Fit for Green Cooling

# Module D – Electrical basics for refrigeration installations and safety

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of

Federal Ministry for Economic Cooperation and Development

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

# Introduction to the Refrigeration & air conditioning training guide

The refrigeration, air-conditioning and heat pump (RACHP) sector is facing many changes over the next years. Many refrigerants currently used will be phased-out or phased-down in the close future under the Montreal Protocol and its Kigali Amendment because of their harm to the environment. This includes their ozone-depleting and climate-damaging properties. Additionally, the energy efficiency of a unit is becoming more and more important. For skilled workers in the RACHP sector, this results in many challenges as new technologies are entering the market.

There are several risks from working in the RACHP sector. On the one hand, environmental harm can be caused through the release of ozone-depleting and climate-damaging refrigerants during operating and servicing. On the other hand, the personal safety of the skilled workers handling the equipment and refrigerants as well as the safety of users of equipment has to be ascertained. Dangers include intoxication, refrigerant burns, suffocation, fire and explosion as well as electrical faults leading to fires and electrical shock or bad practice installations causing refrigerant leakages.

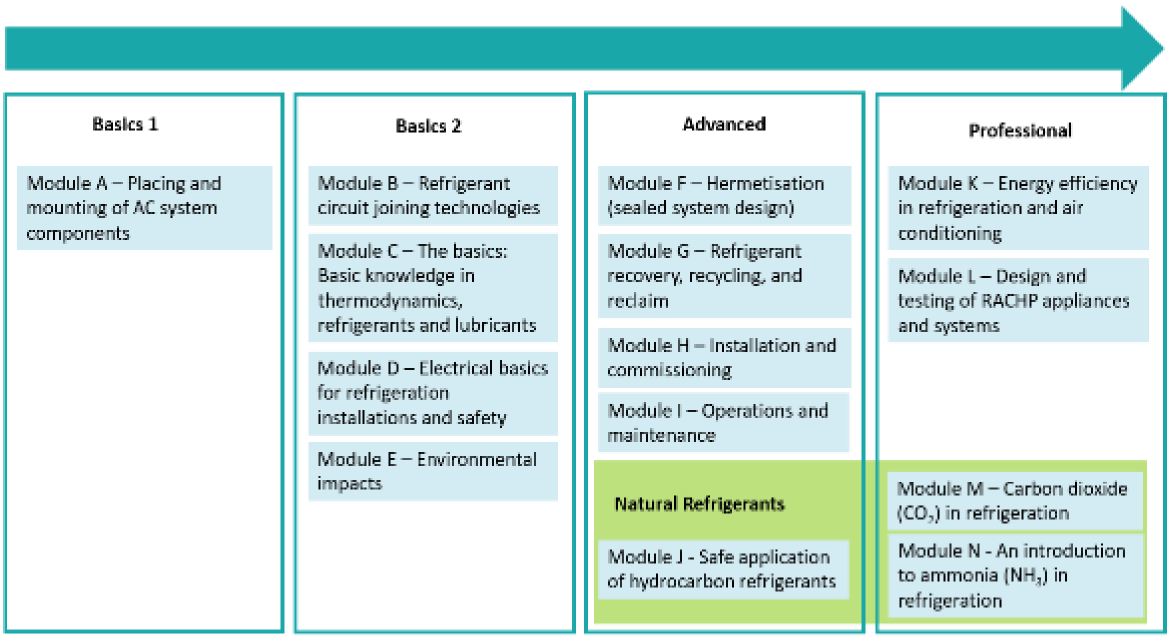
The reduction of greenhouse gases such as hydrofluorocarbons (HFCs) typically requires a combination of technology change, regulatory action and human capacity development. The technical characteristics of refrigerants change dramatically in view of their flammability, toxicity and/or operating pressure level with the transition from the predominantly used hydrochlorofluorocarbons (HCFCs) and (saturated) HFCs with high global warming potential (GWP) to climate friendly refrigerants, including natural refrigerants and a number of unsaturated HFCs (HFOs) with very low GWP.

This module on electrical parts, installation and safety is one part of a series of training modules on best practice guidelines in refrigeration and air conditioning, published by GIZ. Together, the modules form the basis for qualified work of skilled workers and address the mentioned challenges in the RACHP sector. The module content is based on international standards regarding the training of RACHP skilled workers as well as product and general RACHP safety standards. The set of modules range from basic knowledge necessary for skilled workers as well as more advanced qualifications involving the refrigerant circuit and professional level modules (see figure below), for example on energy efficient design or ammonia refrigeration. A good basis is necessary before starting on advanced modules.

The modules can be used to support a national quality infrastructure based on approved best practice codes and international standards. Essential instruments for its implementation include qualification, certification, accreditation, registration, monitoring and financial incentive schemes. Certification of skilled workers and companies is essential to sustainably increase competencies in the RACHP sector. Certification should always be linked to examination by an accredited institution and registration in a country database. Previously determined skills to asses are the basis for certification and an example is contained in the presented modules. The content of the modules is based on skills to assess in standards ISO (DIS) 22712/EN 13313: Refrigerating systems and heat pumps – Competence of personnel.

The following modules are available:

| | |
|---|---|
| **Module A** | Placing and mounting of AC system components |
| **Module B** | Refrigerant circuit joining technologies |
| **Module C** | The basics: Basic knowledge in thermodynamics, refrigerants and lubricants |
| **Module D** | Electrical basics for refrigeration installations and safety |
| **Module E** | Environmental impacts |
| **Module F** | Hermetisation (sealed system design) |
| **Module G** | Refrigerant recovery, recycling, and reclaim |
| **Module H** | Installation and commissioning |
| **Module I** | Operations and maintenance |
| **Module J** | Safe application of hydrocarbon refrigerants |
| **Module K** | Energy efficiency in refrigeration and air conditioning |
| **Module L** | Design and testing of RACHP appliances and systems |
| **Module M** | Carbon dioxide ($CO_2$) in refrigeration |
| **Module N** | An introduction to ammonia ($NH_3$) in refrigeration |




In addition to this handbook, further material for trainers is available, such as trainer manuals, PowerPoint presentations, training agendas and handouts.

# Disclaimer

Reasonable efforts have been taken to ensure that the information or advice is reliable, correct and accurate and accords with current standards as at the date of publication. The information or advice contained in this document is intended for use only by persons who have had adequate technical training in the field to which the code of practice relates. The document has been compiled as an aid only, and the information or advice should be verified before it is applied by any person. The user should also establish the applicability of the information or advice in relation to any specific circumstances.

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Pictures for this module have been provided by Tony Darlow and Rolf Hühren unless otherwise noted.

*Symbols*

The following symbols are used to structure the text and highlight important messages:

✗ Incorrect uses or work processes are highlighted by a red x.

✓ Correct uses or work processes are highlighted by a green check mark.

☛ *See chapter xxx*

*Textbox referring the reader to a different chapter*

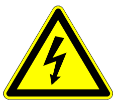
 How to

Referring to instructions describing work routines

Safety relevant message

Message with direct relevance to flammable refrigerants

Other signs used in the document:

 Electricity

 Explosive materials

Asphyxiation

Black text boxes highlight specific topics or additional information.

# Content

# Figures

## Tables

# Learning outcomes

This module is intended for technicians of all levels.

No person shall undertake any work activity where technical knowledge or experience is needed to prevent electrical danger or injury, unless that person has such technical knowledge or experience, or is under such supervision as is necessary for the work undertaken.

National legislation can set out the minimum age and the criteria for competence of persons.

| **Basics 2 level** | |
|---|---|
| **Knowledge** | 1. Know about the basic concept of electricity<br>2. Understanding the hazards which can arise during the work and the precautions to be observed<br>3. Gain knowledge how to acquire experience of electrical work<br>4. Understanding of the installation or type of equipment to be worked on<br>5. Know about observation and application of measures for occupational health and safety and accident prevention regulations.<br>6. Know about appropriate personal protective equipment<br>7. Know about observation and application of environmental protection and rational use of material resources and energy<br>8. Know about tools, equipment and devices that shall be used in accordance with the instructions and/or guidance provided by the manufacturer or supplier<br>9. Acquire ability to recognise at all times whether it is safe to continue working |
| **Skills** | 1. Be able to wire a simple electrical circuit<br>2. Be able to carry out electrical safe isolation<br>3. Be able to conduct an electrical inspection and test |

# List of abbreviations

| Acronym | Definition |
|---|---|
| A | Ampere(meter) |
| AC | Alternating Current |
| ADS | Automatic Disconnection of Supply |
| ALCI | Appliance Leakage Current Interrupter |
| ATEX | Atmosphere Explosible |
| AVO | Amps, Volts and Ohms |
| BT | Battery |
| C | Common |
| CAT | Measurement Categories |
| CE | Conformité Européenne |
| CFC | Chlorofluorocarbon |
| DC | Direct Current |
| EMF | Electromotive Force |
| FL | Full Load (conditions) |
| GFCI | Ground Fault Circuit Interrupter |
| GFI | Ground Fault Interrupter |
| GHG | Greenhouse Gases |
| GWP | Global Warming Potential |
| HBC | High Breaking Capacity |
| HC | Hydrocarbon |
| HCFC | Hydrochlorofluorocarbon |
| HFC | Hydrofluorocarbon |
| HFO | Hydrofluoroolefin |
| HRC | High Rupturing Capacity Fuse |
| IDU | Indoor Unit |
| IMD | Insulation Monitoring Devices |
| IP | Ingress protection |
| IT | Isolé terre - Isolated earthing system |
| MCB | Miniature Circuit Breaker |
| MPCB | Motor Protective Circuit Breaker |
| RACHP | Refrigeration, Air-Conditioning and Heat Pumps |
| ODU | Outdoor Unit |
| OFDN | Oxygen Free and Dry Nitrogen |
| PCB | Polychlorinated biphenyl |
| PD | Potential Difference |
| PE | Protective Earth |
| PEN | Protective Earth and Neutral |
| PPE | Personal Protection Equipment |
| PVC | Polyvinyl Chloride |
| R | Run / Resistor |
| RB | Body Resistance |
| RC | Contact Resistance |
| RCBO | Residual Circuit Breaker with Overcurrent |
| RCCB | Residual Current Circuit Breaker |

| | |
|---|---|
| RCD | Residual Current Device |
| RF | Fault resistance |
| RL | Local Resistance |
| RMS | Root Mean Square |
| RP | Planet Earth Resistance |
| RPM | Revolutions Per Minute |
| RW | Wire conductor resistance |
| S | Start / Switch |
| SELV | Separated Extra Low Voltage |
| SI | Système International (d'Unités) – International System of Units |
| TEWI | Total Equivalent Warming Impact |
| TN | Terre neutre - Earthed System |
| TT | Terre terre - Earthing system |
| UL | Underwriters Laboratories (safety organisation) |
| V | Volt(meter) |
| VA | Volt-amps |
| $Z_s$ | Earth fault loop impedance |

# D1 Electrical concepts

## D1.1 Electricity

*Figure 1-1 Michael Faraday (Source: Wikimedia/Project Gutenberg)*

Michael Faraday was the scientist who discovered how to produce electricity in 1831 when he inserted a bar magnet into a coil of copper wire and found that his action generated a brief wave of electricity, as indicated on his meter which was connected to the two ends of the coil of copper wire.

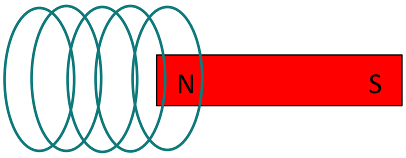



*Figure 1-2 Electric concept (Source: HEAT GmbH)*

The system of holding the coil of wire stationary while varying the strength of the magnetic field is the basic process used in power stations. However, the bar magnet is replaced by a rotating electromagnet and the coils are arranged so that the windings are cut by the magnetic field as the magnet rotates.

## D1.2 Electrical charge

The basis of all electrical energy is the electric charge. There are two kinds of electric charge: **positive** (protons) and **negative** (electrons).

