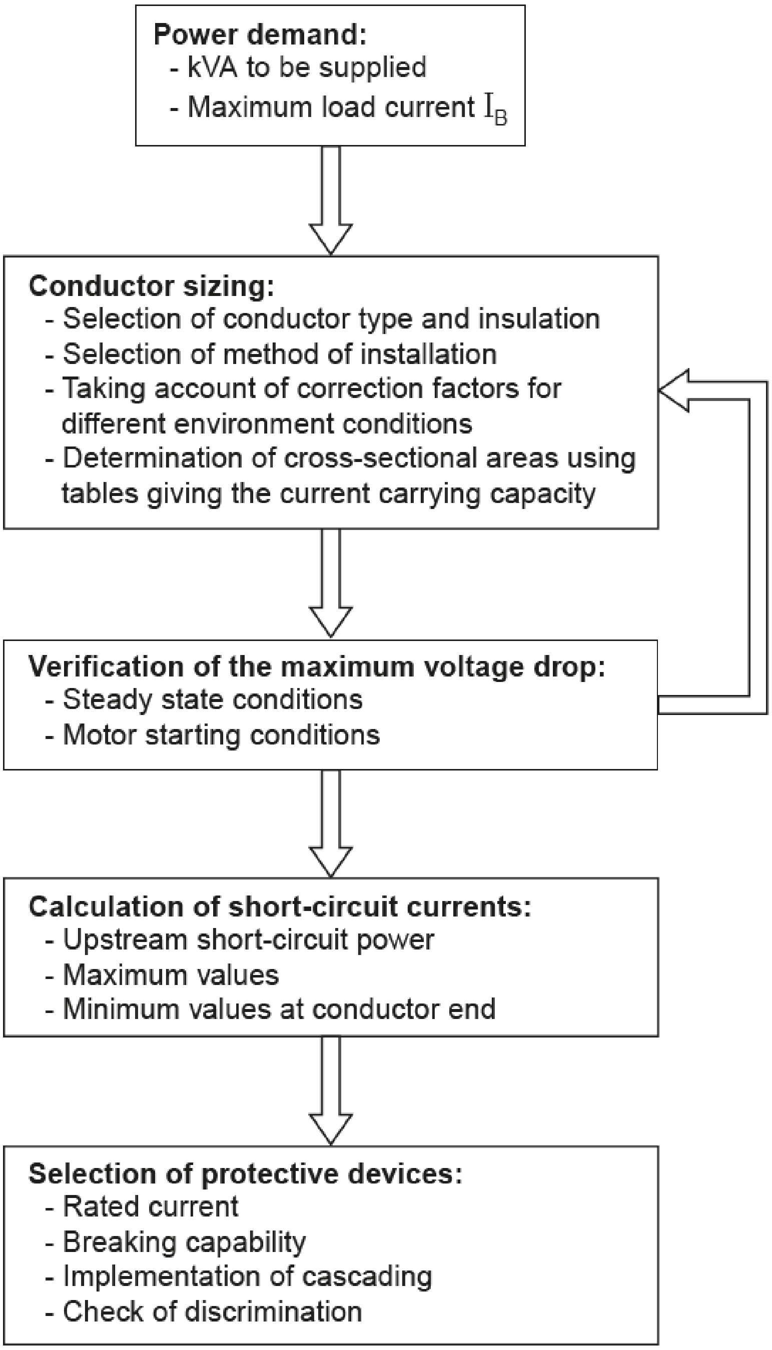


Fig 4.2. Diagram for the selection of cable size and protective device rating for a circuit [8]

Example of calculation of the cable cross-section current

Let's find out what if you need to determine the cross-section of copper cable to connect three-phase home appliances with a total capacity of P = 27,5 kW with power factor cosφ = 0,93. Such a connection is made with five-core cable is laid in the ground (Method D.1, Table 4.4). The power house is made from three-phase network.

Taking into account the reactance, power in appliances and equipment is as follows:

P = 27,5 kW;

S = 29,56 kVA

Defines the currents of the input:

$$I = \frac{S}{\sqrt{3} * U} = \frac{29560}{\sqrt{3} * 400} = 42{,}7\ A$$

At five-core cable takes into account only the phase cores. For cable laid in the ground, you can determine the current of 42,7 A and cross-section 10 mm² with current-carrying capacities I_Z = 52 A (according to Table 4.4).

Example of the calculation of cable voltage drop

For Example, it is necessary to calculate the voltage drop on the carrying cross-section of conductor *s* =2,5 mm² (cupper – γ= 56$\frac{m}{\Omega mm^2}$), with a length of *l* =20 m. It is required to connect the one -phase welding transformer with a capacity of *S*= 7 kVA.

- Resistance of the wire is:

$$R = \frac{2 * l}{\gamma * s} = \frac{2 \times 20}{56 * 2{,}5} = 0{,}2857\ \Omega$$

- The current in the conductor:

$$I = \frac{S}{V_{phase}} = \frac{7000}{230} = 30{,}43\ A$$

- The voltage drop across carry:

$$\varDelta V = R \times I = 0{,}2857 \times 30{,}43 = 8{,}694\ V$$

- Percentage of voltage drop:

$$\Delta V_{\%} = \frac{\Delta V}{V_{phase}} \times 100 = \frac{8{,}694}{230} \times 100 = 3{,}78\%$$

Suitable for carrying a welding machine according to the requirements of the rules of operation of electrical installations, because the percentage drop on it the voltage is in the normal range. However, its value in the supply lead remains large, which may adversely affect the welding process. Here it is necessary to check the lower allowable limit of the supply voltage for the welding machine.

5. Electric shock protection in the low voltage installations

5.1. Effects of electric shock

An electric shock is the pathophysiological effect of an electric current through the human body.

Its passage affects essentially the muscular, circulatory and respiratory functions and sometimes results in serious burns. The degree of danger for the victim is a function of the magnitude of the current, the parts of the body through which the current passes, and the duration of current flow.

The rule IEC 60479-1 defines four zones of current-magnitude/ time-duration, in each of which the pathophysiological effects are described (Fig 5.1). Any person coming into contact with live part of electrical equipment risks an electric shock.

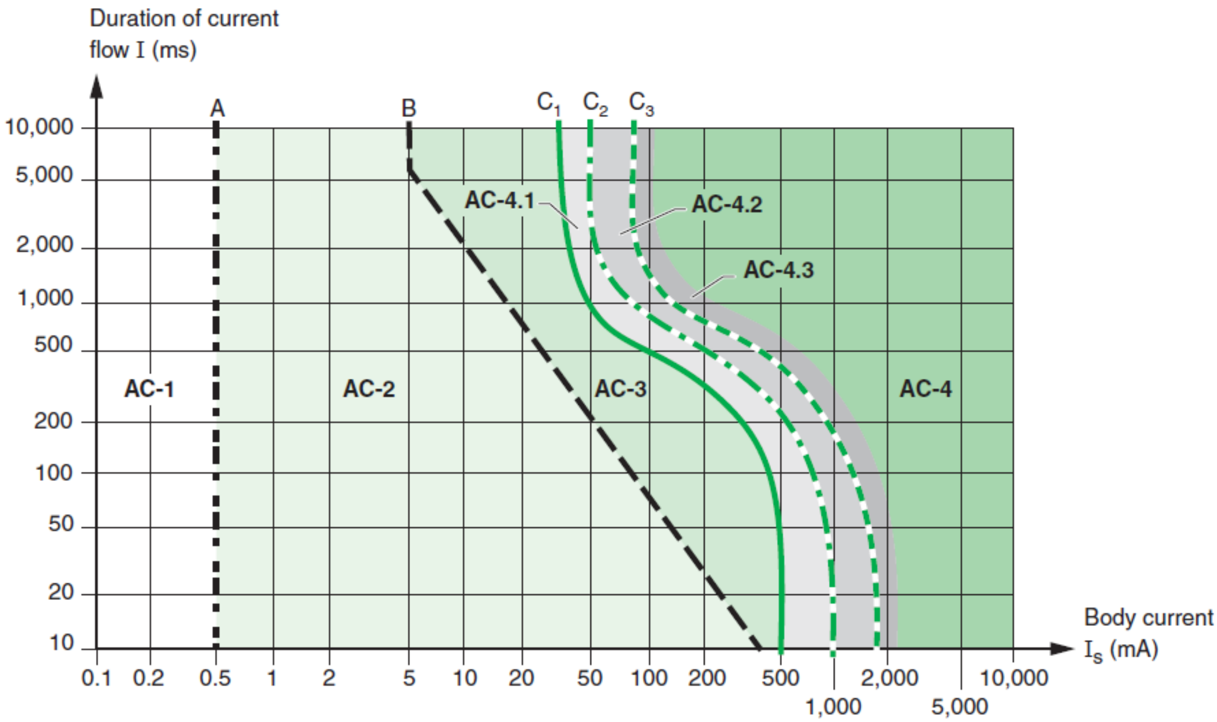


Fig. 5.1. Zones time/current of effects of AC current on human body when passing from left hand to feet, where: A curve – threshold of perception of current, B curve – threshold of muscular reactions, C_1 curve – threshold of 0% probability of ventricular, fibrillation, C_2 curve – threshold of 5% probability of ventricular fibrillation, C_3 curve – threshold of 50% probability of ventricular, fibrillation [5].

The effects of electric shock in individual zones (Fig. 5.1) are as follows:

- AC-1 zone: Imperceptible,
- AC-2 zone: Perceptible,

- AC-3 zone: Reversible effects: muscular contraction,
- AC-4 zone: Possibility of irreversible effects,
- AC-4-1 zone: Up to 5%probability of heart fibrillation,
- AC-4-2 zone: Up to 50% probability of heart fibrillation,
- AC-4-3 zone: More than 50% probability of heart fibrillation.

Therefore, the protection of persons against electric shock in low voltage installations must be provided in conformity with appropriate national standards and statutory regulations, codes of practice, official guides and circulars, etc. Relevant IEC standards include: IEC 60364 series, IEC 60479 series, IEC 60755, IEC 61008 series, IEC 61009 series and IEC 60947-2.

5.2. Measures of electric shock protection

The fundamental rule of protection against electric shock is provided by the standard IEC 61140 which covers both electrical installations and electrical equipment. Hazardous-live-parts shall not be accessible and accessible conductive parts shall not be hazardous.

A protective measure in low voltage installations shall consist of:

- an appropriate combination of a provision for basic protection and an independent provision for fault protection, or
- an enhanced protective provision which provides both basic protection and fault protection.

In each part of an installation one or more protective measures shall be applied, taking account of the conditions of external influence.

The following protective measures against direct contact (basic protection) are permitted:

- basic insulation of live parts,
- barriers or enclosures,
- obstacles,
- placing out of reach.

The following protective measures against indirect contact (fault protection) are permitted:

- automatic disconnection of supply,
- double or reinforced insulation,
- electrical separation for the supply of one item of current-using equipment,
- extra-low-voltage (SELV and PELV).

The protective measures applied in the installation shall be considered in the selection and erection of equipment.

5.3. Measures of basic protection

5.3.1. Basic insulation of live parts

The insulation is intended to prevent contact with live parts. Therefore, live parts shall be completely covered with insulation which can only be removed by destruction. For equipment and installation, the insulation shall comply with the relevant standard for the electrical equipment. Resistance values of insulation have to higher than those of Table 5.1.

Table 5.1. Minimum values of insulation resistance [8]

Nominal circuit voltage **V**	**Test voltage d.c.** **V**	**Minimum insulation resistance** **MΩ**
SELV and PELV	250	0,5
Up to and including 500 V, including FELV	500	1
Above 500 V	1 000	1

The insulation resistance shall be sured between:

a) live conductors, and

b) live conductors and the protective conductor connected to the earthing arrangement.

5.3.2. Barriers or enclosures

Barriers or enclosures are intended to prevent contact with live parts. Live parts shall be inside enclosures or behind barriers providing at least the degree of protection IPXXB or IP2X except that, where larger openings occur during the replacement of parts, such as certain lampholders or fuses, or where larger openings are necessary to allow the proper functioning of equipment according to the relevant requirements for the equipment:

- suitable precautions shall be taken to prevent persons or livestock from unintentionally touching live parts, and
- it shall be ensured, as far as practicable, that persons will be aware that live parts can be touched through the opening and should not be touched intentionally, and
- the opening shall be as small as is consistent with the requirement for proper functioning and for replacement of a part.

Where it is necessary to remove barriers or open enclosures or to remove parts of enclosures, this shall be possible only:

- by the use of a key or tool, or
- after disconnection of the supply to live parts against which the barriers or enclosures afford protection, restoration of the supply being possible only after replacement or reclosure of the barriers or enclosures, or
- where an intermediate barrier providing a degree of protection of at least IPXXB or IP2X prevents contact with live parts, by the use of a key or tool to remove the intermediate barrier.

5.3.3. Obstacles

The protective measures provide basic protection (protection against direct contact) only. They are for application in installations with or without fault protection (protection against indirect contact) that are controlled or supervised by skilled or instructed persons

Obstacles are intended to prevent unintentional contact with live parts but not intentional contact by deliberate circumvention of the obstacle.