Everything is made up of minute particles called atoms. Materials which consist of the same kind of atom are called elements. The simplest atom is that of hydrogen which is made up of a single proton in its nucleus and a single electron orbiting around it.

If we could see it, it would resemble the Earth with the moon orbiting around it.

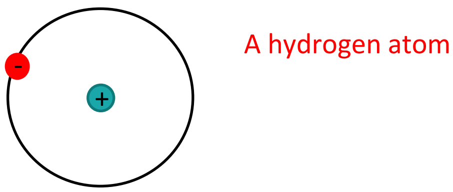



*Figure 1-3 Simplified visualisation of a hydrogen atom (Source: HEAT GmbH)*

The atomic structure of matter relies on two types of electric charge. Every atom consists of a nucleus of positively charged particles called protons, around which negatively charged particles called electrons are orbiting.

The number of electrons in an atom often equals the number of protons in the nucleus, and the atom is then said to be balanced. If most of the atoms in the piece of material are electrically balanced, the material is said to be **electrically neutral**, or uncharged.

If a material loses some of the electrons which belong to its atoms so that it contains more protons than electrons it is then **positively charged**.

The opposite position may occur where an object gains more electrons than are needed to balance all the protons in the atoms. The object is then **negatively charged**.

Electric charges share with magnetic poles the property of exerting forces upon one another. It must be remembered that identical charges repel one another and dissimilar charges attract one another. This rule applies to the charges of the electron and proton.


*Figure 1-4 Electric charges exerting forces upon one another (Source: HEAT GmbH)*

As the nucleus is positive and the electron is negative, the electron is bound in orbit and is normally prevented from flying off because of the attraction between the two particles. The number of orbiting electrons in a given atom depends on the type of material.

The basic principle that like charges repel and unlike charges attract can be used to force electrons to move in the same general direction and thus to produce **current flow**.

Current flow can be achieved with an external negative charge (which is no more than a point with an abundance of electrons) placed at one end of a conductor and an external positive charge (a point with a deficit of electrons) placed at the other end. This forces free electrons to flow towards the positive end, since electrons are negatively charged and unlike charges attract.

Further, the external negative charge repels free electrons into the material so that there is ordered directional electron flow from negative to positive.

In conductors, the electrons not tightly linked to the atoms can be dislodged from their orbit by the force from an electric power supply. In this situation some of the negatively charged electrons are free to move and flow towards the positive terminal of the power supply.

## D1.3 Commonly used electrical symbols

Standardised symbols are used for drawing electrical circuit diagrams or other diagrams showing electrical components, such as conductors, batteries, motors, etc. The figure below shows some important symbols needed for electric diagrams in simple RAC technologies, as they are defined in the standard EN 60617.

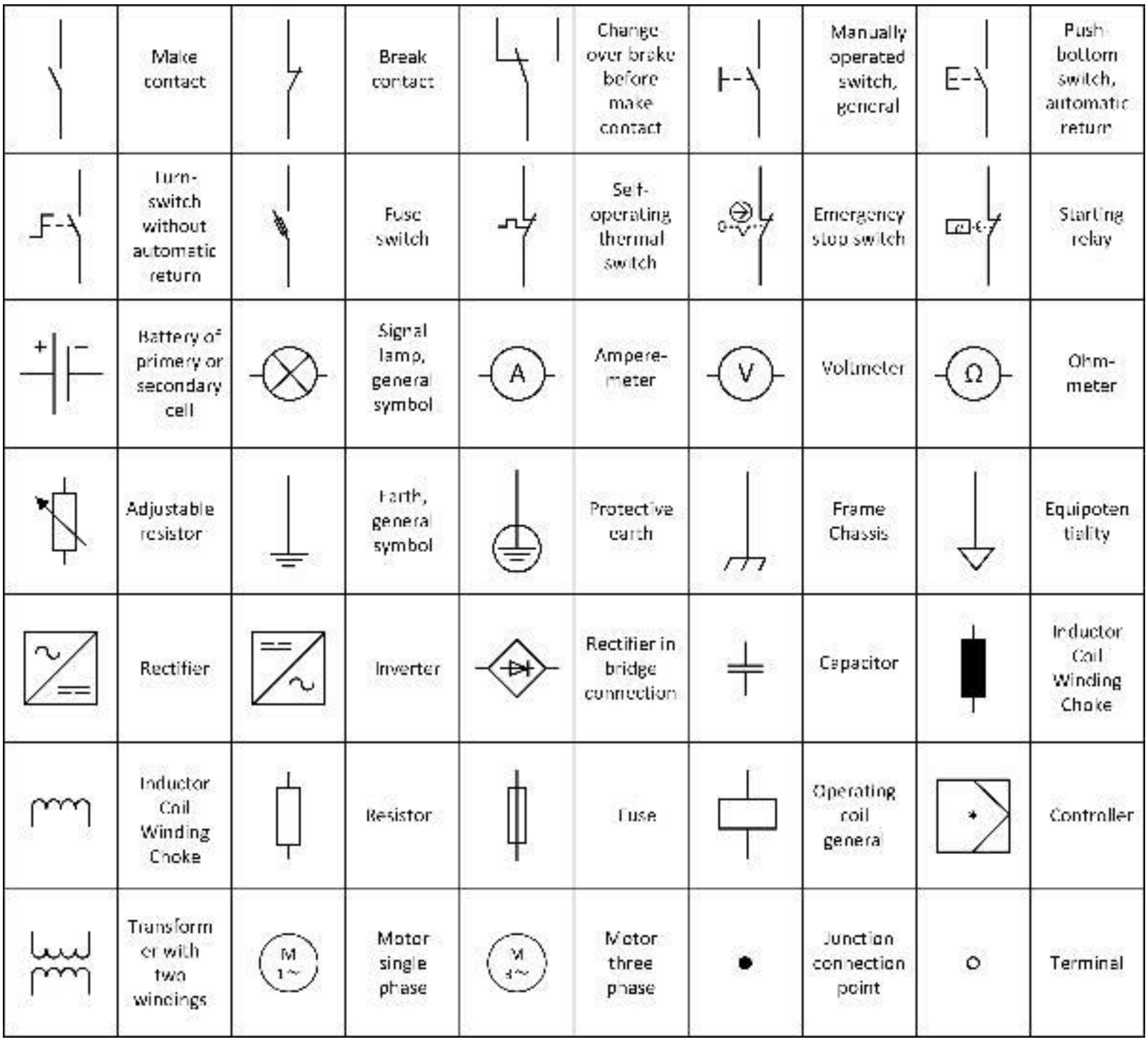



*Figure 1-5 Commonly used electrical symbols according to EN 60617-2:1996 (Layout by HEAT GmbH)*

The example below shows a schematic diagram of a simple electric circuit with battery, switch and lamp.

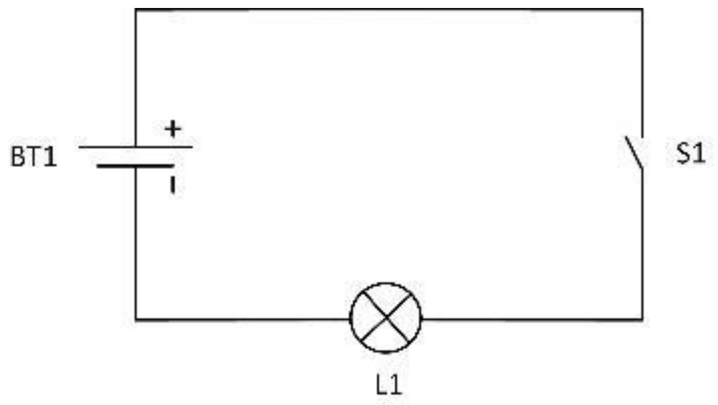



*Figure 1-6 A Simple electrical circuit with battery (BT1), switch (S1) and lamp (L1) (Source: HEAT GmbH)*

## D1.4 Conductors and insulators

Materials where the outer electrons of a material are not tightly bound in their orbits and can easily be dislodged to produce free electrons, are called **conductors** (e.g. copper and aluminium). Good conductors have electrons on their outer orbits which can easily be moved between atoms to produce a flow of electrons through the material.

However, if the orbiting electrons are so tightly bound that they cannot easily be encouraged to break away from their orbits these materials are called **insulators**. Insulators have virtually no free electrons available to form an electric current (e.g. glass, air, plastics and ceramics).

The most common types of conductors found in electrical installations are:

| | |
|---|---|
| Copper: | found in cable and flex |
| Brass: | found in electrical accessories, such as terminal blocks |

The most common type of insulator used in electrical installations is plastic, of which polyvinyl chloride (PVC), a thermoplastic, is the most widely used. Its wide use is due to its ability to be plasticized, which results in a range of flexible plastics, from rigid to pliable. The softer material is used as insulating covering for electric cables and flexes.

## D1.5 Free electrons

Consider a copper atom illustrated in the following diagram. It has 29 orbiting electrons arranged in four shells.

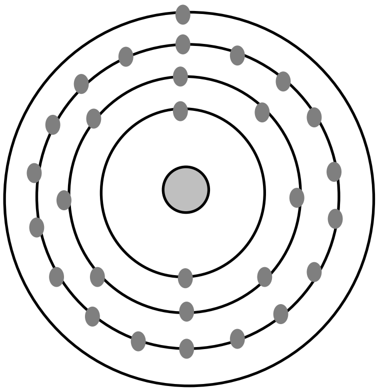


*Figure 1-7 Copper atom (Source: HEAT GmbH)*

The electron positioned on the outer orbit, farthest from the nucleus, is only weakly attracted to the positively charged nucleus, because of the distance from the nucleus. This means that it can easily fly off or be dislodged. Electrons dislodged from their orbit can swap from atom to atom at random within the material and are called free electrons. These free electrons can form the basis of an electric current.

Under normal conditions, free electrons move randomly in a conductor; the effects of temperature changes cause this movement.

This movement is usually equal in all directions so that no electrons are given up by the material and none are added. This should not be confused with electric current.

However, if the free electrons are encouraged to move in the same general direction within the conductor and are made to enter and leave it, this flow does constitute an electric current.

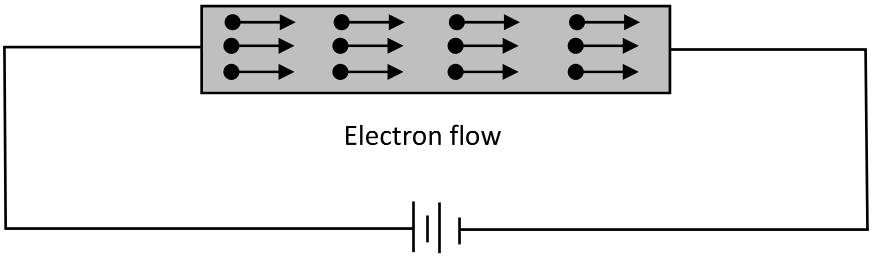



*Figure 1-8 Electron flow (Source: HEAT GmbH)*

# D2 Electrical terms

## D2.1 Potential difference (electric pressure)

Electrical energy is stored in material when it is either positively or negatively charged. The energy is contained in the charge because, in order to produce it, electrons have to be forced together against the forces of repulsion which exist between them (charging a battery). The amount of charge stored in any given piece of material depends upon how many electrons it has lost or gained. Because electrons are very small, many millions have to be displaced to produce a measurable charge. The extent to which an object is charged is termed **'potential'**.

Potential difference (voltage) is measured in volts.

**Voltage** is the force behind electricity. It is sometimes referred to as electric pressure and can be compared with the water pressure in a plumbing system. The pressure which drives the water is due to the difference of levels between the tank and the tap. The difference in the voltage levels between two points is called the potential difference (p.d.).