Obstacles shall prevent

- unintentional bodily approach to live parts, and
- unintentional contact with live parts during the operation of live equipment in normal service.

Obstacles may be removed without using a key or tool but shall be secured so as to prevent unintentional removal.

5.3.4. Placing out of reach

Protection by placing out of reach is intended only to prevent unintentional contact with live parts. Simultaneously accessible parts at different potentials shall not be within arm's reach. Two parts are deemed to be simultaneously accessible if they are not more than 2,50 m apart (Fig. 4.2).

If a normally occupied position is restricted in the horizontal direction by an obstacle (e.g. handrail, mesh screen) affording a degree of protection less than IPXXB or IP2X, arm's reach shall extend from that obstacle. The values of arm's reach apply to contact directly with bare hands without assistance (e.g. tools or ladder).

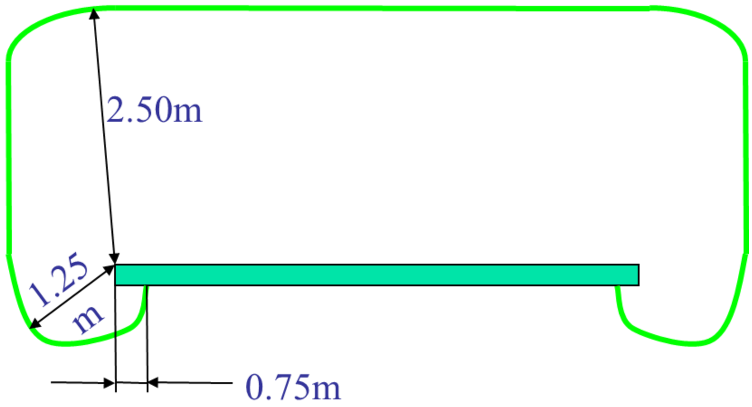


Fig. 5.2. Zone of arm's reach [8].

5.3.5. Automatic disconnection of supply

Automatic disconnection of supply is a protective measure in which

- basic protection is provided by basic insulation of live parts or by barriers or enclosures,and
- fault protection is provided by protective equipotential bonding and automatic disconnection in case of a fault.

Because exposed-conductive-parts shall be connected to a protective conductor, each circuit shall have available a protective conductor connected to the relevant earthing terminal. Additional, in each building, incoming metallic parts which are liable to introduce a dangerous potential difference and do not form part of the electrical installation shall be connected to the main earthing terminal by protective bonding conductors; examples of such metallic parts may include:

- pipes supplying services into the building, for example gas, water, district heating systems;
- structural extraneous-conductive-parts;
- accessible reinforcement of constructional reinforced concrete.

A protective device (circuit-braker, fuse, Residual Current Device RCD) shall automatically switch off the supply to the line conductor of a circuit or equipment in the event of a fault of negligible impedance between the line conductor and an exposed-conductive-part or a protective conductor in the circuit or equipment within the disconnection time required in Table 5.2.

Table 5.2. Maximum disconnection times according to IEC 60364-4-41 [8]

System	50 V < $U_0 \leq$ 120 V s		120 V< $U_0 \leq$ 230 V s		230 V < $U_0 \leq$ 400 V s		U_0 > 400 V s	
	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.
TN	0,8	[a]	0,4	1	0,2	0,4	0,1	0,1
TT	0,3	[a]	0,2	0,4	0,07	0,2	0,04	0,1

U_0 is the nominal a.c. or d.c. line to earth voltage.

[a] Disconnection may be required for reasons other than protection against electric shock.

In TN systems a disconnection time not exceeding 5 s is permitted for distribution circuits

In addition to circuit breakers and fuses as protective devices, RCDs must be used in some installations as additional protection. Additional protection by means of a residual current protective device (RCD) with a rated residual operating current not exceeding 30 mA shall be provided for:

- a.c. socket-outlets with a rated current not exceeding 32A that are liable to be used by ordinary persons and are intended for general use, and
- a.c. mobile equipment for use outdoors with a rated current not exceeding 32A.

TN system

In TN systems the neutral point of the power supply system shall be earthed. Exposed-conductive-parts of the installation shall be connected by a protective conductor to the main earthing terminal of the installation which shall be connected to the earthed point of the power supply system. It is recommended that protective conductors (PE and PEN) should be earthed where they enter any buildings too.

In TN systems, the following protective devices may be used for fault protection (protection against indirect contact):

– overcurrent protective devices,

– residual current protective devices (RCDs),

but, a residual current protective device (RCD) shall not be used in TN-C systems.

The characteristics of the protective device (circuit breaker, fuses or RCD) and the circuit impedances shall fulfil the following requirement:

$$Z_S \times I_a \leq U_0 \tag{5.1}$$

where:

Z_s – is the impedance in ohms (Ω) of the fault loop comprising:

- the source,
- the line conductor up to the point of the fault, and
- the protective conductor between the point of the fault and the source;

I_a – is the current in amperes (A) causing the automatic operation of the disconnecting device within the time specified in Table 5.2.

U_o – is the nominal a.c. or d.c. line to earth voltage in volts (V).

TT system

In TT systems all exposed-conductive-parts collectively protected by the same protective device shall be connected by the protective conductors to an earth electrode common to all those parts. The neutral point of the power supply system shall be earthed. Generally in TT systems, residual current protective devices (RCDs) shall be used for fault protection. Alternatively, overcurrent protective devices may be used for fault protection provided a suitably low value of Z_s is permanently and reliably assured.

Where a residual current protective device (RCD) is used for fault protection (protection against indirect contact) the following conditions shall be fulfilled:

The disconnection time as required by Table 5.2, and

$$R_A \times I_{\Delta n} \leq 50\,V \qquad (5.2)$$

where:

R_A – is the sum of the resistance in Ω of the earth electrode and the protective conductor for the exposed conductive-parts,

$I_{\Delta n}$ – is the rated residual operating current in A of the residual current protective device (RCD).

Where an overcurrent protective device is used (circuit breakers or fuses) the following condition shall be fulfilled:

$$Z_S \times I_a \leq U_0 \qquad (5.3)$$

where

Z_s – is the impedance in Ω of the fault loop comprising:

- the source,
- the line conductor up to the point of the fault,
- the protective conductor of the exposed-conductive-parts,
- the earthing conductor,

– the earth electrode of the installation and
– the earth electrode of the source;

I_a – is the current in A causing the automatic operation of the disconnecting device within the time specified in Table 5.2;

U_0 – is the nominal a.c. or d.c. line to earth voltage in V.

IT system

In IT systems live parts shall be insulated from earth or connected to earth through a sufficiently high impedance. This connection may be made either at the neutral point of the system or at an artificial neutral point. The latter may be connected directly to earth if the resulting impedance to earth is sufficiently high at the system frequency.

The fault current is then low in the event of a single fault to an exposed-conductive-part or to earth and automatic disconnection is not imperative. Provisions shall be taken, however, to avoid risk of harmful pathophysiological effects on a person in contact with simultaneously accessible exposed-conductive-parts in the event of two faults existing simultaneously.

Exposed-conductive-parts shall be earthed individually, in groups, or collectively.

In a.c. systems the following condition shall be fulfilled to limit the touch voltage to:

$$R_A \times I_d \leq 50\ V \tag{5.4}$$

where:

R_A – is the sum of the resistance in Ω of the earth electrode and protective conductor for the exposed-conductive-parts;

I_d – is the fault current of the first fault of negligible impedance between a line conductor and an exposed-conductive-part. The value of I_d takes account of leakage currents and the total earthing impedance of the electrical installation.

In IT systems the following monitoring devices and protective devices may be used:

– insulation monitoring devices (IMDs);
– residual current monitoring devices (RCMs)
– insulation fault location systems (IFLS);
– overcurrent protective devices;
– residual current protective devices (RCDs).

Where an IT system is designed not to disconnect in the event of a first fault, the occurrence of the first fault shall be indicated by either:

– an insulation monitoring device (IMD), which may be combined with an insulation fault location system (IFLS), or

– a residual current monitor (RCM), provided the residual current is sufficiently high to be detected.

The device shall initiate an audible and/or visual signal which shall continue as long as the fault persists. The signal can be initiated via a relay contact output, an electronic switching output or a communication protocol. A visual and/or an audible alarm system shall be arranged at a suitable place, so that it is perceived by responsible persons. If there are both audible and visible signals, it is permissible for the audible signal to be cancelled. It is recommended that a first fault be eliminated with the shortest practicable delay.

5.3.6. Double or reinforced insulation

Double or reinforced insulation is a protective measure in which

- basic protection is provided by basic insulation, and fault protection is provided by supplementary insulation, or
- basic and fault protection is provided by reinforced insulation between live parts and accessible parts.

This protective measure is intended to prevent the appearance of dangerous voltage on the accessible parts of electrical equipment through a fault in the basic insulation.

Where this protective measure is to be used as the sole protective measure (i.e. where a whole installation or circuit is intended to consist entirely of equipment with double insulation or reinforced insulation), it shall be verified that effective measures, for example by adequate supervision, are in place so that no change can be made that would impair the effectiveness of the protective measure. Therefore this protective measure shall not be applied to any circuit that includes, for example, a socket-outlet with an earthing contact.

Where the protective measure double or reinforced insulation is used for the complete installation or part of the installation, electrical equipment shall be of the following types, and type tested and marked to the relevant standards:

- electrical equipment having double or reinforced insulation (Class II equipment),
- electrical equipment declared in the relevant product standard as equivalent to Class II, such as assemblies of electrical equipment having total insulation. This equipment is identified by the symbol ⧈.

Electrical equipment having uninsulated live parts shall have reinforced insulation applied in the process of erecting the electrical installation. The electrical equipment being ready for operation, all conductive parts separated from live parts by basic insulation only, shall be contained in an insulating enclosure affording at least the degree of protection IPXXB or IP2X.

The following requirements apply as specified:

- the insulating enclosure shall not be traversed by conductive parts likely to transmit a potential; and
- the insulating enclosure shall not contain any screws or other fixing means of insulating material which might need to be removed, or are likely to be removed, during installation and maintenance and whose replacement by metallic screws or other fixing means could impair the enclosure`s insulation.

Where the insulating enclosure must be traversed by mechanical joints or connections (e.g. for operating handles of built-in apparatus), these should be arranged in such a way that protection against shock in case of a fault is not impaired.

Conductive parts enclosed in the insulating enclosure shall not be connected to a protective conductor. However, provision may be made for connecting protective conductors which necessarily run through the enclosure in order to serve other items of electrical equipment whose supply circuit also runs through the enclosure. Inside the enclosure, any such conductors and their terminals shall be insulated as though they were live parts, and their terminals shall be marked as PE terminals. Exposed-conductive-parts and intermediate parts shall not be connected to a protective conductor.

5.3.7. Electrical separation for the supply of one item of current-using equipment

Electrical separation is a protective measure in which

- basic protection is provided by basic insulation of live parts or by barriers and enclosures, and
- fault protection is provided by simple separation of the separated circuit from other circuits and from earth.

This protective measure shall be limited to the supply of one item of current-using equipment supplied from one unearthed source with simple separation. The separated circuit shall be supplied through a source with at least simple separation, and the voltage of the separated circuit shall not exceed 500 V. Live parts of the separated circuit shall not be connected at any point to another circuit or to earth or to a protective conductor. To ensure electrical separation, arrangements shall be such that basic insulation is achieved between circuits.

Flexible cables and cords shall be visible throughout any part of their length liable to mechanical damage. For separated circuits the use of separate wiring systems is recommended. If separated circuits and other circuits are in the same wiring system, multi-conductor cables without metallic covering, insulated conductors in insulating conduit shall be used, provided that:

- the rated voltage is not less than the highest nominal voltage, and

– each circuit is protected against overcurrent.

The exposed-conductive-parts of the separated circuit shall not be connected either to the protective conductor or exposed-conductive-parts of other circuits, or to earth. If the exposed-conductive-parts of the separated circuit are liable to come into contact, either intentionally or fortuitously, with the exposed-conductive-parts of other circuits, protection against electric shock no longer depends solely on protection by electrical separation but on the protective provisions to which the latter exposed-conductive-parts are subject.

5.3.8. Extra-low-voltage (SELV and PELV)

Protection by extra-low-voltage is a protective measure which consists of either of two different extra-low-voltage systems

- SELV or
- PELV.

This protective measure requires:

- limitation of voltage in the SELV or PELV system to the upper limit of voltage Band I, 50 V a.c. or 120 V d.c., and
- protective separation of the SELV or PELV system from all circuits other than SELV and PELV circuits, and basic insulation between the SELV or PELV system and other SELV or PELV systems, and
- for SELV systems only, basic insulation between the SELV system and earth.
- In certain cases in special localization limit the value of the extra-low voltage to a value lower than 50 V a.c. or 120 V d.c.. SELV and PELV circuits shall have:
- basic insulation between live parts and other SELV or PELV circuits, and
- protective separation from live parts of circuits not being SELV or PELV, provided by double or reinforced insulation or by basic insulation and protective screening for the highest voltage present.