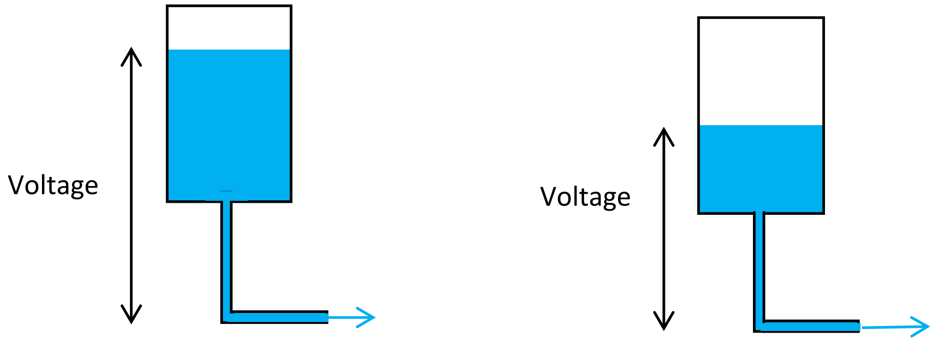



*Figure 2-1 Analogy to show potential difference using different water levels (Source: HEAT GmbH)*

Charge passes across a potential difference only when the two objects are connected by a material which allows electricity to flow through it, i.e. a conductor. Normally, the passage of charge takes the form of a movement of negatively charged electrons but, sometimes, there is a two-way movement of positively and negatively charged particles.

When two charged objects are connected by a conductor, charge passes until the two objects reach the same potential, at which point all movement of charge stops (e.g. a battery goes flat).

Any equipment that works by electricity needs a power supply. Different equipment needs different types of supply. A torch may require three 1.5 V DC batteries, while an electric kettle needs a 230 V AC supply. The very high voltages that are used on power lines carried by pylons are measured in kilovolts (kV), where one kilovolt is equal to 1,000 V.

Another term for voltage is **electromotive force**, or **EMF.**

## D2.2 Electric current (amperes)

When charge moves from one place to another, an **electric current** is said to flow. Electric current is always regarded as flowing from the more positively charged object to the more negatively charged object.

In a simple conventional electrical circuit, an electric current will only flow if it can return to its source. The route it takes is known as a circuit. If you break a circuit by cutting or disconnecting a wire that forms that circuit (i.e. the switch), the current stops.

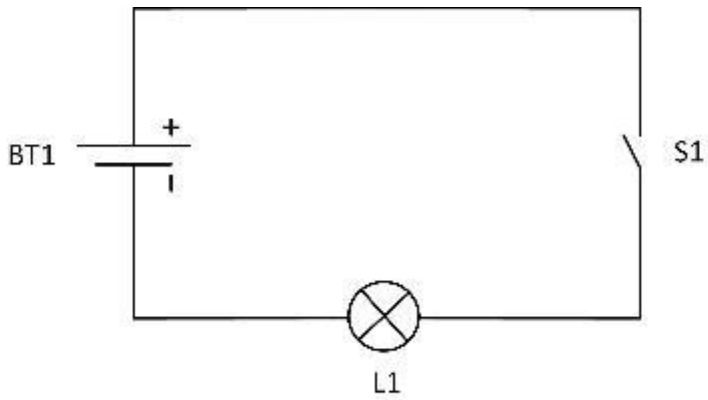



*Figure 2-2 Electrical circuit with battery (BT1), switch (S1) and lamp (L1) (Source: HEAT GmbH)*

The unit of electrical current is the **ampere** (symbol A), and this is measured (expressed) in **amperes** (A). A heating resistor of an electric shower can take around 30 A, while the small components such as an electronic component in a mobile phone, may take only 1 milliampere (mA), which is one thousandth of an ampere.

Risk of electric shock

It is the current (flown through parts of the body) which kills people – it only requires a very small amount of electrical current, as low as 50mA, to kill people.

☛ More on safe isolation and electric shock can be found in chapter D9

***Note: Voltage appears across components and current flows through them.***

To measure voltage the meter is connected in parallel with the component as in Figure 2-4; whereas to measure current the meter would need to be connected in series, so that the current flowing through the component also flows through the meter.

*Figure 2-3 Example of a typical clamp meter (Source: Fluke)*

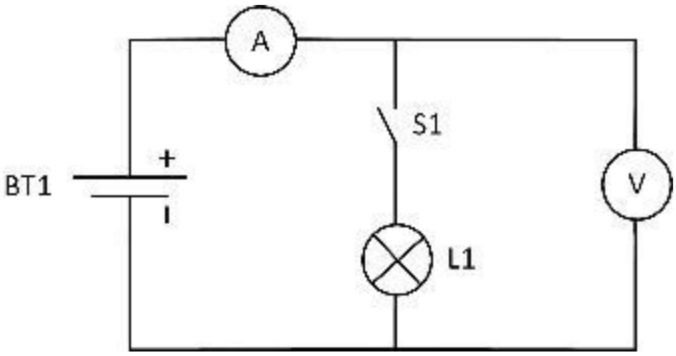



*Figure 2-4 Positioning of Voltmeter (V) and Amperemeter (A) in electrical circuit with battery (BT1), switch (S1) and lamp (L1) (Source: HEAT GmbH)*

Measuring current this way is not practical and is only suitable for measuring small current flows. Therefore, most skilled worker (see also chapter 9.1) will measure current using a clamp meter.

*Figure 2-5 Typical use of a clamp amperemeter (Source: Amprobe)*

To use a clamp meter to measure current you need to be able to clamp the meter around the live wire connected to the component as in Figure 2-5.

## D2.3 Resistance

If we compare electric current to a flow of water, the path it flows along, which is the electrical circuit, can be compared to a central heating system in a house which has radiators and the associated valves that reduce the flow of water in the system, i.e. they create resistance to the water flowing through the system.

In all electrical circuits, even the circuit conductors provide some degree of **resistance** to the flow of current. This is why voltage is always needed to push the current around the circuit to overcome the resistance.

### Resistors

Resistors are very common elements of electronic circuits, being found in almost all electronic devices. They are designed to have a specific resistance value.

An important property of resistors is that they limit the flow of current in a circuit. By connecting a resistor in series in a circuit, it is thus possible to decrease and control the amount of current in the

circuit. Another important property of resistors is that they convert electrical energy into heat. The higher the current flowing in the resistor, the more heat it produces.
This property can be detrimental in certain circuits, as the heat generated may be undesirable and thus requires to be removed from the device using a fan, such as in a computer.

However, the heat generated by a resistor can also be the purpose of its use. For example, most of the heating elements used for cooking are resistors. Other examples include water heaters, and fan heaters. The filament in an incandescent light bulb is also essentially a resistor. Usually the size of a resistor is an indication of its ability to dissipate heat. The bigger the resistor is, the more heat it can dissipate.

Resistance may cause problems in a circuit, since overheating is a major cause of electrical breakdowns and can cause sparking and fires. If, when terminating conductors into electrical accessories or flexible cords into plugs, the terminal screw is not tightened sufficiently, the resulting high-resistance connection will get hot and will damage the accessory and poses hazards within the work area.

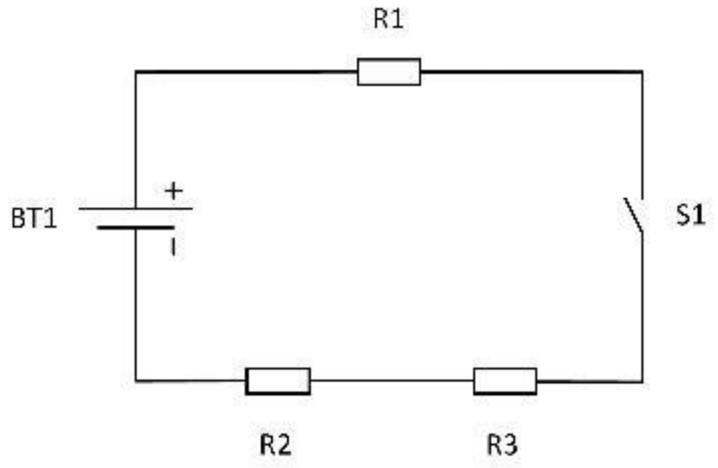



*Figure 2-6 Simple electrical circuit with three resistors (R), battery (BT) and switch (S) (Source: HEAT GmbH)*

The above Figure 2-6 shows a simple electrical circuit with a power supply BT1 (battery), three resistors (R1, R2, R3, which could be heating elements or light bulbs or similar) and a switch S1.

Each of the components fitted into the circuit produces resistance to the flow of electricity as do the conductors joining all of the components together. The flow of electricity has to pass through each resistor in turn and so these resistors are said to be **in series connection**.

For example, if an 110 V electric drill is accidentally connected to a 230 V supply system, too much current will flow through it and it may burn out. One solution would be to fit some kind of series resistor in the circuit to limit the current if it is connected to a 230 V supply. This would enable the drill to work on either 230 V or 110 V systems.

Resistance is measured in **ohms**, and the omega symbol (Ω) is used to represent it.

Typical values of resistance used in electrical installation and maintenance work are:

1 kΩ = 1000 Ω
1 MΩ = 1,000,000 Ω

### How to test a resistor

A resistor is tested by measuring its resistance using an ohmmeter.

The measured resistance should be within the range of the nominal value indicated on the resistor.

If the measured resistance is zero or infinite, the resistance needs to be replaced.

Make sure that the resistor is isolated from the circuit during the measurement.

#### Cables and flexes

Other factors to consider are the lengths of cables and flexes. The longer the cable runs, the greater the resistance, and hence the greater the heat created. Care needs to be taken to ensure that any heat created in cables due to applied load and conductor resistance does not damage the insulation. Also, you have to consider the current carrying capacity if any of the cable is covered with thermal insulation. (Specifications are listed with international standards such as IEC 60364 for electrical installations of buildings.

## D2.4 Relationship between voltage, current and resistance

To understand electricity, it may help to think of it as a plumbing system:

- the height of the water in the tank is voltage (volts),
- the water flowing in the pipework is current (amps),
- any valves in the pipework is resistance (ohms).

For any given voltage:

- the more you open any valves in the pipework (less resistance) the more the water flows (more current),
- if you close any valves in the pipework (more resistance) less water flows (less current).

From the above statements it can be seen that:

**VOLTS** push **AMPS** through **OHMS**

## D2.5 Ohm's law

If there is a high resistance in a circuit, a high voltage will be required to push the current round the circuit. If the voltage falls and the resistance of the circuit remains the same, less current will flow. This shows that the voltage, current and resistance in a circuit are related to each other. This relationship is known as Ohm's law, named after George Ohm, a German physicist.

Ohm's law applies only to metallic conductors and to carbon and only at constant temperature.

It applies:

**Relationship of temperature and resistance:**

The higher the temperature of a metallic conductor, the greater its resistance. The lower the temperature, the lower the resistance.

For simplicity in mathematical equations the following mnemonic can be used:

| | |
|---|---|
| Voltage is represented by | U, expressed in volts (V) |
| Current is represented by | I, expressed in amperes (A) |
| and Resistance is represented by | R, expressed in ohms (Ω) |

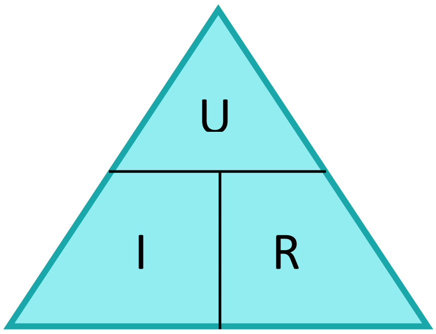



*Figure 2-7 The triangle of Ohms Law (Source: HEAT GmbH)*

Expressed mathematically:

$$I = \frac{U}{R}$$

Ohm's law can be reformulated in the following two equations:

$$U = I \times R$$

$$R = \frac{U}{I}$$

Consider, for example, the circuit shown in Figure 2-4 of a power source connected to an indicator light. Suppose that we know two of the three parameters of the circuit and that we want to calculate the third using Ohm's law. If the battery has a nominal voltage (EMF) of 3 V and the bulb a resistance of 3 Ω, a current of 1 A will flow when the switch is closed.

Using Ohm's Law

$$I = \frac{U}{R} \qquad I = \frac{3\,V}{3\,\Omega} \qquad I = 1\,A$$

As these equations show, whenever two of the three parameters (voltage, current, and resistance) of a conductor or circuit are known, the other parameter can be calculated. These equations also show that, for a given resistance, the current flowing in a conductor or circuit is directly proportional to the voltage applied to it. For example, if the voltage doubles, the current also doubles.
It is important to understand that Ohm's law applies only to ohmic resistors (not to semiconductors). This includes normal resistors and components that have a linear relationship between voltage and current. The resistance of a diode or a lamp cannot be calculated using Ohm's law, because current and voltage at these components do not have a linear relationship. Normal resistors always have the same value within their limits, independent of voltage and current. Only this resistance value can be calculated with Ohm's law.

## D2.6 Resistors in series

As mentioned above, if a circuit contains several components (each one a **resistor**), where the electricity has to flow through each resistor in turn, then this represents resistors in series (see the diagram below).

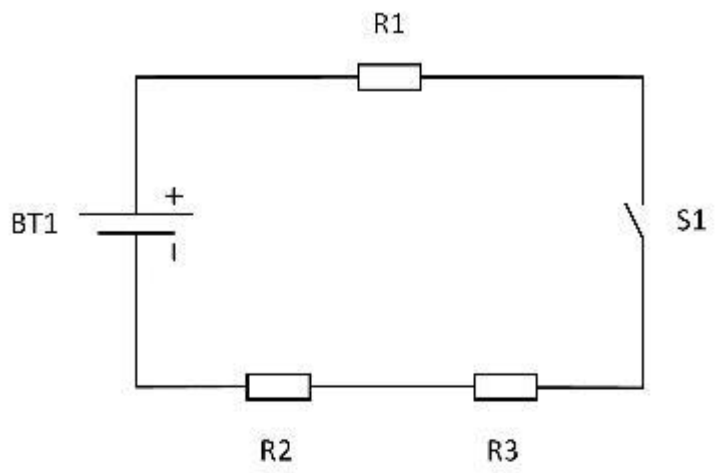



*Figure 2-8 Resistors in an electrical circuit in series (Source: HEAT GmbH)*

In the above circuit the same current passes through each resistor in turn. If each resistor has a resistance of 10 Ω, the total resistance of the circuit would be 30 Ω.

Mathematically -

$$RT = R1 + R2 + R3$$

$$RT = 10\,\Omega + 10\,\Omega + 10\,\Omega$$

$$RT = 30\,\Omega$$

With an EMF of 30 V, it is obvious (applying Ohm's law) that a current of 1 A would flow, and that this 1 A current would be common to all three resistors.

The total EMF of 30 V would be distributed across the total load of all three resistors. If all the resistors were the same (with the same current and power rating factors), each resistor would, in effect, have 10 V across its terminals.

This can be proved by applying Ohm's law, expressed as follows:

Voltage across resistor:

$U = I \times R$

$U = 1A \times 10\,\Omega$

$U = 10\,V$

If the resistors did not all have the same resistance, different voltages would be developed across the terminals of each lamp.

For example: If R1 = 5 Ω, R2 = 10 Ω and R3 = 15 Ω

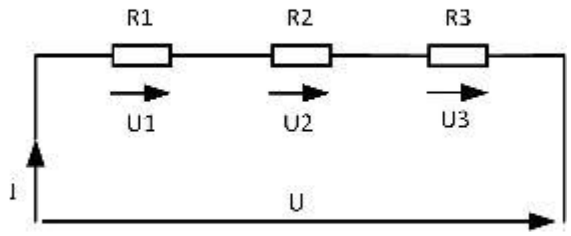


*Figure 2-9 Resistors in series, example for calculation (Source: HEAT GmbH)*

The total resistance of the circuit is 30 Ω, and a common current of 1 A will flow through each of the resistors in turn. However (from Ohm's law) we can see that the voltage across each resistor would be different. For example:

$U1 = I\,x\,R1 \quad U1 = 1A\,x\,5\Omega \quad U1 = 5\,volts$

$U2 = I\,x\,R2 \quad U2 = 1A\,x\,10\Omega \quad U2 = 10\,volts$

$U3 = I\,x\,R3 \quad U3 = 1A\,x\,15\Omega \quad U3 = 15\,volts$

## D2.7 Potential difference (p.d.)

The voltage across each of the resistors is the **potential difference** (p.d.) required to sustain the common current (in this case of 1 A).

If a similar circuit is devised with resistors in series, different voltages can be taken at different points. For example:

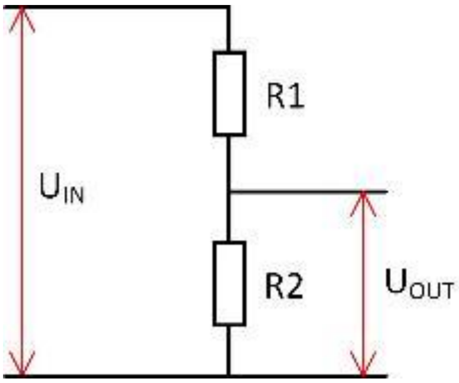



*Figure 2-10 Potential Difference (Source: HEAT GmbH)*

The total resistance of this circuit is 2 x 10 Ω = 20 Ω. If the input voltage U (E) is 120 V, a current of 6A will flow through the circuit. The total voltage of 120 V will be 'divided' across the two resistors. Since they both have the same value (10 Ω), the 'voltage drop' or 'potential difference' across each would be 60 V and the voltage measured between the two resistors would be 60 V.

This type of circuit is called a 'potential divider' network and is commonly used where different or varying voltages are required.

## D2.8 Variable resistance

Where different voltages are required, this can be achieved by placing a **variable resistor** in the circuit. For example:

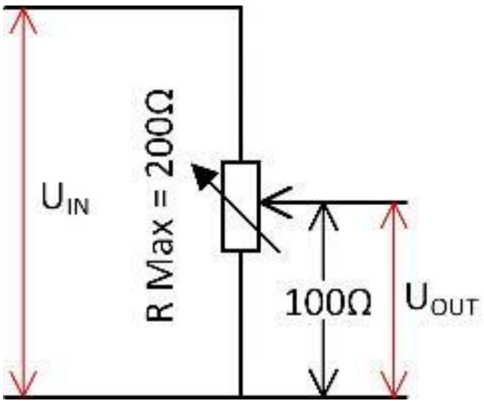



*Figure 2-11 Variable resistance (Source: HEAT GmbH)*

In this type of circuit, the output voltage (with no load connected) is 'tapped off' according to the position of the wiper arm. This type of circuit could be used to control the speed of model cars.

## D2.9 Parallel circuits

Components (resistors) in an electrical circuit may also be connected 'in parallel' - that is, the same voltage is applied to each resistor but the current flowing in each will vary, depending on its resistance. The greater the resistance, the less the current will flow through each resistor.

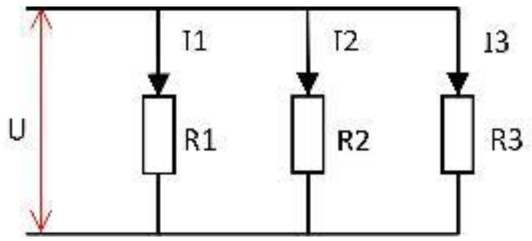



*Figure 2-12 Parallel circuits (Source: HEAT GmbH)*

For example: If R1 = 3 Ω, R2 = 8 Ω and R3 = 5 Ω

To work out the total resistance in a parallel circuit (and exemplarily with three resistors) we use the following formula:

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

Referring to the above drawing:

$$\frac{1}{RT} = \frac{1}{3\Omega} + \frac{1}{8\Omega} + \frac{1}{5\Omega}$$

$$\frac{1}{RT} = \frac{40}{120\Omega} + \frac{15}{120\Omega} + \frac{24}{120\Omega}$$

$$\frac{1}{RT} = \frac{79}{120\Omega}$$

$$RT = \frac{120\Omega}{79}$$

$$RT = 1.52\ \Omega$$

An alternative method to work out the total resistance of a parallel circuit is using the formula in a slightly different way:

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

But this time turn each resistor in the circuit into a decimal as below:

$$\frac{1}{RT} = 0.333 + 0.125 + 0.2$$

$$\frac{1}{RT} = 0.6583$$

$$RT = \frac{1}{0.6583}$$

$$RT = \underline{1.5189\ \Omega}$$

Another important formula (shown below) which can be used, is if there are two resistors forming a parallel circuit.

$$RT = \frac{R1\ x\ R2}{R1 + R2}$$

## D2.10 Electric power

To do work, electricity generates **power** and power is the rate at which electrical energy is converted into other kinds of energy, such as heat, light or movement (in the case of electric motors).

The unit of power is the watt (Joule/second = J/s), and typical values of power used in electrical circuits are:

Kilowatt = 1,000 watts or 1 kW

Megawatt = 1,000,000 watts or 1 MW

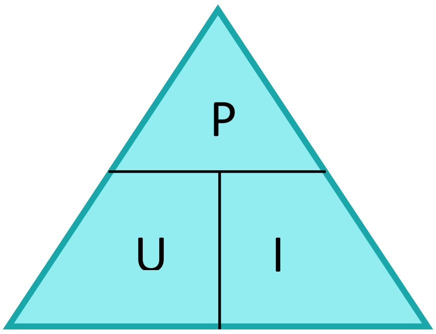



*Figure 2-13 The triangle for power calculation (Source: HEAT GmbH)*

Electrical power can be calculated by multiplying the voltage by the current:

Watts (P) = volts (V) x amps (I)

The different formulas can be presented in an electrical engineering formula wheel. As both U for voltage and E for electromotive force (EMF) are used in different countries, there are two versions of the wheel. The SI units stay the same. In accordance with IEC 60027-4, “Letter symbols to be used in electrical technology”, we can use the formulas expressed in Figure 2-14.

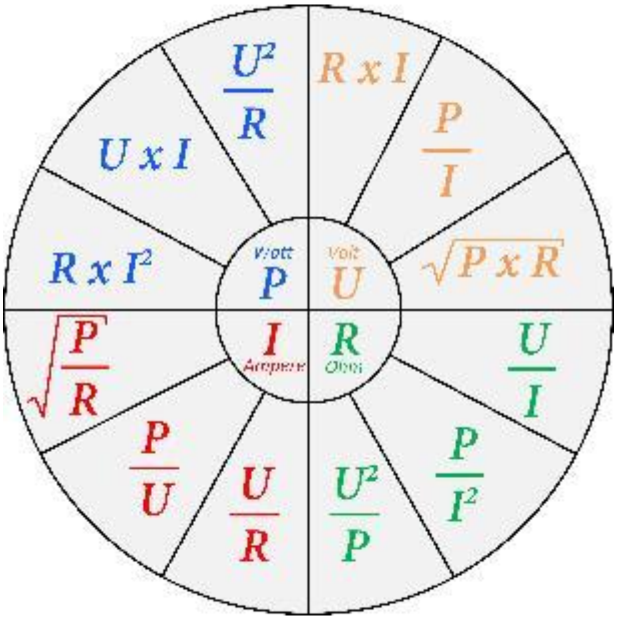



*Figure 2-14 Electrical engineering Formula Wheel with voltage (U) (Source: HEAT GmbH)*

Where EMF is used, Figure 2-15 applies.