Additional SELV circuits shall have basic insulation between live parts and earth, but the PELV circuits and/or exposed-conductive-parts of equipment supplied by the PELV circuits may be earthed.

Protective separation of wiring systems of SELV and PELV circuits from the live parts of other circuits, which have at least basic insulation, may be achieved by one of the following arrangements:

- SELV and PELV circuit conductors shall be enclosed in a non-metallic sheath or insulating enclosure in addition to basic insulation;

- SELV and PELV circuit conductors shall be separated from conductors of circuits at voltages higher than Band I by an earthed metallic sheath or earthed metallic screen;
- circuit conductors at voltages higher than Band I may be contained in a multi-conductor cable or other grouping of conductors if the SELV and PELV conductors are insulated for the highest voltage present;
- the wiring systems of other circuits are in compliance with 412.2.4.1;
- physical separation.

Plugs and socket-outlets in SELV and PELV systems shall comply with the following requirements:

- plugs shall not be able to enter socket-outlets of other voltage systems;
- socket-outlets shall not admit plugs of other voltage systems;
- plugs and socket-outlets in SELV systems shall not have a protective conductor contact.

If the nominal voltage exceeds 25 V a.c. or 60 V d.c. or if the equipment is immersed, basic protection (protection against direct contact) shall be provided for SELV and PELV circuits by:

- insulation, or
- barriers or enclosures.

Basic protection (protection against direct contact) is generally unnecessary in normal dry conditions for

- SELV circuits where the nominal voltage does not exceed 25 V a.c. or 60 V d.c.;
- PELV circuits where the nominal voltage does not exceed 25 V a.c. or 60 V d.c. and exposed-conductive-parts and/or the live parts are connected by a protective conductor to the main earthing terminal.

In all other cases, basic protection is not required if the nominal voltage of the SELV or PELV system does not exceed 12 V a.c. or 30 V d.c.

6. Form and scope of design documentation for electrical installations

The design documentation is a study in which the method of solving a specific technical issue is presented. It should give a complete answer to the contractor as to how the electrical installation (in other cases, e.g. substation or power line) designed by the designer should be constructed so that it is built in accordance with the requirements of standards and regulations and technical knowledge. The project documentation should be:

- complete – it should contain all the information enabling the contractor to carry out the installation design in accordance with the designer's intention and intentions,
- clear (legible) – it should have such a layout as is customary, it should be written with the use of command sentences like:
  - The installation should be made with YDY 3x1.5mm2 cable
  - Sockets should be mounted at a height of 40 cm above the floor
  - Mount light fittings directly to the ceiling.
  - The pages of the design should be numbered, just as all tables, drawings and diagrams should be numbered,
- consistent (unambiguous) – in each part of the design (technical description and drawings) provided information, solutions should be identical.

There cannot be a situation, for example, that in the technical description we have stated: "Machine No. 1 to be supplied with YDY5x4mm2 cable" while on the building plan or on the diagram the device "Machine 1" has a different type of power supply cable specified.

The project documentation should include a cover page that includes:

- title of the dossier in full,
- name of the design unit,
- name and address of the investor,
- names of the designers (in the actual design, with design authorisation numbers)
- place and date of the design preparation

A list of the contents of the documentation should be included, immediately after the title page.

The design documentation for the electrical installation should consist of five parts:

1. The first part is usually information in general, among which are:
   – the basis of the study – this is a list of documents with which the designer had to get acquainted before starting the design. These are e.g. instructions and expectations of the investor, documentation of other branches, influencing the execution of the electrical design, connection

conditions issued by the distribution company, architectural background and arrangements with the architect, current norms and regulations, etc.

– scope of the study in which the designer presents what the design includes, e.g. electrical lighting and power installation, socket outlet installation, emergency lighting installation, RTV/SAT installation, power line design, etc.

For the electrical installation, the scope of the basic design is usually: lighting installation, single-phase socket installation, 3-phase socket installation, power installation, switchgear design with equipment, electric shock protection, surge protection, fire protection plus possibly power supply to the building.

This section may also include other subsections, e.g. assumptions to the design or technical characteristics of the facility, if the designer considers them necessary to make the design coherent and fully understandable to its recipient.

2. The next section is the Technical Description. It can be said that the technical description is a detailed instruction to the contractor on how he should carry out the designed installation. The technical description must be consistent with the technical drawings (referred to below). Both parts of the technical description and the drawings must contain exactly the same information, so that there are no discrepancies between them, leading to ambiguities in the design and problems in the contractor's understanding of the designer's intentions. In addition, the information contained in the description and the technical drawings can and should be repeated. It is not advisable to avoid repeating the same information in both design elements. Admittedly, not every piece of information can be duplicated, some of it will be, e.g. only in the diagrams and some only in the description.

The technical description can be divided into the following elements:

– description of the lighting installation and plug sockets: it should contain information on which luminaires should be used in individual rooms and in what quantity, how and at what height they should be fixed, with what kind of cable the lighting installation should be made, how cables should be laid (flush-mounted, flush-mounted in pipes, surface-mounted in trays, etc.), what kind of protection for individual circuits should be installed. It is good practice to include the information in a table if possible. This makes the design clearer and more readable. An excerpt from an example of a table forming part of the technical description of lighting is given below (Table 6.1). Reference should also be made to the drawing showing the building plan with the lighting installation and the single line diagram of the installation.

Table. 6.1. Sample list of lighting fixtures.

No. noun.	Name of the room	Type of lamp	Number of lamps	Nethod of assembly	Assembly height
–	–	–	Pc.	–	meters
1.	Production hall	1115 PO 236PC	168	Directly on the ceiling	4,7
2.	Product warehouse	1115 PO 236PC	9	Directly on the ceiling	4,7
3.	Packaging warehouse	1115 PO 236PC	8	Directly on the ceiling	4,7
4.	Men’s cloakroom	1028 SD 136	12	Directly on the ceiling	3,0
5.	Women’s cloakroom	1028 SD 136	12	Directly on the ceiling	3,0
6.	Canteen	1028 SD 136	12	Directly on the ceiling	3,5
7.	Kitchen	1028 SD 136	9	Directly on the ceiling	2,7

In addition, it is worth stating in the description the height of the lighting switches and the height of the sockets in the various rooms. With regard to the socket installation, it is advisable to specify the cable with which it should be made and refer to the drawing on which the building projection with the location of the sockets is marked (provide drawing number and page).

The technical description of the lighting installation and the sockets should also include information on the IP class (in justified cases also the IK class) of the electrical equipment to be installed by the contractor.

– description of power installation: it should contain information on the type and cross-section of cables designed to supply power to individual machines, the manner of running the cables (under the plaster, in pipes under the plaster, in cable trays, in channels in the floor), as well as the applied protective devices in individual circuits. Again, it is a good idea to use a summary in the form of a table to increase the clarity and legibility of the design.
– switchgears: this subchapter should contain a description of the switchgears used and their equipment. The designer should specify at least the protection class of the switchgear enclosure, its dimensions and, depending on the operating environment, the IP class. The description should also refer to the switchgear diagram drawings. The drawing number and page number of the switchgear diagram should be referred to,
– protection against electric shock: the designer should describe the devices providing protection against electric shock for each circuit of the installation, including, where necessary, the protection against electric shock of the switchgear enclosures,
– surge protection: the type of circuit-breakers used and their location should be specified,

– power supply system: within the scope of the school project of the installation, it is sufficient to specify the cross-section and type of power supply cable, the device constituting its overload and short-circuit protection and the type and power of the transformer selected.

The third part is the technical calculations. The extent of the calculations made and included in the technical documentation is entirely up to the designer and the scope of the project. In a school project, all calculations (or at least examples from each scope and determined by the instructor) should be included in the design documentation and all calculation results tabulated in clear tables.

The fourth part of the design documentation is the drawings and diagrams. In order to produce the drawings that form part of the electrical design, it is necessary to have specific software to enable them to be produced quickly and accurately. Software that works with dwg file formats is usually sufficient. Each electrical drawing should be produced in accordance with the general rules for producing technical drawings, i.e. be produced on a suitable format (from A4 to A0 or other non-standard formats for linear objects), a border should be made on each technical drawing, no matter what format it is. The border should be made with a continuous line 5mm from the edge of the sheet. Each drawing should have a drawing plate, which is placed in the lower right-hand corner of the sheet so that it adheres to the border line. An example of a drawing plate is shown in Fig. 6.1.

Company name/logo:				
Drawing name:				
Specjalty:	NAME		Qualification number	Signature
MADE BY:				
DESIGN BY:				
REVIEW BY:				
Projection method:	*Date:*	*Scale*	*Sheet:*	*Drawing number:*

Fig. 6.1. Example of a drawing plate (source: own elaboration)

When completing and assembling project documentation, it is important that the drawings are properly folded and clipped into the documentation. The basic principle is that the drawing plate must be visible without unfolding the drawing, irrespective of what format sheet the drawing is on. This means that the sheet with the drawing must be properly folded. We have an example of folding an A3 sheet in Fig. 6.2.

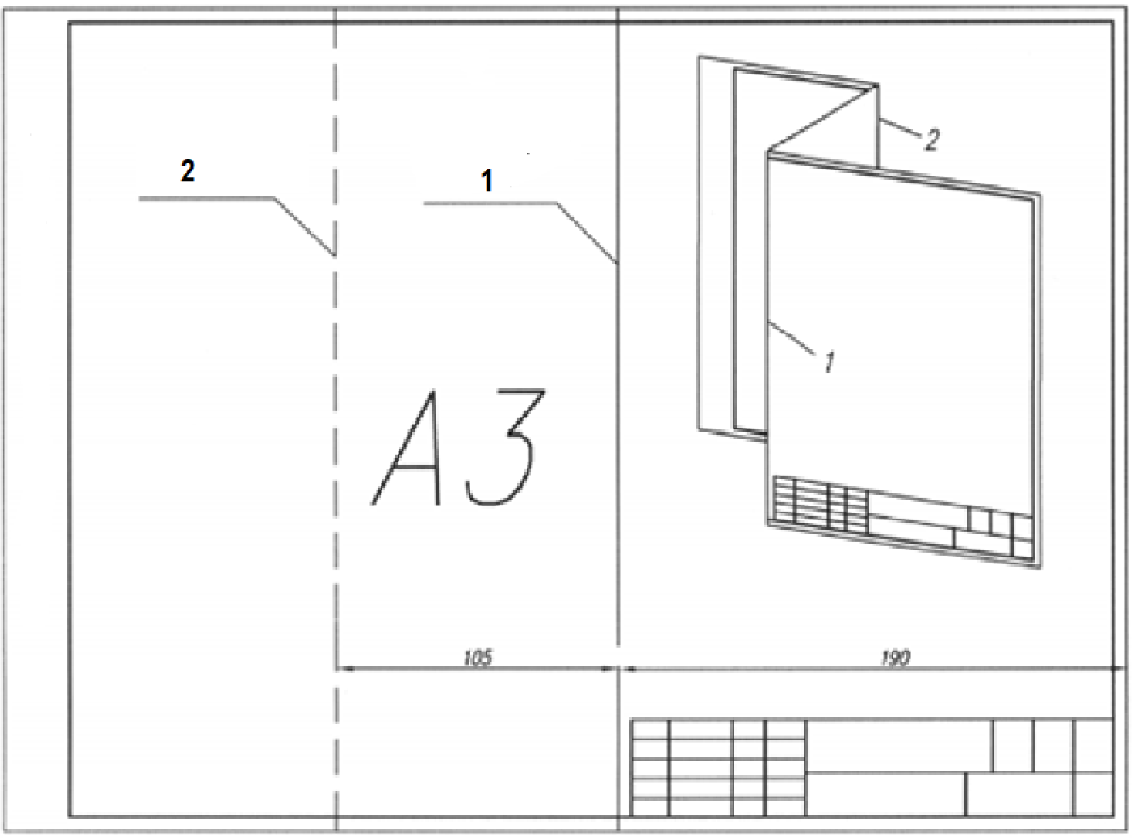


Fig. 6.2. Correctly folding an A3 drawing for insertion into a workbook [2]

Instructions on how to fold larger formats can be found i.e. at https://www.youtube.com/watch?v=QkN5Uh_qqFA

The drawings that should be included in the project are:

Electrical installation plans:

Plan of the building with the distribution of lamps in individual rooms and the dimensioning of distances between lamps and between lamps and walls. There should be a legend on the drawing which includes the symbols of the various types of luminaires on the plan, together with their names to identify the luminaires. It should also be indicated which luminaires belong to which circuits and which circuits belong to the lighting switchgears if there is more than one. These designations, if not intuitively understood, should also have an explanation on the drawing in the Legend section. It is not necessary to draw the wire routing routes as they will blend together on a smaller format drawing when printed. This will make the drawing unreadable. An example of a building plan with the lighting installation plotted is shown in Fig. 6.3.