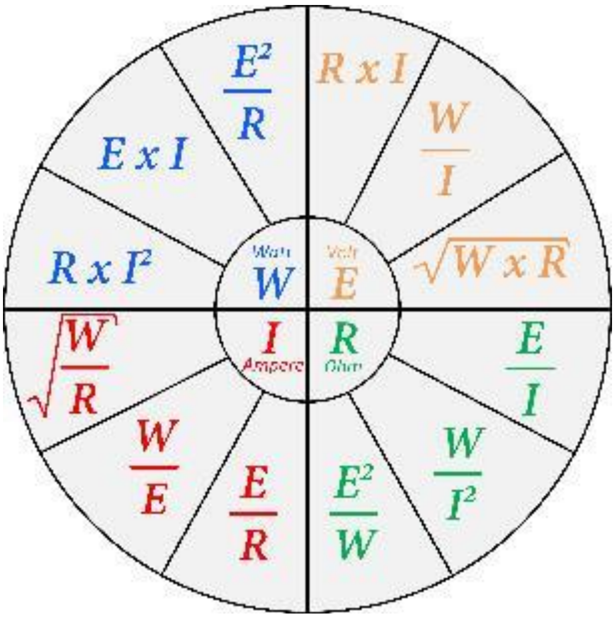



*Figure 2-15 Electrical engineering Formula Wheel with voltage/electromotive force (E) (Source: HEAT GmbH)*

It must be remembered that the formula applies accurately only to direct current (DC) supplies, but it can be used for rough calculations for alternating current (AC) circuits.

**Alternatively, transposing the formula:**

$$I = \frac{P}{U}$$

**or**

$$U = \frac{P}{I}$$

Example: What is the actual current taken by a 10.8 kW electric shower, if the supply system is 230 V?

$$I = \frac{P}{U}$$

$$I = \frac{10{,}800\ VA}{230\ V}$$

$$I = \underline{47\ A}$$

# D3 Types of power supply

The two types of power supply are, **alternating current** (known as AC) and **direct current** (known as DC). Alternating current is the type of electricity generated in power stations and then supplied to domestic, commercial and industrial premises by the local electricity distributor.

Direct current is the type of electricity you get from a battery or from rectifiers used to convert AC to DC.

## D3.1 Alternating current (AC) theory

Up to this point, we have only considered current which flows in the same direction all of the time.

When we consider AC current in a circuit, however, the current flows one way and then back again in the opposite direction. So, it flows in both directions, essentially taking turns in which way it flows.

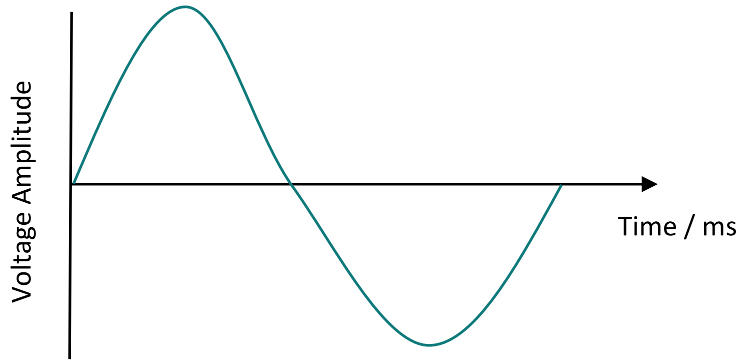



*Figure 3-1: Alternating sine wave (Source: HEAT GmbH)*

The number of cycles of current flow which occurs in one second is called the **frequency** of the alternating current. A frequency of 50 Hz is standard for electricity supplies throughout the EU. In other countries like some South American countries, it is 60 Hz, and in the United States the standard is 120 V and 60 Hz AC electricity.

### D3.2 Advantages of alternating current

Generators are the only practical means of supplying continuous power. AC generators (or alternator) are a relatively simple machine so this is one of the advantages of using an AC electrical system.

The principle of converting mechanical power into electrical power is the same for all electrical generators that operate by means of electromagnetic induction. The mechanical power is supplied to the generator in the form of the rotation of a mechanical shaft.

There are other advantages which AC has over DC that tend to reduce the costs of power production. Among the most important are:

1. Motors designed to operate from AC supplies are much simpler and easier to maintain than similar apparatus designed to work from DC supplies.

2. AC voltages can be changed very easily both to higher and lower voltages by means of a transformer.

3. Transmitting higher voltages is more efficient, due to the fact that they carry less current for a given amount of power and, consequently, the loss or volt drop is reduced.

### D3.3 Root Mean Square (RMS) current and voltage

The **root mean square** (RMS) value is the value most commonly used when expressing mains voltage as a value of 230 V.

The RMS is essentially the average voltage being supplied by the system. When the mains waveform reaches a peak value, maximum current and hence maximum power is developed in the load. Similarly, as the sine wave voltage reaches zero, no current and therefore no power is generated.

Because the frequency of the mains is 50 Hz, the fact that the power drops to zero 100 times per second is not noticed, as 100 times per second maximum power is generated when the waveform reaches its peak values. The power is effectively averaged out during each cycle.

To produce the same average power in the load, the peak value must be higher than the RMS value. The relationship between the peak and RMS values has long been established.

## D4 Electromagnetic induction

Electrical energy is produced in a conductor (usually copper wires) by the magneto-electric effect created when a conductor is moved in a magnetic field. The creation of a voltage in a conductor by this means is termed **'induction'**. We say that a current is induced in a conductor, provided that the conductor forms part of an overall circuit.

Therefore, a similar result can be achieved if the conductor is stationary and the magnetic field is moved.

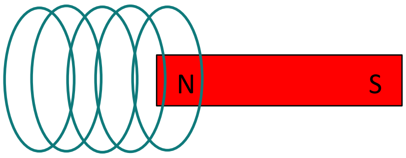



*Figure 4-1 Electromagnetic induction (Sourec: HEAT GmbH)*

## D4.1 Mutual induction

Looking at the above figure, a permanent magnet provides the magnetic lines of flux to cut the conductor. If we replaced the bar magnet by an electromagnet, where a current is passed through a coil to produce a magnetic field and the necessary lines of magnetic flux induces a voltage across the conductor, we would get the same effect.

**Mutual induction** is where a current in one coil induces a current in another adjacent coil.

## D4.2 Transformers

**Transformers** are inductive devices which work on the basis of mutual induction. They only work when there is a continually changing primary flux to permit an induced voltage to be developed across the secondary set of windings. Therefore, they can only be used to transform AC voltages; they cannot work at all in pure DC circuits where the primary current is kept constant.

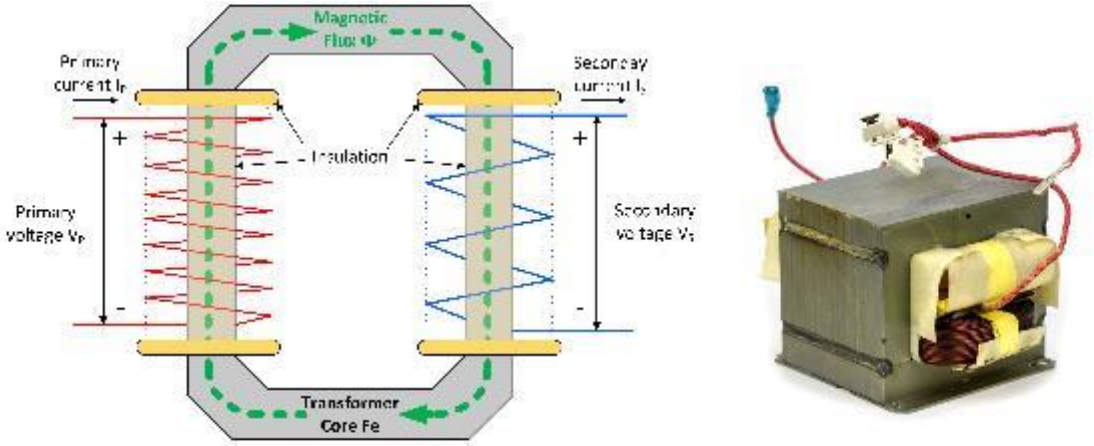



*Figure 4-2: Left: Concept of a transformer (Source: HEAT GmbH) and right: Example of Isolating Transformer 150 VA 230 $V_S$ / 12 $V_P$ (© mariakunz/123RF.com)*

Transformers are used to convert voltage - they change the level of one AC voltage to another, either upwards or downwards. Alternatively, they can be used as isolation devices, allowing two circuits to be coupled without having a direct electrical connection. This is referred to as **electrical separation** (with isolating transformers) and is used to reduce the risk of electric shock. It is used to isolate mains AC voltages from ground. A typical application is a shaver socket in a bathroom.

When the number of turns on the primary winding equals the number of turns on the secondary, then the induced secondary voltage will equal the applied primary voltage. The transformer is then said to have a 1:1 turns ratio. In practice, losses within the transformer mean that the turns ratio only gives an approximate guide to the primary secondary voltage relationship.

A turns ratio of 20:1 would produce a voltage across the secondary coil of one twentieth of the input voltage (i.e. a 230 V input would produce an 11.5 V output). Transformers can also be used to increase the voltage. A turns ratio of 1:3 would produce 690 V output from normal mains input (if we ignore any losses).

Secondary windings often have a number of connection points which provide a variety of outputs. Some transformers include a centre tap in the secondary coil, which is usually earthed. This is a safety measure and effectively halves the maximum output voltage relative to Earth.

In most cases the soft iron core and outer casing are bonded to Earth. This type of transformer is used to supply 110V portable tools on construction sites.

## D4.3 The rating of a transformer

As with all electrical equipment we must always consider the maximum current that can be carried without exceeding the rating of the transformer. They are limited in the amount of current they can supply from their secondary windings. If you try to draw too much current, the windings will get hot, which could melt the winding's insulation and thus burn it out, the transformer developing then a short circuit. The transformer can also get too hot while being used.

Small transformers (e.g. 120 V primary windings – 24 V secondary windings) are cooled by the surrounding air; some may even have fans to assist with the dissipation of the heat. High voltage transformers however will need more than air to cool them. They will contain an oil to absorb the heat when they are in use and the oil then carries the heat to the casing which then gives up the heat to the surrounding air. Casings are often ribbed to provide a larger surface area so as to loose heat more efficiently.



**Attention:**

Older transformers may contain a potentially dangerous, highly toxic coolant oil PCB (polychlorinated biphenyl). Any sign of a thick and heavy fluid coming from the casing, it may well be PCB. **Do not touch it.**

**Handling of such substances only by specialists with body fully covered by personal protective equipment (PPE).**

Beginning in the 1970s, production and new uses of PCBs were banned in many countries.
Some newer applications with power transformers are using $SF_6$ gas (sulphur hexafluoride). This is considered as dry gas insulation technology. It should be treated with the same care because $SF_6$ has an extremely high global warming potential (GWP) of 23,900 times that of $CO_2$.

Ensure that these substances are handled and disposed of only by an approved waste disposal company!

*(Source Picture: Handwerkskammer Stuttgart)*

Transformers are power-rated in volt-amps (VA). Watts cannot be used to represent power dissipation in a transformer because the voltage and current are not in phase with each other as they are in a pure resistance. By using a volt-amps figure (which is essentially the same, arithmetically speaking), it is relatively simple to calculate the current that can be drawn from a transformer.

If a transformer has a particular VA rating, that is the maximum power that can be drawn from the secondary winding or windings.

Example: Consider a mains step-down transformer that has a VA rating of 12 kVA and a single secondary winding of 110 V.
*What maximum current can safely be drawn from the secondary winding?*

*Calculation:*

| | | |
|---|---|---|
| VA | = | Volts x Amperes |
| 12,000 | = | 110 x Amperes |
| 12,000 / 110 | = | Amperes |

The maximum current of the secondary winding is 109.1 A

## D5 Capacitors

A **capacitor** (formerly called a condenser), is a simple device for the storage of electrical energy. Capacitors are used in electrical circuits for many purposes: For example, they can temporarily store electrical energy, compensate for fluctuations in DC power supplies, filter frequencies or influence the behavior of flip-flop circuits. They can therefore be found as an elementary component in almost every electrical circuit.

It comprises two parallel metal plates, insulated from each other. If a DC voltage is connected across them, one of the plates becomes rich in electrons; the other plate becomes correspondingly poor.

In acquiring this charge, a current flows – but it does so only for an instant. No sustained direct current can flow between the plates, since they are insulated from each other.

If the DC source is removed, the capacitor will retain its charge until it is discharged through an external circuit.

If there is a need to discharge a capacitor in order to prevent electric shock or a potential source of ignition (especially when working with HC units), carry out the following procedure:

1. With power source disconnected from the unit
2. Secure the capacitor(s) and
3. place a 1000 Ω resistor across the terminals for 5 seconds.

**NOTE: Do not use a wire, screw driver or pliers to shortcut the terminals of the capacitor and avoiding sparking.**

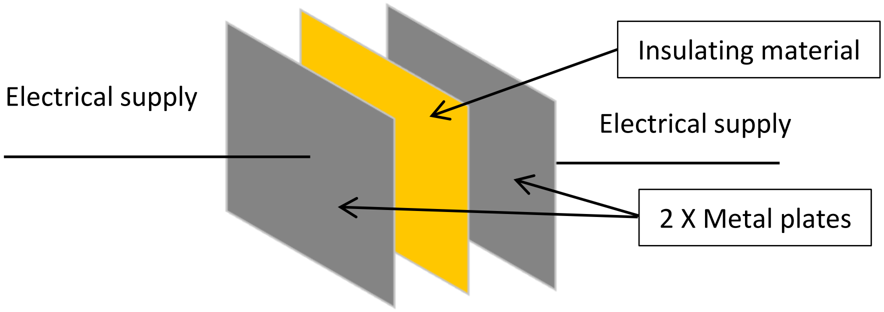



*Figure 5-1 Concept of a capacitor (Source: HEAT GmbH)*

*Figure 5-2 Example of a capacitor 80 µF (Source: Winai Tepsuttinun / 123rf.com)*

If an alternating current is fed to a capacitor it will commence to charge on one half-cycle but, as the voltage falls from its peak, it will attempt to discharge and to charge again (in the opposite direction) on the next half-cycle, and so on.

As a result, a capacitor appears to pass current when connected to an AC source, but prevents the passage of DC current.

The larger the area of the plates in a capacitor, the greater the **capacitance**. In practice a capacitor is made from two thin sheets of metal foil, insulated by a dielectric, often made from waxed paper, mica or a similar material. The dielectric is simply the insulation between the two metal plates.

Capacitors are rated in farads, however practically this is far too big, and the **micro-farad** (one millionth of a farad) is the unit in common use. This will be written as µF.

## D6 Rectifiers

It may be a requirement to convert an alternating current into a direct current. The process of doing this is known as rectification. A **rectifier** is rather like an electrical non-return valve, which permits current to pass freely in one direction, but which prevents current passing in the opposite direction.

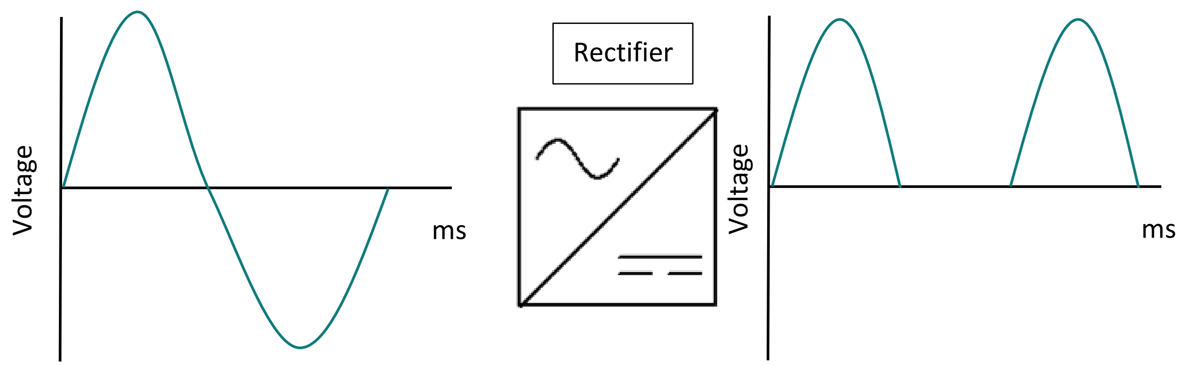



*Figure 6-1 Concept of a rectifier (Source: HEAT GmbH)*

The above figure shows a simple rectifier which only allows the positive peak voltages from an AC supply to pass through.

As previously described, an alternating current is one which passes through a cycle from a positive peak through zero to a negative peak and then back to zero voltage again. A simple rectifier prevents current passing on the negative cycle and only permits the positive element to pass through. The output would be a series of positive peak voltages.

Rectifiers can be a single, solid-state diode or a more complex, full-wave or bridge rectifier. The bridge rectifier is arranged as to rectify both the positive and negative half-cycles of an alternating current, producing a DC output at twice the original frequency and twice the average voltage. This rectified output can then be smoothed to produce a DC output at a stable frequency.

Rectifiers are commonly found in control equipment.

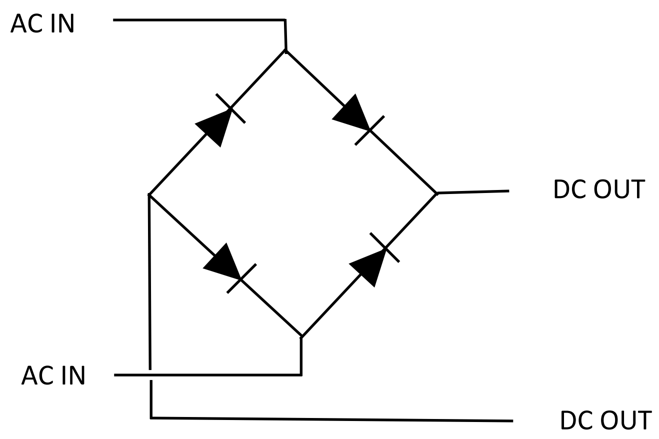



*Figure 6-2 Bridge rectifier (Source: HEAT GmbH)*

The above figure shows a more complex bridge rectifier which allows the positive peak voltages to freely pass through, but also turns the negative peak voltages into positive peak voltages.

The result is a DC voltage but at twice the average voltage as the ingoing AC voltage.

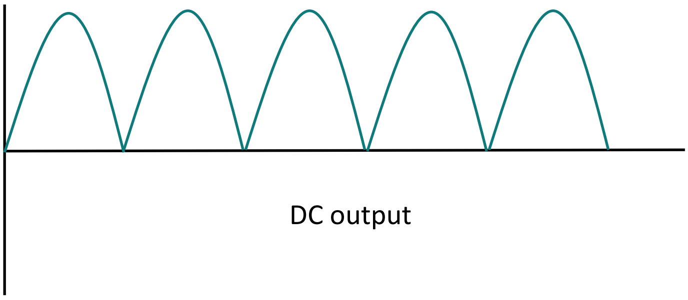



*Figure 6-3 DC output (Source: HEAT GmbH)*

Some DC components will quite happily work on the above rectified AC output (DC), but other components will only work on smooth DC, so there are filter circuits available which will change the above DC output to smooth DC.

# D7 Three-phase induction motor

Of all electric motors the simplest is the squirrel-cage type of induction motor used with a **three-phase** supply. The stator of the squirrel-cage motor consists of three fixed coils. The rotor is made up of a core, in which is attached a series of heavy conductors arranged in a circle around the shaft and parallel to it.

## D7.1 Stator

The design of the **stator** is determined by the number of field coils used per phase. In three-phase motors, there is a minimum of two coils per phase; the maximum is determined by the speed of the motor and the available space.

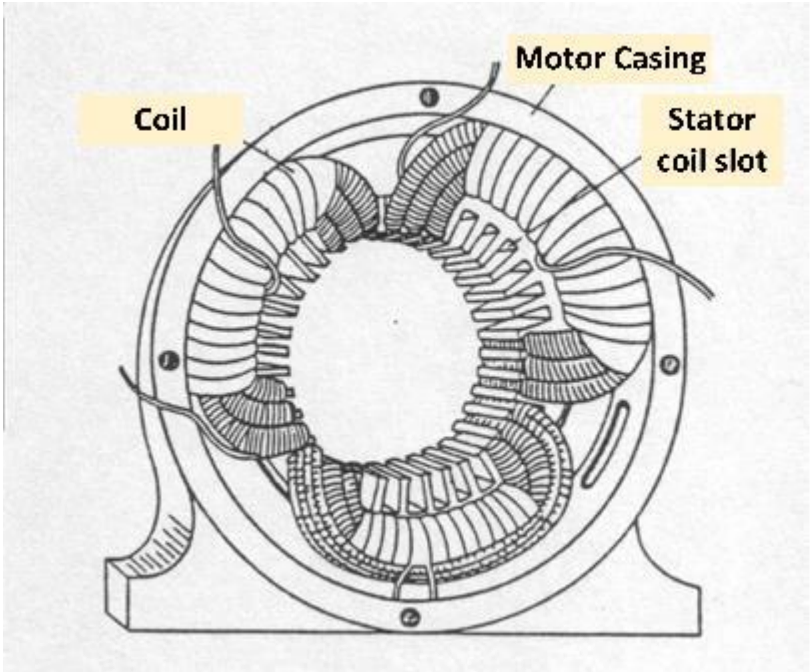



*Figure 7-1 Three Phase Induction Motor Stator (Source: LUA NRW (2006))*

## D7.2 Rotor

As the name suggests, the **rotor** is the part of the motor which rotates and is connected to the piece of equipment which is required to turn.

Squirrel-cage induction motors are very common and almost 90 % of the three-phase AC induction motors are of this type. They cost less and can start at heavier loads than their single-phase counterparts. Most induction motors contain a rotor in which the conductors are made of either aluminium or copper and are arranged in a cylindrical format resembling a 'squirrel cage'.

In squirrel-cage induction motors there is no electrical connection to the rotor, and the rotor is made of solid, un-insulated aluminium or copper bars short-circuited at both ends of the rotor with solid rings of the same metal; this forms a low-resistance circuit that consists of a number of single-turn coils.

The rotor is inserted in the space between the field coils which are fitted in to the stator, and any magnetic flux in those windings surrounds the rotor.

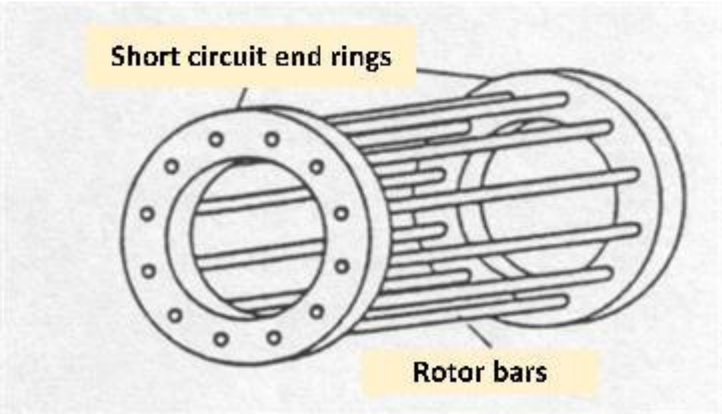



*Figure 7-2 Simple rotor (Source: LUA NRW (2006))*

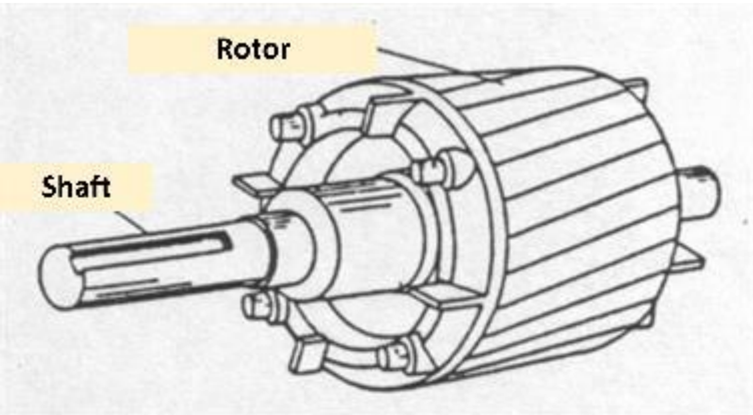



*Figure 7-3 Rotor complete with shaft (Source: LUA NRW (2006))*

## D7.3 Three-phase windings rotating fields

Electrical power generated at power stations is AC and, because of this, many motors are designed to operate using AC. Power supplies may be single-phase or three-phase, but the majority of larger AC motors operate on a three-phase supply.