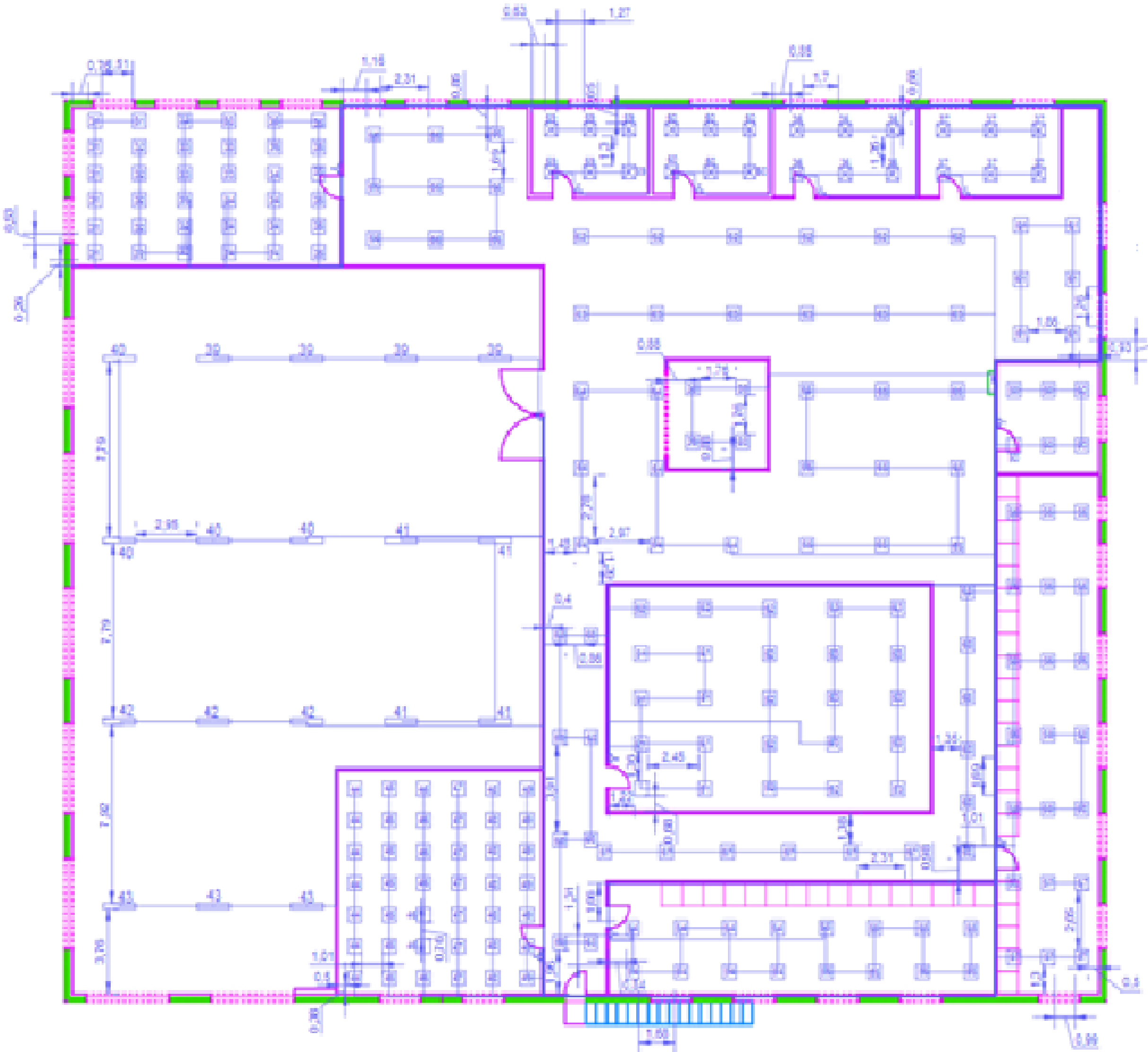


Fig. 6.3. Lighting installation on the building plan (example) (source: own elaboration)

Plan of the building with the location of the single-phase and three-phase sockets marked on it. The layout of the sockets should be shown on the drawing, with dimensioned distances indicating where they are to be installed. Single-phase and three-phase sockets should be marked with appropriate symbols and numbered in such a way that it is possible to identify their assignment to individual circuits and the circuits to the distribution boards to which they are to be connected. An example of a socket installation on a building plan is given in Fig. 6.4. As with the lighting installation, it is not necessary to draw the conductor routes to understand the drawing and to make it unambiguous, but only to identify which sockets belong to the same circuit and to which distribution board they are to be connected if more than one distribution board is marked on the plan.

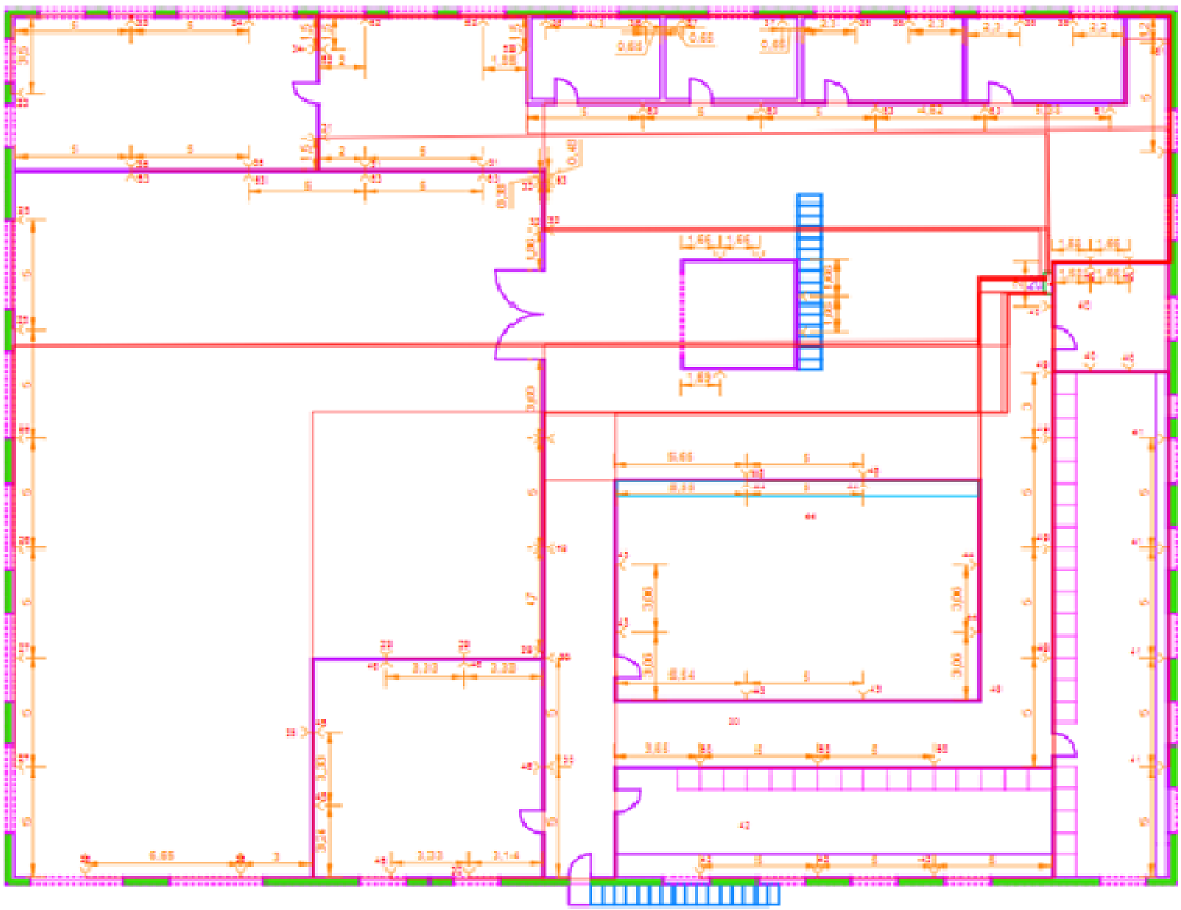


Fig.6.4. Installation of single-phase outlets on the building plan (example) (source: own elaboration)

A plan of the building with the power supply system marked on it. The building plan should show the location of the equipment to be supplied. How the equipment is arranged in the building (on the shop floor) is the responsibility of the building owner or production technologist, and they should provide information on this. In order to show the power installation on the building plan, the cable routing from the device to the corresponding distribution panel is drawn and the symbols for the cables used in the individual circuits are marked. The equipment should be numbered and a legend placed on the drawing should make it possible to identify the individual machines/equipment. If the number of machines on the shop floor is large, it is possible to omit drawing the feeders and, as for the lighting system, to number the devices belonging to the same circuit and assign them to the corresponding switchgear.

Building plans are usually drawn at a scale of 1:50 or 1:100.

Electrical installation diagrams:

The diagram of the whole installation can be shown in one drawing, or the circuits connected to the individual switchgear can be shown in separate drawings. How the schematic is divided into individual drawings is up to the designer. There is no rigid rule as to how the scheme should be divided into individual drawings, other than that the scheme should be clear and logical.

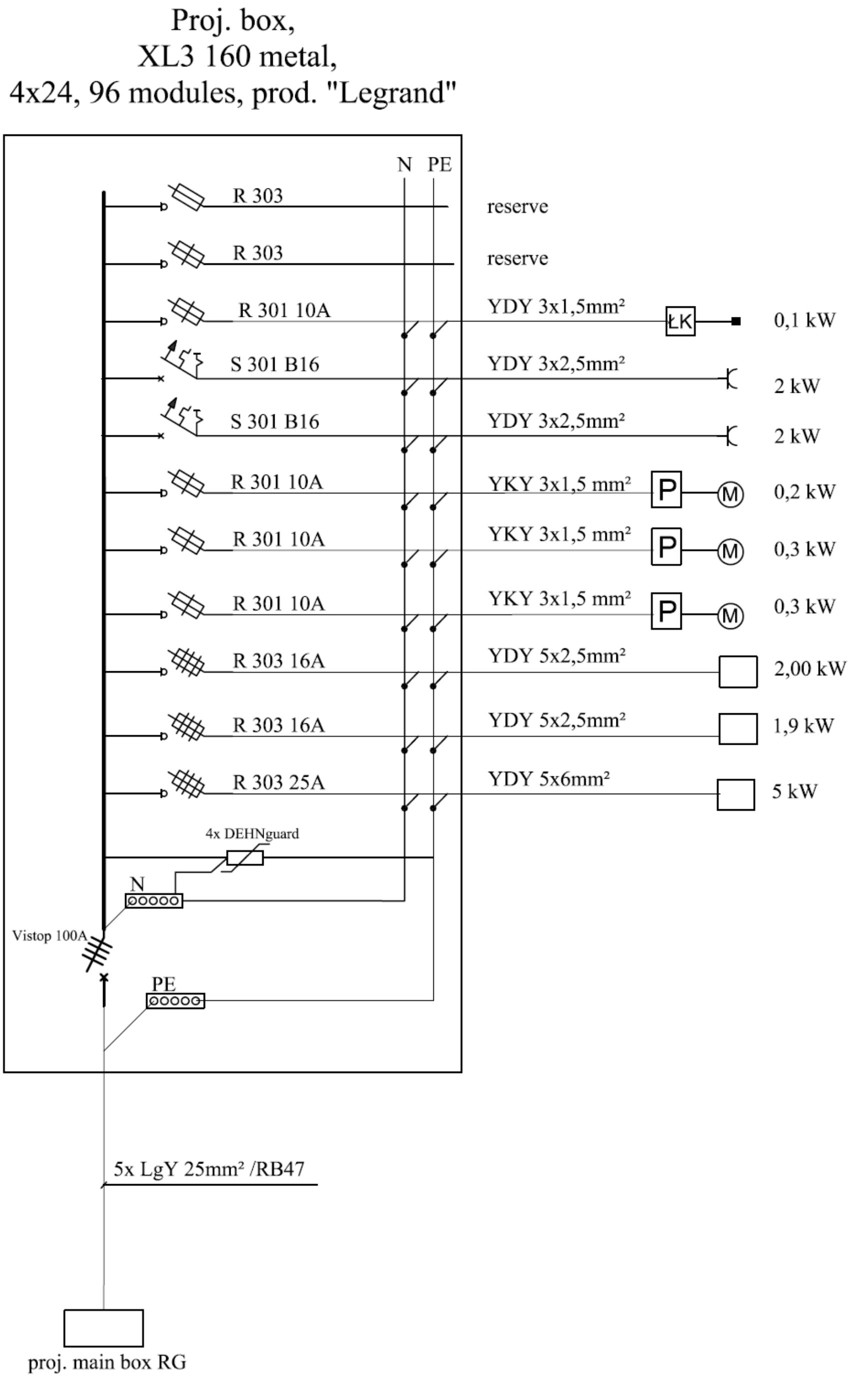


Fig. 6.5. Example diagram of switchgear (box) (source: own elaboration)

There is no need to draw the same circuits more than once, e.g. if there are 10 identical machines, supplied by the same wires and protected by the same devices, it is sufficient to draw one circuit and sign 'x10' under the machine symbol. This will increase the legibility of the diagram.

In the schematic diagrams, use the symbols customary according to EN 60617 for the load and power devices: switches, disconnectors, fuses, etc. The contacts of these devices should be shown on the diagram. The contacts of these devices shall be shown in the diagram in the de-energised state. An example of a main switchgear diagram is shown in Fig. 6.5.

A bill of materials is also part of the design documentation. It contains a list of all materials to be used by the installation contractor with their quantity resulting from the design. In order to make the specification more legible, it can be divided into sections, e.g. lighting installation, socket installation, power supply installation, etc. A fragment of a sample list is presented in Table 6.2.

Table 6.2. Excerpt from a sample bill of materials for electrical installation

Bill of materials	unit	qty.
Power cable YKYżo 3x10	lm.	230
Calendered PVC tape – blue	lm.	230
Non-standard sand	m^3	33
Galvanised steel wire rod 35x4	lm.	72
Galvanised steel rod with diameter of 8 mm	lm.	95
Universal roof bracket,	pc.	95
Universal connector	pc.	14
Measurement connector	complet	4
Conductor- type YDYżo 3x2.5	lm.	480
Conductor- type YDYżo 3x1.5	lm.	480
Conductor- type YDY 3x1.5	lm.	360
Conductor- type YDY 2x1.5	lm.	50
Flush – mounted socket	pc.	35
Single installation switch	pc.	4
Installation candle switch	pc.	24
Installation bell button	pc.	4

The project documentation also includes a formal part, which the school project does not have. The formal part includes, for example:

1. Designer's statement that the design has been carried out in accordance with the regulations and technical knowledge,
2. Designer's entitlements,
3. Certificate of membership of the designer to the Chamber of Civil Engineers,
4. Conditions for facility connection issued by the Distribution Company,
5. OSH information.

7. Language note

In order to become successful in the field of electrical engineering and electrical installation design, it is essential to bear in mind that some of the language phrases and grammatical rules may slightly differ from general English that we use.

In the 1980s a concept called Simplified English was launched in the United States of America and it was later developed into Simplified technical English. It is a controlled form of English language with limited vocabulary and rigorous writing rules. It was created to make technical documents easier to understand for specialists who are not native speakers of English. Even people with low language skills are able to understand technical documents. There are no unnecessary words or phrases and scope for creativity is minimal.

Even though Simplified Technical English was originally developed for aviation, it can surely be used in most areas of technical English.

The main goals for Simplified Technical English are:

- reduce ambiguity,
- make user manuals more comprehensive for non-native speakers of English,
- make technical texts clearer,
- focus on the most important aspects,
- make human translations easier and cost-effective.

Some of the rules that can be helpful when dealing with electrical installation design:

1. Remove non-relevant information (before doing so, the user has to make sure that this piece of information will not cause any misunderstanding when deleted)
2. Make sure that there is no ambiguity when it comes to words. Some words have a few meanings, be sure that you're using the one that refers to electrical installation
3. Try not to use too many nouns in one row, no more than three is enough.
4. Don't use the passive voice in the text. It is commonly used when it's not relevant who the doer of the action is. At this point we have to highlight that technical English is more about simple instructions and essential vocabulary rather than sophisticated tenses and fancy words. When using active voice, it is much clearer to the reader who is responsible for doing what.
   Instead of: *The fuse needs to be replaced*, write *The engineer needs to replace the fuse.*
5. Use imperative forms of the verb instead of using modal verbs.
   Instead of: *You should/must obey the instructions*, write: *Obey the instructions*

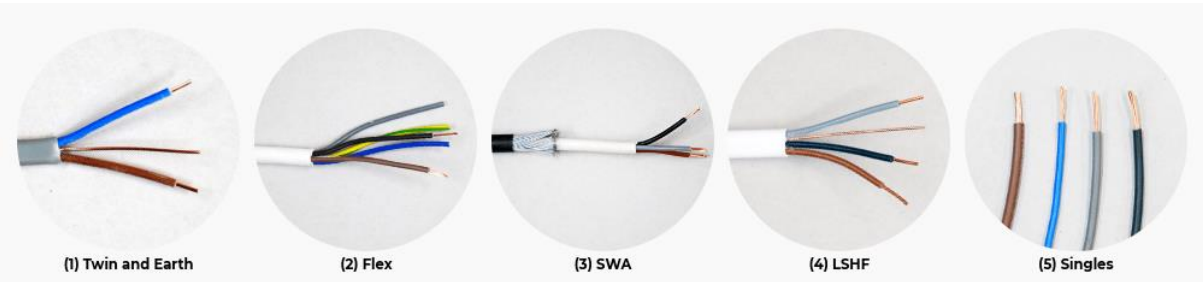
6. Be consistent when using professional terms. Don't use synonyms.
7. If you provide norm numbers, double check numbers or letters.

If it is necessary to implement visuals into the work, here are some examples with the representation of information:

- a bar chart/table is best to show a comparison between items,
- a scatter plot is best to show a correlation,
- a map is best to show location,
- a pie chart is best to show proportions of a whole,
- a diagram is best to describe a structure,
- a histogram/line graph is best to show trends.

The terminology connected to electrical installations is very wide, yet there are some basic words and phrases an engineer needs to master.

1. Cable types



2. Units of measurements (symbols and names):

a) Ω – Ohm,
b) W – Watt,
c) V – volt,
d) A – amper.

3. Protective devices

4. Test and inspection

a) Inspection,

b) safe isolation,

c) design current,

d) proving unit,

e) departure.

5. Tools

a) wire strippers,

b) multimeter.

6. Other:

a) AC or a.c. – alternating current,

b) DC or d.c. – direct current,

c) transformer,

d) electrical grid,

e) service panel,

f) circuit braker,

g) branch circuit,

h) neutral conductor,

i) grounding conductor,

j) short circuit,

k) outlet,

l) electrical box.

If unsure, go to https://www.electropedia.org/ and look up words and phrases connected to electrical installations and other topics within electrical engineering.

8. Websites www

American Academy of Forensic Sciences (AAFS)	www.aafs.org
American Burn Association	www.ameriburn.org
American National Standards Institute (ANSI)	www.ansi.org
American Society for Testing and Materials (ASTM)	www.astm.org
American Society of Safety Engineers (ASSE)	www.asse.org
American Society of Training and Development	www.astd.org
British Standards Institute (BS)	www.bsi-global.com
Canadian Society of Forensic Sience (CSFS)	www.csfs.ca
Comitato Elettrotecnico Italiano (CEI)	www.ceiuni.it
Engineering Consulting and Design (ECD)	www.ecd.it
EUROPACABLE	www.europacable.com
European Association of Electrical Contractors	www.aie-elec.org
European Committee for Electrotechnical Standarization (CENELEC)	www.cenelec.be
European Copper Institute	www.eurocopper.org
IAS Electrical Safety Workshop	www.ieee-cic.org/safety1/esw.htm
Institute of Electrical and Electronic Engineers (IEEE)	www.ieee.org
International Electrical Testing Association (NETA)	www.netaworld.org
International Electrotechnical Commission (IEC)	www.iec.ch
International Federation for Safety of Electrical Users	www.fisuel.com
International Organization for Standardization (ISO)	www.iso.ch
International Union of Electricity Applications	www.uie.org
International Union of Electrotechnology (UIE)	www.uie.org
National Electrical Manufacturer's Association	www.nema.org
National Electrical Safety Foundations (NESF)	www.nesf.org
National Fire Protection Association (NFPA)	www.nfpa.org
Occupational Safety and Health Administration (OSHA)	www.osha.gov
Polski Komitet Normalizacyjny	www.pkn.pl
Professional Electrical Apparatus Recyclers League (PEARL)	www.pearl1.org
Standard Association of Australia (AS)	www tandard.com.au
Standards Association of New Zealand (NZS)	www.standards.co.nz

9. The Polish-English Dictionary

A	
alarm akustyczny	acoustic alarm system
alarm optyczny	visual alarm system
alarm pożarowy	fire alarm system
aparat medyczny	medical apparatus
aparat rentgenowski	X-ray unit
aparatura elektromedyczna	medical electrical equipment
aparatura łączeniowa	switchgear
aparatura sterownicza	controlgear
asymetria napięcia	voltage unbalance
atmosfera zewnętrzna	external atmosphere
autotransformator	autotransformer
awaryjne urządzenie łączeniowe	emergency switching device
awaryjne wyłączanie	emergency switching
awaryjne zatrzymanie	emergency stopping
B	
badania odbiorcze	initial verification
badania okresowe	periodic testing
badania typu	type tests
bardzo krótka przerwa	very short break
bardzo niskie napięcie	extra-low voltage
basen jachtowy	marina
basen natryskowy	shower basin
basen pływacki	swimming pool
bateria akumulatorów	storage battery
beton	concrete
bezpieczeństwo	safety
bezpieczeństwo instalacji elektrycznych	safety of electrical installations
bezpieczeństwo obsługi	safety services
bezpiecznik	fuse
błąd montażu	assembly fault
błąd produkcyjny	manufacturing fault
brak uszkodzenia	fault free
brodzik	paddling pool
bruzda (na przewody)	trunking
budowla tymczasowa	temporary structure
budynek handlowy	commercial building
budynek prefabrykowany	prefabricated building
budynek wysokościowy	high-rise building
C	
całka Joule'a	Joule integral
całkowity czas działania	total operation time
cechowanie	marking
cechy agresywne	aggresive nature
cementownia	cement works
centralne ogrzewanie	central heating system

charakterystyka czasowo-prądowa	time-current characteristic
charakterystyka obciążenia	characteristic of the load
charakterystyka urządzenia ochronnego	characteristic of protective device
charakterystyka zwłoczna	time-lag characteristic
chroniona część czynna	protected live part
ciało człowieka	body of person
ciało ludzkie	human body
ciało stałe	solid body
ciało zwierzęcia	animal body
ciągłość elektryczna	electrical continuity
ciągłość przewodów	continuity of the conductors
ciecz palna	flammable liquid
ciężar własny	own weight
ciśnienie	preassure
czas działania	operating time
czas działania urządzenia ochronnego	operating time of protective device
czas łukowy	arc time
czas przedłukowy	prearcing time
czas przełączania	change-over time
czas rozruchu	start-up time
czas trwania	duration
czas umowny	conventional time
czas użytkowania	working live
czas wyłączenia	disconnecting time
czas zadziałania	response time
czerpnia powietrza	air instake
częste przemieszczanie	frequent movement
częstotliwość	frequency
częstotliwość przemysłowa	power frequency
części jednocześnie dostępne	simultaneously accessible parts
części o różnych potencjałach	parts at different potentials
części wyposażenia	items of equipment
część aplikacyjna (aparatu elektromedycznego)	applied part (of the medical electrical equipment)
część czynna	live part
część czynna niebezpieczna	hazardous-live-part
część niebezpieczna	hazardous part
część nieprzewodząca dostępna	accessible non-conductive part
część przewodząca dostępna	exposed conductive part
część przewodząca obca	extraneous conductive part
część usuwalna	removable part
część wewnętrzna	internal part
czujka pożarowa	fire detection
czynności łączeniowe	switching operations

D

dane znamionowe	rating
dławik gaszący	arc-suppresion coil
dławnica kablowa	cable gland
dobór urządzeń	selection of equipment
dokument normalizacyjny	normative document
dolna granica wartości temperatury otoczenia	lower limit of range of ambient temperature
domek ruchomy	mobile home

dopuszczalny przyrost temperatury	temperature-rise limit dopuszczalny spadek
napięcia	admissible voltage drop
dostępność wyposażenia elektrycznego	accessibility of electrical equipment dotyk
bezpośredni	direct contact
dotyk niezamierzony	unintentional contact
dotyk pośredni	indirect contact
dotyk wielkopowierzchniowy	large-area contact
doziemienie	earth fault
drabinka instalacyjna	ladder support
drgania wysokiej częstotliwości	high-frequency oscillations
droga dostępu (do urządzenia)	access path (to the device)
droga ewakuacyjna	escape route
droga ziemno-powrotna	earth-return path
drukowanie	printing
drut	wire
drut wiązałkowy	binding wire
drzwi z napędem elektrycznym	electrically driven door
dwufazowy	two-phase
dwuprzewodowy układ sieci	two-wire system
działanie niezamierzone	inadvertent operation
działanie ognia	fire effect
działanie zamierzone	deliberate action
dzienne wahania obciążenia	daily variaton of demand
dzień burzowy	thunderstorm day
dźwig	crane

E

efekt cieplny	termal effect
efekt kominowy	chimney effect
ekran metalowy	metallic screen
ekran ochronny	protective screen
ekran przewodzący	conductive screen
ekranowanie ochronne	protective screening
ekwipotencjalność	equipotentiality
elektromagnes dźwigowy	lifting magnet
elektryczna rezystancja ciała ludzkiego	electrical resistance of the human body element
grzejny	heating element
element kompensujący	compensatory measure
element topikowy	fusing element
energia rozładowania	discharge energy
etykieta samoprzylepna	adhesive label

F

fibrylacja komór sercowych	ventricular fibrillation
filtr elektrostatyczny	electrostatic precipitator