*Operation – the way it works*

The diagram below illustrates a three-phase supply.

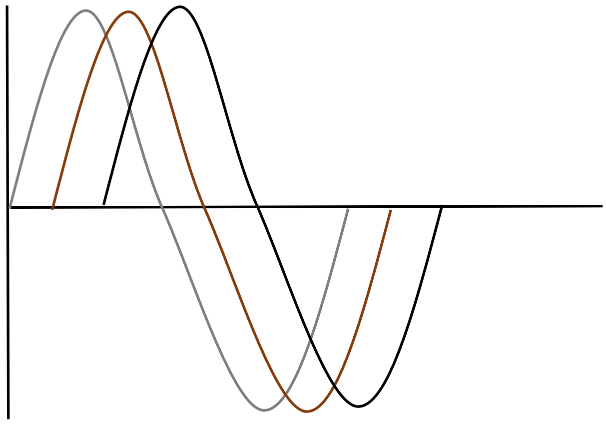


*Figure 7-4 Three-phase supply diagram (Source: HEAT GmbH)*

A magnetic field will be produced in each pair (keeping with our simple stator) of windings, the strength of which will depend upon the voltage in that particular phase at any instant of time. When the voltage is zero the magnetic field will be zero, and maximum voltage will produce the strongest magnetic field.

As the voltages in the three-phases are 120° out of phase (see the relationship in the diagram above), the magnetic fields produced will also be 120° out of phase.

The rotor of a three-phase induction motor turns due to the rotating magnetic fields. The coils in the stator connected to the grey phase induce a magnetic field first, and then as the voltage in the grey phase drops to zero, the voltage in the coils connected to the brown phase induce a magnetic field in those coils and so on.

As the rotating field of the stator cuts the rotor bars of the rotor, an EMF is induced into the conductors which form a closed circuit. A magnetic field is set up by the current flowing in the rotor conductors which interacts with the rotating magnetic field, causing the rotor to turn in the direction of the magnetic field.

There are two different methods of connecting a three-phase supply to a motor, in either 'star' or 'delta'. Each winding could have two or more poles per phase depending upon the speed required.

The number of poles (windings) per phase is what determines the speed of the motor. A motor with a two-pole winding will complete one revolution in one cycle, but if you double that to a four-pole winding, the motor will now complete one revolution for every two cycles of the supply.

The more the number of poles per winding is increased; the speed of the rotating magnetic field is decreased, so for slower speeds, increase the pairs of windings (poles).

## D7.4 Three-Phase Motor speed

The synchronous speed (the speed at which the magnetic field rotates) of AC motors depends upon the frequency of the supply and the number of pairs of poles on the stator. The synchronous speed can be calculated using the following formula:

$$n_s = \frac{f \times 60}{p}$$

When $n_s$= speed in Revolutions Per Minute (RPM)
f = frequency in cycles/second (hertz = Hz)
p = number of pairs of poles
60 = seconds per minute

Therefore, a motor wound with two poles per phase and connected to a supply of 50 Hz would have a synchronous speed of:

$$n_s = \frac{50Hz \times 60}{1p}$$

$$n_s = 3000 \text{ RPM}$$

In reality, synchronous and actual speeds are not achieved. The difference between synchronous and actual speed is called slip. Synchronous speed assumes everything is perfect and in any mechanical machine there will always be losses.

There will be approximately 5 % loss (also called slip) under full (FL) load conditions.

*Table 7-1 Motor speeds for three-phase machines*

| **Motor speeds for three-phase machines (50 Hz)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of poles | | 2 | 4 | 6 | 8 | 10 | 16 |
| Synchronous speed | RPM | 3,000 | 1,500 | 1,000 | 750 | 600 | 375 |
| Approx. FL speed | RPM | 2,900 | 1,440 | 960 | 720 | 570 | 360 |

# D8 Single-phase AC motors

A single-phase AC supply will not produce a rotating magnetic field produced by a three-phase supply. To start an AC motor a rotating magnetic field is required.

When there is only a single-phase supply, the magnetic field in the windings rises to maximum, falls to zero and then rises to a maximum in the opposite direction. This creates only a 'pulsating' magnetic field which rises and falls with the supply frequency but does not rotate around the stator.

This pulsating magnetic field in the windings built into the stator will not cause the rotor to rotate. To get the rotor to rotate we need to create a rotating magnetic field.

One way to create a rotating magnetic field in the stator is to introduce a second winding known as a start winding. This is displaced on the stator by 90° to the main field winding, which is commonly known as the run winding.

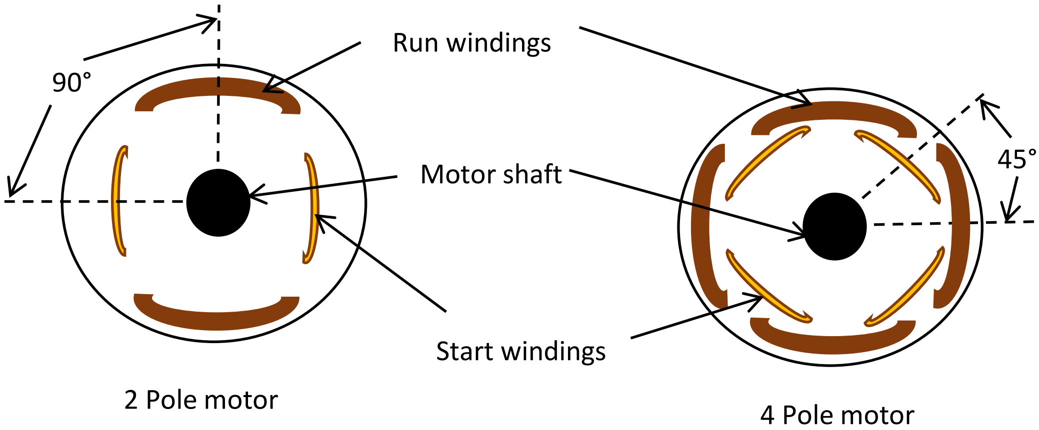



*Figure 8-1 Single Phase Motor showing offset start windings (1 pair of windings and 2 pairs of windings) (Source: HEAT GmbH)*

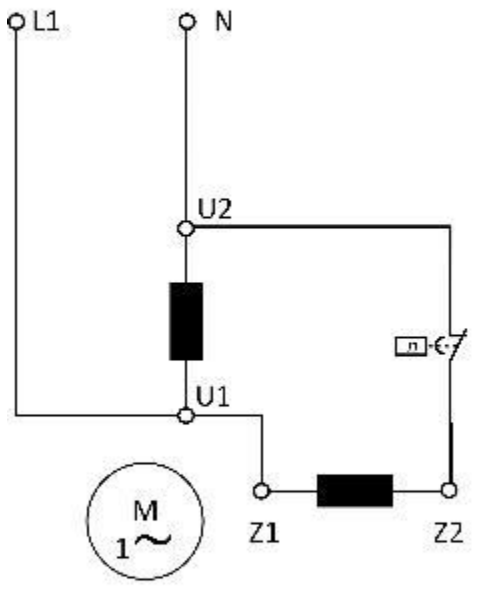
## D8.1 The split-phase motor (also known as resistance start motor)

The split phase motor has two windings built into the stator – a run winding and a start winding (the latter being only used to start the motor, as the name suggests). The run winding has low resistance and high reactance (*reactance* is the resistance offered to the AC currents by inductors and capacitors only) and the start winding has high resistance and low reactance.

Therefore, the start windings will create a magnetic field first followed by a magnetic field in the run windings and hence there is now a rotating magnetic field which will cause the motor to rotate.

The running winding is created with thicker wire than the starting winding and therefore has less resistance than the starting winding, which is made up of very fine wire.
The starting winding is only required for a very short time and is automatically cut out by a centrifugal switch or relay when the motor reaches about 75 % full speed.

| | |
|---|---|
| C | Capacitor |
| L1 | Line |
| N | Neutral |
| M1 | Compressor motor |
| U1 | Run winding terminal |

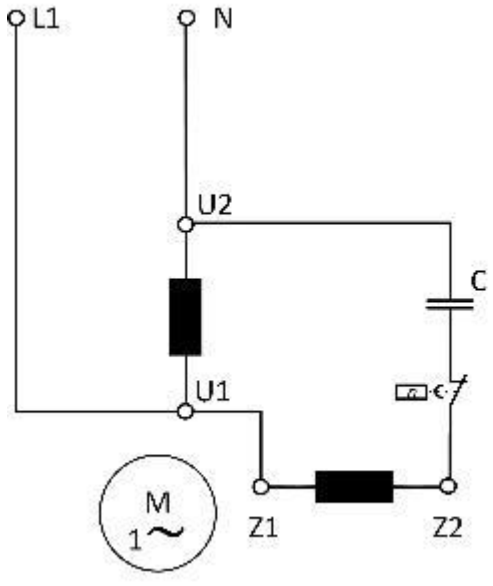



| | |
|---|---|
| U2 | Run winding terminal |
| Z1 | Start winding terminal |
| Z2 | Start winding terminal |
| *n* | Start relay |

*Figure 8-2 Typical Split Phase (or Resistance Start) Motor (Source: HEAT GmbH)*

## D8.2 Capacitor start motor

In capacitor start motors, during the starting sequence, as the capacitor is connected in series with the starter winding (as shown below), the current through the starter winding ***Is*** leads the voltage V, which is applied to the circuit; whereas the current through the run (or main) winding ***Im***, lags the applied voltage V across the circuit. The bigger the difference between the ***Is*** and ***Im***, the better the resulting rotating magnetic field.

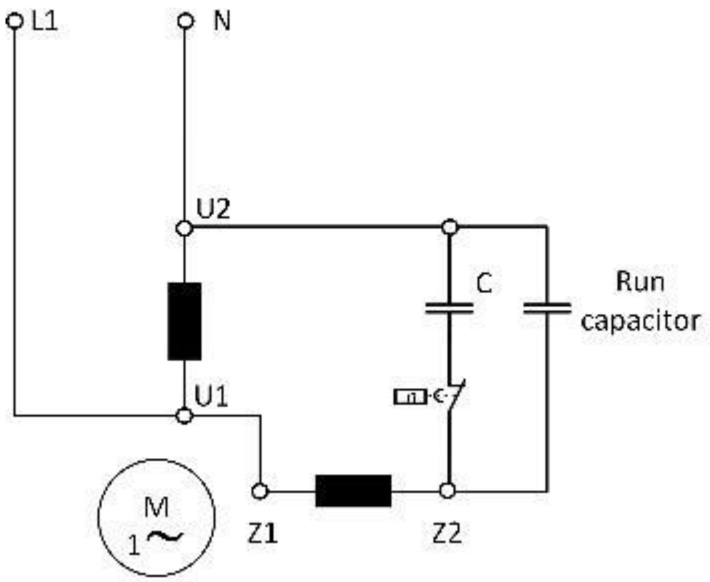



| | |
|---|---|
| C | Capacitor |
| L1 | Line |
| N | Neutral |
| M1 | Compressor motor |
| U1 | Run winding terminal |
| U2 | Run winding terminal |
| Z1 | Start winding terminal |
| Z2 | Start winding terminal |
| *n* | Start relay |

*Figure 8-3 Typical Capacitor Start Motor (Source: HEAT GmbH)*

The capacitors are usually fixed to the frame of the motor but can be mounted separately nearby.