G

generator prądotwórczy	generator set
główka bezpiecznika	fuseholder
główna szyna uziemiająca	main earthing bar
główny przewód ochronny	main protective conductor
główny zacisk uziemiający	main earthing terminal

gniazdo bezpiecznikowe	fuse base
gniazdo wtyczkowe	socket-outlet
górna granica wartości temperatury otoczenia	upper limit of range of ambient temperature
górna powierzchnia obudowy	top surface of enclosure
grunt niestabilny	unstable ground
grzejnik akumulacyjny	storage heater
grzejnik do sauny	sauna heater
guma przewodząca	conductive rubber

H

hamowanie przeciwprądem	reverse-current braking

I

impedancja	impedance
impedancja dla składowej zerowej	zero-sequence impedance
impedancja pętli zwarciowej	fault-loop impedance
impedancja pomijalna	negligible impedance
impedancja źródła	source impedance
instalacja elektryczna	electrical installation
instalacja informatyczna	information technology installation
instalacja ochrony odgromowej	lighting protection system
instalacja odbiorcza	consumer's installation
instalacja przewodami giętkimi	flexible wiring
instalacja silnoprądowa	electric power installation
instalacja specjalna	special installations
instalacja stała	fixed installation
instalacja tymczasowa	temporary installation
instalacja uziemiająca	earthing arrangement
instalacja zewnętrzna	outdoor installation
iskra	spark
izolacja ciekła	liquid insulation
izolacja dodatkowa	supplementary insulation
izolacja gazowa	gas insulation
izolacja podwójna	double insulation
izolacja powietrzna	air insulation
izolacja robocza	basic isolation
izolacja równoważna	equivalent insulation
izolacja stała	solid insulation
izolacja wzmocniona	reinforced insulation
izolacyjne właściwości elektryczne	electrical insulating characteristic
izolowanie części czynnych	insulation of live parts
izolowany system zasilania (IT)	isolated power system (USA)

J

jednofazowy	single-phase

K

kabel jednożyłowy	single-core cable
kabel nieopancerzony	non-armoured cabel
kabel sygnałowy	signal cable
kabel wielożyłowy	multicore cable
kabel zasilający	feeder

kabel zbrojony	armoured cable
kabina natryskowa	shower cabinet
kanał (przewodowy)	ducting
kanał kablowy	cabel chanel
kanał przewodowy	cable ducting
kaskada wodna	waterfall
kategoria przepięcia	overvoltage category
kategoria wpływu zewnętrznego	category of external influence
kierunek wirowania	direction of rotation
klimatyzacja	air-conditioning system
kocioł	boiler
kodyfikacja wpływów zewnętrznych	codification of external influences
kolejność faz	phase sequence
komora grzewcza	heating cabinet
komora ognioszczelna	fire-segregated compartment
kompatybilność	compatibility
kompatybilność elektromagnetyczna	electromagnetic compatibility
kompetencje osób	capability of persons
konserwacja	maintenance
konstrukcja obiektu budowlanego	construction of building
konstrukcja podtrzymywania ciśnienia powietrza	air-support structure
konstrukcja samonośna	self-supporting structure
kontrola doziemienia	earth fault monitoring
konwekcja	convection
konwekcja powietrza	air convection
koordynacja izolacji	co-ordination of insulation
koordynacja układu sieci	co-ordination of the type of system
koordynacja zabezpieczeń	co-ordination of protections
korekcja błędu	error corection
korozja elektrochemiczna	electrochemical corrosion
korozja elektrolityczna	electrolytic corrosion
korytarz nadzoru	maintenance gangway
korytarz obsługi	operating gangway
korytko instalacyjne bez perforacji	inperforated tray
korytko perforowane	perforated tray
kroploszczelne	drip-tight
kształt żyły (przewodu)	form of conductor

L

lampa wyładowcza	discharge lighting
licznik elektryczny	electricity meter
linia napowietrzna	overhead line
linka nośna	support wire
listwa instalacyjna z przegrodami	skirting trunking

Ł

łączenie	switching
łącznik jednobiegunowy	single-pole switching device
łącznik pomocniczy	auxiliary switch
łuk elektryczny	electric arc

M

magistrala uziemiająca	earthing bus conductor
maksymalny prąd dopuszczalny	maximum current allowable
maszyna wirująca	rotating machine
materiał ceramiczny	ceramic material
materiał drewnopodobny	wood-like material
materiał izolujący cieplnie	thermally insulating material
materiał konstrukcyjny	constructional material
materiał magazynowany	stored material
materiał niemetalowy	non-metalic material
materiał niepalny	non-combustible material materiał odporny na łuk
elektryczny	arc-combustible material
materiał palny	flammable (combustible) material
metalowa rura wodociągowa	metallic water-pipe
metalowy element konstrukcyjny	structural metallic part
metalowy element systemu	metallic system component
miejsce suche	dry location
migotanie serca, fibrylacja serca	cardiac fibrillation
milimetr kwadratowy	square milimeter
moc w watach	wattage
molo	pier
montaż (instalacji elektrycznej)	erection (of electrical installation)

N

nabrzeże	quay
nadmierna temperatura	excess temperature
nagromadzona energia elektryczna	stored electrical energy
napięcie doładowywania	floating voltage
napięcie dotykowe	touch voltage
napięcie dotykowe spodziewane	prospective touch voltage
napięcie fazowe	line-to-neutral voltage
napięcie indukowane	inducted voltage
napięcie krokowe	step voltage
napięcie ładowania	charging voltage
napięcie międzyfazowe	line-to-line voltage s(voltage between phases)
napięcie pomiarowe	test voltage
napięcie powrotne	recorvery voltage
napięcie probiercze	test voltage
napięcie przewodowe	line-to-line voltage
napięcie udarowe wytrzymywane	impulse withstand voltage
napięcie wyjściowe	output voltage
napięcie wynoszone	transferred voltage
napięcie względem ziemi	voltage to earth
napięcie zakłóceniowe	fault-voltage
napięcie znamionowe	nominal voltage
napięcie znamionowe prądu przemiennego	nominal a.c.r.m.s. voltage
napis ostrzegawczy	warning notice
naprawa	repair
narażenia cieplne	thermal stresses
narażenia dynamiczne	dynamic stresses
narażenia mechaniczne	mechanical stresses
nastawienie prądu	current setting

niebezpieczeństwo pożaru	fire risk
niebezpieczna część czynna	hazardous-live-part
niebezpieczne napięcie dotykowe	dangerous touch voltage
niedociążenie	under-utilization
niesymetria obciążenia	asymmetrical load
nietętniący prąd stały	ripple-free direct current
nieuziemione połączenia wyrównawcze miejscowe	earth-free local equipotential bonding
niezamierzony dotyk do części czynnych	unintentional contact with live part
niezawodność	reliability
norma	standard
normalizacja międzynarodowa	international standardization
normalne użytkowanie	normal use
numer katalogowy	catalogue number

O

obciążalność prądowa długotrwała	continuous current-carrying capacity, current-carrying capacity
obciążenie cieplne	thermally load
obciążenie cykliczne	cyclic load
obciążenie mechaniczne	mechanical stress
obciążenie o szybkich zmianach	rapidly fluctuating load
obciążenie spodziewane	load to be expected
obiekt budowlany	building
obniżenie napięcia	drop in voltage
obniżenie się jakości	deterioration
obrabiarka	machine-tol
obrażenia ciała	injury
obszar obsługi wyposażenia elektrycznego	electrical operating area
obszar ograniczony	restricted area
obszar ruchu elektrycznego	close electrical operating area
obszar widoczny	visible area
obudowa	enclosure
obudowa ferromagnetyczna	ferromagnetic enclosure
obudowa izolacyjna	insulating enclosure
obudowa transformatora	transformer tank
obudowa zamykana	lockable enclosure
obwód	circuit
obwód doprowadzający	incoming circuit
obwód jednofazowy	single-phase circuit
obwód magnetyczny	magnetic circuit
obwód nieuziemiony	unearthed circuit
obwód odbiorczy	consumer installation
obwód odprowadzający	outgoing circuit
obwód oświetleniowy	lighting circuit
obwód pomiarowy	measuring circuit
obwód pomocniczy	auxiliary circuit
obwód rozdzielczy	distribution circuit
obwód sterujący	control circuit
obwód uziemiony	earthed circuit
obwód wejściowy	input circuit
obwód wewnętrzny urządzenia	internal wiring of apparatus

obwód wtórny	secondary circuit
obwód wyjściowy	output circuit
obwód wyższego napięcia	higher voltage circuit
obwód wzbudzenia	exciter circuit
ochrona dodatkowa	fault protection
ochrona ludzi	protection of persons
ochrona mechaniczna	mechanical protection
ochrona odgromowa (obiektów budowlanych)	lightning protection (of buildings)
ochrona podstawowa	basic protection
ochrona przeciwpożarowa	protection against fire
ochrona przed dotykiem bezpośrednim	protection against direct contact
ochrona przed prądem przetężeniowym	protection against overcurrent
ochrona przed przegrzaniem	protection against overheating
ochrona przed przepięciami	protection against overvoltage
ochrona przed skutkami oddziaływania cieplnego	protection against thermal effects
ochrona przed skutkami spadku napięcia	protection against undervoltage
ochrona przy dotyku pośrednim	protection against indirect contact
ochrona przy uszkodzeniu	fault protection
ochrona w przypadku uszkodzenia	protection in case of a fault
ochrona wzmocniona	enhanced protective ochrona
zapewniająca bezpieczeństwo	protection for safety
ochrona zwierząt domowych	protection of livestock
oddziaływanie cieplne	thermomechanical stress
oddziaływanie dynamiczne	electro-mechanical stress
oddziaływanie elektromechaniczne	electromechanical stress
oddziaływanie elektromagnetyczne	electromagnetic influence
oddziaływanie elektrostatyczne	elektrostatic influence
oddziaływanie jonizujące	ionizing influence
oddzielenie elektryczne	electrical separation
oddzielny przewód ochronny	separate protective conductor
odchylenie napięcia	voltage tolerance
odległość bezpieczna	safety distance
odlewanie	moulding
odłączenie	isolation
odporność na starzenie	resistant to ageing
odporność na uderzenia	resistance to impact
odporny na deszcz	rain proof
odporny na deszcz ze śniegiem	sleet resistant
odporny na korozję	corrosion resistant
odporny na lód	ice resistant
odporny na warunki pogodowe	weather proof
odskoki styków przekaźnika	bouncing of relay contacts
odstęp izolacyjny	clearance
oględziny	visual inspection, inspection
ogniwo galwaniczne	primary cell
ograniczenie ładunku	limitation of charge
ograniczenie napięcia	limitation of voltage
ograniczenie prądów przetężeniowych	limitation of overcurrent
ograniczenie wartości prądu	limiting a current
ogranicznik przepięć	lightning arrester
ograniczone źródło prądu	limited-current-source
ogrodzenie	barier

ogrzewanie	heating
ogrzewanie podłogowe	floor heating
ogrzewanie sufitowe	ceiling heating
określony umownie	conventionaly defined
olejoszczelny	oil-tight
ołów	lead
oparzenie prądem elektrycznym	electrical burn
oprawa oświetleniowa	lampholder, luminaire
oprawa oświetleniowa zewnętrzna	external luminaire
oprawa wisząca	pendant luminare
oprawka źródła światła	lampholder
oprzewodowanie	wiring system
oprzewodowanie giętkie	flexible wiring system
oprzewodowanie stałe	fixed wiring
oscylacja napięcia	voltage oscillation
osłona ceramiczna	earthenware duct
osłona kabla	cable covering
osłona metalowa	metallic covering
osłona niemetalowa (izolacyjna)	non-metalic sheath
osoba niepoinstruowana	uninstructed person
osoba poinstruowana	instructed person
osoba postronna	ordinary person
osoba wykwalifikowana	skilled person
osprzęt	fittings, accessories
osprzęt linii napowietrznej	overhead line fittings
osprzęt mocujący	fixing device
ostra krawędź	sharp edge
ościeżnica	architrave
oświetlenie	lighting
oświetlenie bezpieczeństwa	safety lighting, emergency lighting
oświetlenie fluorescencyjne	fluorescent lighting
oświetlenie podwodne	underwater lighting
oświetlenie zewnętrzne	external lighting
otoczenie metaliczne	metallic surrounding
otoczenie pacjenta	patent environment
otwór wentylacyjny	vent

P

palec probierczy	test finger, rest finger
pancerz kabla	armouring of a cable
para	steam
para wodna	steam, water vapour
parametry obwodu elektrycznego	characteristics of the circuit
parametry przewodów ochronnych	characteristics of protective conductors
pełny zestaw próbek	full set of samples
pierścieniowy obwód odbiorczy	ring final circuit
plac budowy	construction site
plaża	beach
pleśń	mould growth
płomień	flame
płyn przewodzący	conducting fluid
pobór mocy	power consumption

podgrzewacz wody	water heater
podłoga podwójna	suspended floor
podłoga przewodząca	conductive floor
podłoże z drutu	wire mesh
podpora metalowa	metal support
podpora przewodu	cable support
podpora przewodów napowietrznych	overhead wiring support
podział instalacji	division of installation
podstawa przeciwwstrząsowa	anti-vibration mounting
pojazd rekreacyjny	recreational vehicle
pojazd wypoczynkowy	leisure accommodation vehicle
pojedyncze uszkodzenie	single-fault
pojemność cieplna	heat capacity
pojemność cieplna właściwa	volumetric heat capacity
pokrycie wewnętrzne	inner skin
pole elektryczne	electric field
pole magnetyczne	magnetic field
pole o częstotliwości radiowej	radio frequency field
pole przekroju poprzecznego	cross-sectional area
pole rozdzielnicy	switch bay
połączenia między przewodami	connections between conducors
połączenia wyrównawcze	equipotential bonding
połączenia wyrównawcze dodatkowe	supplementary equipotential bonding
połączenie cynowe	tin-soldered joint
połączenie elektryczne	electrical connection
połączenie giętkie	flexible connection
połączenie gwintowe	screwed connection
połączenie lutowane	soldered connection
połączenie mechaniczne	mechanical connection, mechanical joint
połączenie sygnałowe	signal connectin
połączenie śrubowe	screwed joint
połączenie światłowodowe	fibre optic link
połączenie wewnętrzne	internal connection
połączenie wyrównawcze nieuziemione	non-earthed equipotential bonding
połączenie wyrównawcze ochronne	protective-equipotential-bonding
połączenie zewnętrzne	external connection
położenie geograficzne	geographical location
pomieszczenie handlowe	commercial premise
pomieszczenie medyczne	medical location
pomieszczenie mieszkalne	residential premise
pomieszczenie ogrodnicze	horticultural premise
pomieszczenie przemysłowe	industrial premiss
pomieszczenie rolnicze	agricultural premise
pomieszczenie ruchu elektrycznego	electrical operating area
pomieszczenie sterownicze	control room
pomieszczenie użyteczności publicznej	public premise
pompa	pump
pompa elektryczna	electric pump
ponowne zamykanie	reclosing
porażenie prądem elektrycznym	electric shock
porażenie śmiertelne	electrocution
potencjał elektryczny ziemi	electric potential of earth

potencjał powierzchni ziemi (względem ziemi odniesienia)	earth-surface voltage (to earth)
potencjał przewodu ochronnego	potenctial of protective conductor
potencjał ziemi	earth potential
potencjometr	potentiometer
powierzchnia dolna	bottom surface
powierzchnia dostępna	accessible surface
powierzchnia dotykana	touchable surface
powierzchnia przewodząca	conducting surface
powierzchnia użyteczna	usable surface
powierzchnia zamknięta	closed surface
powłoka kabla	sheath of a cable
powłoka ołowiana	lead sheath
powrót napięcia	restoration of voltage
poziom bezpieczeństwa	degree of safety
poziom kontrolowany	controlled level
poziom napięcia	voltage level
poziom przepięć	overvoltage level
praca normalna	normal service
prace ziemne	earthworks
prąd błądzący	stray current
prąd dopuszczalny	current allowable
prąd dotykowy	touch current
prąd nastawiony	current setting selected
prąd ograniczony	cut-off current
prąd pierwszego doziemienia	first fault current
prąd pojemnościowy	capacitive current
prąd przemienny	alternating current (a.c.)
prąd przetężeniowy	overcurrent
prąd rażeniowy	shock current
prąd roboczy	steady current
prąd rozruchowy	starting current
prąd rozruchowy początkowy	inrush current
prąd różnicowy	residual current
prąd różnicowy zadziałania	Residual operating current
prąd stały	direct current (d.c.)
prąd stały nietętniący	d.c. ripple-free
prąd upływowy doziemny	earth-leakage current
prąd wyzwalający	operating current
prąd wyzwalający różnicowy (znamionowy)	rated operating residual current
prąd zakłóceniowy	fault current
prąd znamionowy	current rating
prąd zwarcia doziemnego	earth fault current
prąd zwarciowy asymetryczny	asymmetrical short-circuit current
prąd zwarciowy doziemny	earth-fault current
prąd zwarciowy spodziewany	prospective short-circuit current
prądnica	generator
prądnica przewoźna	mobile power generator
prądnica stacjonarna	fixed power generator
proces produkcyjny	manufacturing process
procesy niebezpieczne	hazardous processes
procesy toksyczne	toxic processes

produkty spalania	products of combustion
projektowanie	design
promieniowanie cieplne	heat radiation, thermal radiation
promieniowanie jonizujące	ionizing radiation
promieniowanie podczerwone	infra-red radiation
promieniowanie słoneczne	solar radiation
prostownik	rectifier
protokołowanie	reporting
próba wstępna	initial verification
próbka	sample
próg bólu	threshold of pain
próg wyczuwalności	threshold of perception
prysznic	shower head
przeciążenie	overload
przedział częstotliwości	frequency range
przegląd	inspection
przegląd okresowy	periodic inspection
przegroda ogniowa	fire barrier
przegroda	divider
przegroda izolacyjna	insulating barrier
przegroda ognioodporna	fire-proof shutter
przegrzanie	overheating
przekaźnik	relay
przekaźnik podnapięciowy	undervoltage relay
przekładnik prądowy	current transformer
przekrój	cross-section area
przekrój przewodu	cross-section of conductor
przekrój znormalizowany	standard cross-sectional area
przekrój żyły	cross-sectional area of conductor
przekształcenie energii elektrycznej	conversion of electrical energy
przekształtnik elektroniczny	electronic converter
przepięcie	overvoltage, stress-voltage
przepięcie atmosferyczne	lightning overvoltage
przepięcie dorywcze	temporary overvoltage
przepięcie łączeniowe	switching overvoltage
przepięcie przejściowe	transient overvoltage
przepisy bezpieczeństwa	safety rules
przepływ powietrza	air flow
przestrzeń instalacyjna	building void
przestrzeń wewnętrzna	indoor location
przestrzeń zagrożona wybuchem	potentially explosive atmosphere
przestrzeń zewnętrzna	outdoor location
przesył energii	transmission of energy
przesyłanie	transmission
przeszkoda ochronna (elektrycznie)	protective obstacle (electrically)
przetwarzanie danych	data processing
przetwornica dwumaszynowa	motor-generator set
przewodność cieplna	thermal conductance
przewody szynowe	busbar trunking system
przewód	conductor
przewód dwużyłowy	twin-core cable
przewód fazowy	phase conductor

przewód giętki	flexible cable
przewód goły	bare conductor
przewód izolowany	insulated conductor
przewód jednożyłowy	single-core cable
przewód jednożyłowy giętki	flexible single-core cable
przewód mostkujący	bonding conductor
przewód napowietrzny	overhead conductor
przewód neutralny	neutral conductor
przewód ochronny	protective conductor
przewód odgromowy	overhead earth wire
przewód opancerzony	armoured cable
przewód połączenia wyrównawczego głównego	main equipotential bonding conductor
przewód powrotny	return conductor
przewód przetwarzania danych	data cables
przewód roboczy	live conductor
przewód sztywny	rigid cable
przewód samonośny	supporting conductor
przewód szynowy	busbar trunking system (busway)
przewód środkowy	mid-point conductor
przewód uziemiający	earth wire, earthing conductor, earthing lead
przewód uziemiający funkcjonalny	functional earthing conductor przewód
uziemiający ochronno-funkcjonalny	functional earhing and protective conductor
przewód uziemiający ochronny i ekwipotencjalny	protective earthing and functional bonding conductor
przewód uziemienia funkcjonalnego	functional earthing conductor przewód
wielożyłowy	multiconductor cable, multicore cable
przewód zasilający	supply conductor
przesyłanie danych	data communication
przyczepa turystyczna	caravan
przypadkowy dotyk	accidental contact
przyrząd pomiarowy	measurement instrument
przyspieszenie	acceleration
przyspieszenie maksymalne	maximum acceleration
punkt bezpośrednio uziemiony	directly earthed point
punkt gwiazdowy	star-point
punkt neutralny	neutral point
punkt neutralny niedostępny	available neutral point
punkt neutralny sztuczny	artifical neutral point
punkt przyłączeniowy	tap-off point
punkt środkowy	mid-point
punkt wrzenia	boiling point
puszka łączeniowa	junction box
pył	dust
pyłoszczelny	dust-tight

R

rafineria ropy	oil rafinery
rama okienna	window frame
reflektor	floodlight
reflektor punktowy	spotlight
regulacja temperatury	temperature control
rezystancja ciała ludzkiego	body resistance

rezystancja cieplna gruntu	soil thermal resistance
rezystancja izolacji	insulation resistance
rezystancja styku	contact resistance
rezystancja uziemienia	earthing resistance
rezystancja wewnętrzna	internal resistance
rezystywność gruntu	electric resistivity of soil
rezystywność cieplna gruntu	soil thermal resistivity
rezystywność materiału	resistivity of material
rodzaj prądu	nature of current
rodzaj zasilania	nature of supply
rozbryzgi (wody)	splashes (of water)
rozdział energii	distribution of energy
rozdzielnica	switchboard, distribution board
rozdzielnica o izolacji gazowej	gas-insulated switchgear
rozdzielnica o izolacji próżniowej	vacuum switchgear
rozgałęźnik wieloobwodowy	multi-way plug in unit
rozgałęzienie obwodu	branch circuit
rozruch urządzenia	starting of equipment
rozrzut wartości	spreed of values
rozwój techniczny	technical development
różne napięcia	different voltages
różne obwody	various circuits
ruchome połączenie przewodzące	movable conductive connection
ruchome źródło separacyjne	mobile separation source
rurka izolacyjna	insulating conduit
ryzyko dopuszczalne	acceptable risk
ryzyko szkody	risk of failure
ryzyko uszkodzeń	risk of damage

S

sala komputerowa	computer room
samoczynne wyłączenie	automatic disconnection
samoczynne zadziałanie	automatic operation
samogasnący	self- extinguishing
samorozluźnianie	self-loosening
schody ruchome	escalators
separacja elektryczna	electrical separation
separacja ochronna	protective - separation
seria pomiarów	series of measurements
siatka	mesh screen
siatka metalowa	metallic grid
sieć ciepłej wody	hot water system
sieć elektroenergetyczna	electrical power network (system)
sieć jednofazowa	single-phase system
sieć lokalna	local area network
sieć napowietrzna	overhead network
sieć niskiego napięcia	low-voltage network
sieć publiczna	public network
sieć trójfazowa	three-phase system
sieć uziemiona skutecznie	effectively earthed system
sieć wyższego napięcia	higher voltage
system sieć z izolowanym punktem neutralnym	isolated neutral system

sieć z punktem neutralnym uziemionym przez rezystor	impedance earthed neutral system
sieć z uziemionym punktem neutralnym	solidly earthed neutral system
sieć zakłócająca	disturbed network
sieć zasilająca prądu stałego	d.c.power supply network
silnik trójfazowy	three-phase motor
siła wyciągania wtyczki	withdrawal force for the plug
skrzynka łączeniowa	connection box
skrzynka przyłączeniowa	junction box
skuteczność uziomu	efficacy of earth electrode
skutki cieplne	thermal effects
skutki mechaniczne	mechanical effects
skutki patofizjologiczne	pathophysiological effects
skutki termiczne	thermal effects
słup żelbetowy	steel reinforced concrete pole
spadek napięcia	voltage drop
spalenie materiału	combustion of material
spawanie	welding
specjalne warunki	special conditions
spodziewany prąd zwarcia	prospective short-circuit current
sposób instalowania	method of installation
sprawdzanie odbiorcze	initial verification
sprawdzenie	testing, verification
sprawdzenie biegunowości	polarity test
sprawdzenie odbiorcze	initial verification
sprawdzenie okresowe	periodic verification
sprzężenie zwrotne	feedback
stabilne właściwości elektryczne	electrical continuity characteristic
stacja transformatorowa	transformer sub-station
stała kontrola uziemienia	earth continuity monitoring
stałe źródło separacyjne	fixed separation source
stan nieustalony	transient (state)
stanowisko izolowane	non – conductive location
statek wycieczkowy	pleasure craft
sterowanie	control
sterowanie potencjałem	potential grading
sterowanie silnika	motor control
stopień bezpieczeństwa	degree of safety
stopień ochrony	degree of protection
strata mocy	power loss
strefa niebezpieczna	danger zone
strefa przemysłowa	industrial area
strefa wpływu	zone of influence
strefa wpływu połączenia wyrównawczego	zone of influence of equipotential bonding
strefa zasięgu ręki	zone of arm's reach
strona odbiorcza prostownika	downstream of rectifier
strona zasilania	supply side
strumień wody	jet of water
stycznik	contactor
styk ochronny	protective conductor contact
styk ruchomy	moving contact
substancja korozyjna	corrosive substance

substancja zanieczyszczająca	polluting substance
sufit	ceiling
sufit podwieszany	false ceiling, suspended ceiling
swobodnie spadające krople (wody)	free-falling drops (of water)
sygnalizacja	signalling
system alarmowy	alarm system
system alarmowy włamaniowy	intruder alarm system
system drabinek instalacyjnych	cable lader system
system gaszenia pożaru	fire extinguishing system
system korytek instalacyjnych	cable tray system
system listew instalacyjnych otwieranych	cable trunking system (CTS)
system listew instalacyjnych zamkniętych	cable ducting system (CDS)
system ochrony odgromowej	lightning protection system
system przywoławczy	paging system
system rozdziału energii	electric power distribution system
system rur instalacyjnych	conduit system
system sterowania cyfrowego	digital control system
system wentylacji (wymuszony)	ventilation system (forced)
system wentylacyjny	ventilation system
system wytwarzania energii	electric power generation system
szatnia	clook-room
szkodliwe skutki	harmful effects
szkodliwe zagrożenie	harmful hazard
sztuczny punkt neutralny	artificial neutral point
szyb konstrukcyjny	building void

Ś

ściana drewniana	wooden wall
ściana izolacyjna	insulating wall
ściana izolowana cieplnie	thermally insulated wall
ściana murowana	masonry wall
ścianka ruchoma	removable partition
średnica	dimension
średnica zewnętrzna	external diameter
środek dodatkowy	supplementary measure
środek ostrożności	safety precaution
środek zmniejszający palność	flame-retardant
środki ochrony	protective measures
środki ochrony przed dotykiem pośrednim	protective measures against indirect contact
środki ostrożności	precautions
środowisko	environment
środowisko chronione	protected environment
środowisko nieprzewodzące	non-conducting environment
śruba metalowa	metallic screw

T

tablica rozdzielcza	switch panel
tablica sterownicza	control panel
tabliczka znamionowa	nameplate
taśma ochronna	protective tape
telekomunikacja	telecommunication
temperatura dopuszczalna	permissible temperature

temperatura eksploatacji	application temperature
temperatura graniczna dopuszczalna	admissible limit temperature
temperatura instalowania	installation temperature
temperatura końcowa	final temperature
temperatura magazynowania	storage temperature
temperatura odniesienia	reference temperature
temperatura otoczenia	ambient temperature
temperatura początkowa	initial temperature
temperatura powietrza niska	low air temperature
temperatura powietrza wysoka	high air temperature
temperatura pracy	operating temperature
temperatura przeciętna	average temperature
temperatura transportowania	transport temperature
tolerancje fabryczne	manufacturing tolerances
trakcja elektryczna	electric traction
trakcja kolejowa	railway track
transformator dwuuzwojeniowy	double wound transformer
transformator dzwonkowy	bell transformer
transformator ochronny (separacyjny)	isolating transformer
transformator spawalniczy	welding transformer
transmisja sygnału	signal transmission
transporter	conveyor
trójfazowy	three-phase
trwałość izolacji	life of insulation
tynk	plaster
typ oprzewodowania	type of wiring

U

uchwyt izolacyjny	insulated clip
uchwyt kablowy	cable support
układ ochronny połączeń ekwipotencjalnych	protective equipotential bonding system
układ medyczny IT	medical IT system
układ rozdzielczy	distribution system
układ uziemiający	earthing arrangement
układ uziemień	system earthing
układ wspólnych połączeń ekwipotencjalnych	common equipotential bonding system
układ wysokiego napięcia	high voltage system
umieszczenie poza zasięgiem ręki	placing out of reach
umowny prąd wyzwalający	conventional operating current
unifikacja międzynarodowa	international unification
urządzenie badane	device under test (DUT)
urządzenie ciągłej kontroli izolacji	insulation monitoring device
urządzenie jednobiegunowe	single-pole device
urządzenie łączące	switching measure
urządzenie ochronne impedancyjne	protective impedance device
urządzenie ochronne napięciowe	fault-voltage operated protective device
urządzenie ochronne przetężeniowe	overcurrent protective device
urządzenie ochrony przepięciowej	overvoltage protective devices
urządzenie odłączające	disconnecting device, isolation measure
urządzenie półprzewodnikowe	semiconductor device
urządzenie produkowane fabrycznie	factory-built equipment
urządzenie przenośne	portable device (equipment)

urządzenie przetwarzania danych	data processing equipment
urządzenie ręczne	hand-held device (equipment)
urządzenie różnicowoprądowe	residual current device
urządzenie ruchome	mobile equipment (device)
urządzenie sterownicze	control device
urządzenie wielobiegunowe	multipole device
urządzenie zabezpieczające	protective device
urządzenie zabezpieczające przetężeniowe	overcurrent protective device
urządzenie zabezpieczające z regulacją nastawy	adjustable protective device
uszczelka	seal
uszczelnienie oprzewodowania	sealing of the wiring system
uszkodzenie	fault
uszkodzenie mechaniczne	mechanical damage
uszkodzenie pojedyncze	single fault
uziemienie	earthing (system)
uziemienie funkcjonalne	functional earthing
uziemienie ochronne	protective earthing, protective grounding (USA)
uziemienie robocze	functional earthing, functional grounding (USA)
uziemienie układu sieci	earthing of system
uziemiony przewód skrajny	earthed line conductor
uziemiony przewód środkowy	earthed mid – wire conductor
uziemiony punkt gwiazdowy	star earthing point
uziemiony punkt układu sieci	earthed point of a power system
uziom fundamentowy	earth electrode embeded in foundation
uziom niezależny	independent electrode
uziom oddzielny	separate earth electrode
uziom płytowy	earth plate
uziom pomocniczy	auxiliary earth electrode
uziom prętowy	earth rod
uziom rurowy	earth pipe
uziomy połączone równolegle	earth electrodes in parallel
uzwojenie pierwotne	input winding
uzwojenie wtórne	outut winding
użytkowanie	utilization

W

wahania napięcia	voltage variation, voltage fluctuations
warnik elektryczny	electric water-heater
wartość bezpieczna	safe value
wartość graniczna	limit value
wartość skuteczna	root-mean-square value (rms value)
wartość szczytowa	peak value
wartość umowna	conventional value
wartość wymagana	required value
warunki chłodzenia	cooling conditions
warunki domowe	household conditions
warunki ewakuacji	conditions of evacuation
warunki gruntowe	soil conditions
warunki klimatyczne otoczenia	ambient climatic conditions
warunki mechaniczne	mechanical conditions
warunki przemysłowe ciężkie	severe industrial conditions
warunki przemysłowe zwykłe	usual industrial conditions

warunki szczególne	special conditions
warunki środowiskowe	environmental conditions
warunki zainstalowania	installation conditions
warunki zakłóceniowe	fault conditions
wąż wodny	hosewater
wentylacja	ventilation
węglowodory	hydrocarbons
wiązka przewodów	group of conductors
wibracje	vibration
wibracje ciągłe, sinusoidalne	stationary vibration, sinusoidal
wilgotność bezwzględna	absolute humidity
wilgotność bezwzględna powietrza	absolute air humidity
wilgotność względna duża	high relative humidity
wilgotność względna mała	low relative humidity
wilgotność względna powietrza	relative air humidity
własne źródło zasilania	private source
właściwości cieplne	thermal propetries
właściwości elektryczne	electrical properties
właściwości mechaniczne	mechanical properties
wnętrze wanny	interior of the bath
wnikanie wody	ingrees of water
wodomierz	water meter
wodoszczelny	water-tight
wodoszczelny iluminator	watertight porthole
wpływ szkodliwy	detrimental influence
wpływy elektryczne	electrical influences
wpływy termiczne	thermal influences
wpływy zewnętrzne	external influences
wskaźnik elektryczny	electrical indicator
wskaźnik stanu izolacji	isolation monitoring device (IMD)
wskaźnik zadziałania	activity indicator
współczynnik jednoczesności	coincidence factor
współczynnik mocy	power factor
współczynnik niejednoczesności	diversity factor
współczynnik obciążenia	load factor
współczynnik poprawkowy	correction factor
współczynnik temperaturowy	temperature coefficient
wstrząsy sejsmiczne	seismic effects
wtyczka	plug
wykrycie uszkodzenia	fault detection
wykrywacz ognia	fire detector
wykwalifikowany personel	qualified personnel
wyładowanie elektrostatyczne	electrostatic discharge
wyłączenie awaryjne	emergency control
wyłączenie natychmiastowe	instantaneous tripping
wyłączenie zasilania	disconnection of supply
wyłącznik awaryjny	emergency switch
wyłącznik zdalnie sterowany	remote-control switch
wymagania bezpieczeństwa	safety requirements, protective requirements
wymagania dla instalacji	requirements for installations
wymagania funkcjonalne	functional requirements
wymagania podstawowe	fundamental requirements

wymagania prawne	legal requirements
wymagania techniczne	technical requirements
wymiana wyposażenia	replacement of equipment
wymiar	dimension
wymuszone ogrzewanie powietrzem	forced air heating
wynik badania	result of the test
wyposażenie elektryczne	electrical equipment
wyposażenie placu budowy	construction site equipment
wyposażenie stacjonarne	stationary equipment
wysoka temperatura powietrza	high air temperature
wysokość (nad poziomem morza)	altitude
wysychanie gruntu	soil drying
wytrzymałość cieplna	heat resistance
wytrzymałość elektryczna	electric strength
wytrzymałość mechaniczna	mechanical strenght
wytrzymałość udarowa	impulse strength
wytwarzanie ciepła	heat generation
wytwarzanie energii elektrycznej	generation of electrical energy
wyzwalacz przeciążeniowy	overload release
wyzwalacz zwarciowy	short circuit relase
wyższe harmoniczne	harmonics
wzajemne oddziaływanie	mutual influence
wzrost temperatury	increase of temperature

Z

zabezpieczenie (urządzenie)	protective equipment
zabezpieczenie podnapięciowe	undervoltage protective device
zabezpieczenie przeciążeniowe	overload protective device
zabezpieczenie rezerwowe	back-up protection
zabezpieczenie zwarciowe	short-circuit protective device
zaburzenie elektromagnetyczne	electromagnetic disturbances
zacisk probierczy	test link
zacisk śrubowy	screw terminal
zacisk uziemiający	earthing terminal
zacisk wyjściowy	outgoing terminal
zaciski źródła zasilania	supply intake point
zagęszczenie ludźmi	density occupation
zagrożenia	dangers
zagrożenie pożarowe	fire risk, fire hazard
zagrożenie termiczne	thermal stress
zagrożenie życia	danger to life
zakłócenia elektromagnetyczne	electromagnetic phenomena
zakłócenia łączeniowe	switching phenomena
zakres częstotliwości	range of frequency
zakres napięciowy	voltage band
załączanie niesamoczynne	non-automatic supply
załączanie samoczynne	automatic supply
zamarzanie gruntu	soil freezing
zamknięcie na kłódkę	padlocking
zamknięty otok	closed ring
zamocowanie antywstrząsowe	anti-vibration mounting
zanieczyszczenia	pollutants

zanik napięcia	loss of voltage, voltage interruption
zanurzalny	submersible
zanurzenie	immersion
zapad napięcia	voltage dip
zapobieganie	prevention
zasilacz prądu stałego	d.c. power supply
zasilanie awaryjne	emergency supply
zasilanie podstawowe	main supply
zasilanie rezerwowe	standby supply
zbrojenie metalowe betonu	metallic reinforcement of concrete
zdalnie sterowany	remotely controlled
zdolność wyłączania	breaking capacity
zespół prądotwórczy	motor-alternator set
zespół prądotwórczy napędzany silnikiem Diesla	diesel-driven generator
zespół prądotwórczy niskonapięciowy	low-voltage generating set
zespół przewoźny	transportable unit
zespół ruchomy	mobile unit
zestaw elektromedyczny	medical electrical system
zewnętrzne źródło zasilania	external supply
zgodność z normą	accordance with the standard
ziemia odniesienia	reference earth, reference ground (USA)
zjawiska atmosferyczne	atmospheric phenomena
złącze instalacji	origin of the installation
złącze kompensacyjne	expansion joint
złączka	connector, coupler
zmęczenie (materiału)	fatigue
zmiany częstotliwości sieci	power-frequency variations
zmostkowany	bonded across
znak identyfikacyjny	identyfication mark
znak identyfikacyjny wyrobu	product identyfikaction mark
znak towarowy	trade mark
znamionowy różnicowy prąd wyzwalający	rated residual operating current zniekształcenie
liniowe	linear deffection
zniszczenie	damage
zniszczenie materiału	degradation of material
zwarcie	short circuit
zwarcie doziemne	fault to earth, short-circuit to earth
zwarciowa zdolność wyłączania	breaking capacity
zwieranie	short-circuiting
zwłoka czasowa	time delay

Ź

źródło ciepła	heat source
źródło elektrochemiczne	electrochemical source
źródło pomocnicze	auxiliary source
źródło prądu ograniczonego	limited-current-source
źródło ruchome	mobile source
źródło separacyjne	separation source
źródło zasilania	source of supply
źródło zakłócenia	source of disturbance
źródło zewnętrzne	external source

Ż

żarówka	incandescent lamp
żyła okrągła	circular conductor
żyła sektorowa	shaped conductor
żyły równoległe	conductors in parallel

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Attention: access to all websites: 04.2023

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