### D8.3 Capacitor start, capacitor run motor




| | |
|---|---|
| C | Capacitor |
| L1 | Line |
| N | Neutral |
| M1 | Compressor motor |
| U1 | Run winding terminal |
| U2 | Run winding terminal |
| Z1 | Start winding terminal |
| Z2 | Start winding terminal |
| *n* | Start relay |

*Figure 8-4 Typical Capacitor Start Capacitor Run Motor (Source: HEAT GmbH)*

There are two types of capacitor motor:

1. the capacitor start motor as previously illustrated, in which a centrifugal switch or relay disconnects both the capacitor and start winding on gaining speed, similar to the split-phase motor;
2. the capacitor start, capacitor run motor, where two capacitors are used to start the motor; both a large and a small capacitor are connected to the start winding during starting and once the motor is running a centrifugal switch or relay will disconnect the large capacitor, leaving the small capacitor in circuit.

The small capacitor is capable of carrying load. The overall *effect* is a better running torque and an improved power factor.

## D9 Safe isolation

### D9.1 Electrical systems – risks and safety precautions

Electro technical contents are an important part of apprenticeships and training for skilled RACHP workers and should be part of practical and theoretical competence examinations.

Working on electrical circuits is one of the main causes of accidents at work of RACHP workers.

A faulty electrical circuit is also the main reason for accidents on an otherwise normally operating RACHP unit.

Electrical systems and equipment can only be installed, modified, maintained and serviced by a qualified skilled worker or under the leadership and supervision of a qualified electrician in accordance with applicable rules and regulations of electrical engineering.

The following international standards deal with general requirements for electrical installations, specifically with the differentiation and specification of requirements for:

- Skilled electrician
- Electrically trained person
- Electro technical layperson

**IEC 60364-1:2005 (DIN VDE 0100-100:2009-06)** - Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions

**EN 60204-1:2018** - Safety of machinery- Electrical equipment of machines- Part 1: General requirements

Employers and supervisors in the RACHP industry are responsible for determining if a task can be done by a RACHP technician or if a qualified electrician has to be consulted.

## D9.2 Effects of electrical current on the human body

An electrical accident or electric shock is an injury caused by the action of electrical current on a person. The most common consequences of electrical accidents are chemical and thermal effects (burns), neurological effects, muscle irritation (e.g. muscle cramps, tetanic muscle contractions) or muscle paralysis. The latter case may, among other things, lead to life-threatening cardiac arrhythmias such as ventricular fibrillation as well as cardiac arrest or respiratory paralysis with fatal consequences.

Indirectly caused accidents such as falls with significant consequences are not to be underestimated.

The extent of the effect of an electrical accident depends on:

- the current per area (current density) due to circumstances (other than voltage and resistance)
- the type of current - AC or DC
- the frequency (only with pulsating direct current DC or alternating current AC)
- the current path over the body (e.g. hand - hand, hand - foot, left, right)

- the duration of the electric current
- the size of the contact surfaces (in the case of contact without flashover)
- the conductivity at the contact point (in the case of contact without flashover)
- the step voltage (in thunderstorms or grounded electrical systems)
- the state of health or the age of the affected person
- the presence or absence of medical implants

## Current and voltage

When an electrical current flows through the human body, the muscles cramp as the external current is much larger than the body's current in the nerve tracts. At the skin contact spots burns may appear. At higher currents, the injured person is unable to break away from the electrical supply at the contact point.

If alternating current flows through the human heart, this can trigger ventricular fibrillation, which stops the blood circulation. When the heart stops working properly, not enough oxygen reaches the brain and after a short time, brain cells are damaged, possibly leading to death.

Longer current effects also lead to electrolysis processes in the blood and serum of the body cells. The resulting toxic decomposition products can cause effects even days after the accident.

Table 9-1 shows effects for 50 Hz AC of different currents. Additional to the effects listed, thermal tissue damages may be caused by the current values named in the table (burns).

*Table 9-1 Current values and their influences on the human body*

| Current | Influences on the human body |
|---|---|
| Up to 0.5 mA | Not noticeable or slight tingling |
| 0.5 - 5 mA | Significant tingling to muscle spasms, which can usually be overcome |
| 5 - 15 mA | Painful cramps, the release threshold is exceeded |
| 15 - 25 mA | Obstruction of respiration and circulation |
| 25 - 50 mA | Respiratory complaints, cardiac arrhythmias, blood pressure increase |
| > 50mA | Ventricular fibrillation, cardiac arrest after one heart period (≤1 s) |

## Resistance/impedance

The human body can be seen as a substitute resistance or impedance in an alternating current (AC) circuit. The body impedance is not constant but depends on the voltage and its frequency.

Dry skin or an insulated contact area with the floor increase the resistance. Wet skin and a conductive contact surface are more dangerous; the higher the voltage, the lower the body resistance.

### *The body resistance*

The body resistance is the electrical resistance of a human or animal body. This resistance largely determines the limits for the prevention of electrical accidents.

It consists of the skin resistance (about 10,000 Ω in dry condition, about 100 Ω for wet skin) and the resistance of the rest of the body (about 700 Ω to 1,000 Ω). At higher voltages, the skin resistance breaks down causes a disruptive discharge; the higher the touch voltage, the lower the body resistance.

Body resistance, unlike usual resistance, is therefore not constant and there is no linear relationship between body current and contact voltage. Body resistance changes depending on many factors, such as the dryness, the path through the body and personal characteristics. Under extreme conditions, body resistances below 300 Ω are to be expected.

<u>Example:</u>
What is the current passing through the human body, assuming a minimum body resistance value of 1000 Ω (e.g. wet skin, average body resistance) and 230 V mains voltage?

Given: R = 1000 Ω; U = 230 V

Formula (Ohm's Law): $I = \frac{U}{R}$

Calculation: $I$= 230 $V$/1000 Ω = 230 mA

A current of 230mA can already lead to death at the corresponding exposure time (about 0.5 to 1 seconds).

Life-threatening burns are only to be expected in the medium voltage (1 kV up to 52kV) and high voltage range (up to 1 MV). In the low voltage range (AC up to 1000 V; DC up to 1500 V), the risk of ventricular fibrillation and so-called secondary accidents must be expected.
Secondary accidents are accidents caused by sudden and involuntary movements due to shock or startling, such as falling from a ladder as a direct reaction to touching a live part.

The following Table 9-2 shows how a human being can become part of a live electrical circuit and which currents flow through its body.

*Table 9-2 Electrical resistances in case of a fault circuit*

| Electrical resistances | Acronym | Description |
|---|---|---|
| Wire conductor resistance | $R_W$ | Indicates the wire resistance of the connecting cables, usually only a few ohms |
| Fault resistance | $R_F$ | The insulation fault between current-carrying conductors and the conductive housing |
| Contact resistance | $R_C$ | The resistance between the housing and the person touching, for example through clothing |
| Body resistance | $R_B$ | Skin resistance and internal resistance of the touching person at about 1 kΩ |
| Local resistance | $R_L$ | Insulation resistance of the person to earth, through shoes or floor covering |
| Plant earth resistance | $R_P$ | Earth resistance of the installation system, foundation earth, few ohms |

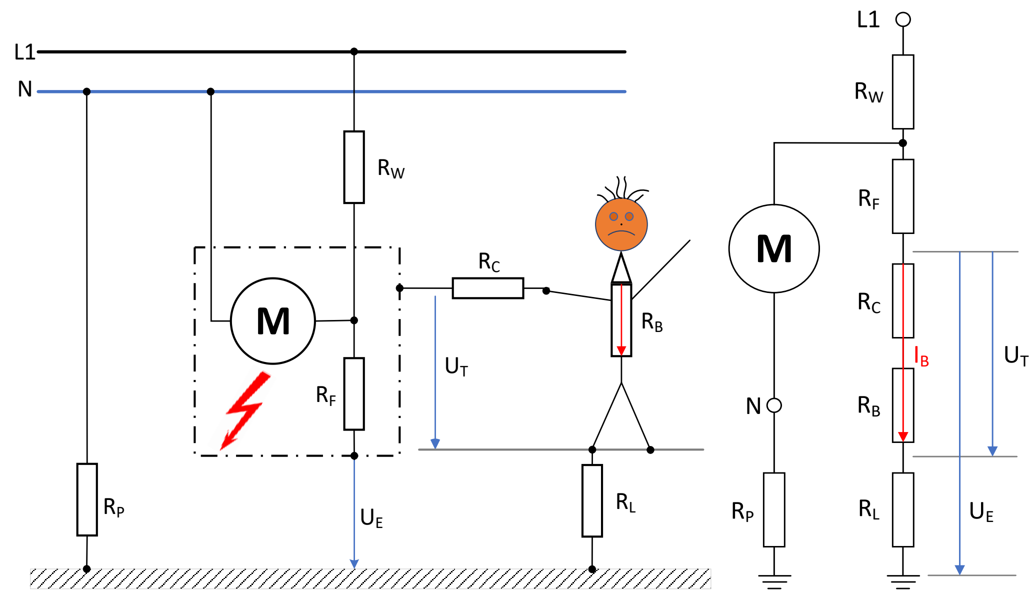



*Figure 9-1 Graphical display of a fault current situation (left). N: Neutral; L: Line Wire; M is a generic motor; and equivalent circuit diagram of a fault current situation (right). The red arrow indicates the current that flows through the body in case of a fault (Source: HEAT GmbH)*

| | | |
|---|---|---|
| **Fault voltage** | **$U_E$** | Voltage to earth in case of insulation faults between the conductor and housing of connected devices |
| **Touch voltage** | **$U_T$** | The by the person bridged voltage between touch point and ground contact |
| **Body current** | **$I_B$** | Current that flows through the body resistance when bridging the touch voltage |
| **Fault current** | **$I_F$** | Current that can flow due to an insulation fault and the resulting fault voltage |

## Duration of the contact

In addition to the value of the current that goes through the body and heart, the duration of the electrical impulse is also important; the longer the contact, the more severe the effect. Low currents can be sustained for a longer time without any effects; higher current can be deadly fast.

Figure 9-2 shows dangerous currents and contact times.

- Area (1): effects of currents up to 0.5 mA are largely harmless, even over a long time.
- Area (2): no lasting damage to health is assumed up to 10 mA and a time ≤ 1 s. For higher body currents, the rate of a safe exposure time decreases. At 50 mA, this maximum may only be at 200 ms.
- Area (3): noticeable health impairment on the body is expected.
- Area (4): is considered as deadly.
- Light green areas indicate the operation of RCD devices for 10 mA and 30 mA.

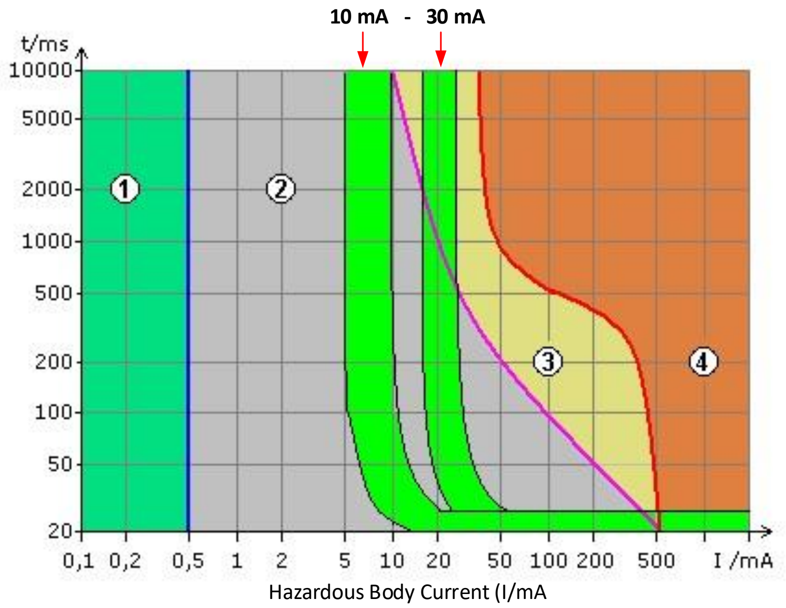



*Figure 9-2 RCD protection - Hazardous body current graph (Source: NUA NRW (2006))*

Only at very high frequencies, most of the current flows on the body surface and only a small proportion passes through it. It is important where the electricity enters and leaves the body, (the transitional contact points of the body), as this influences the flow of the current through the body. If the circuit is closed between hand and body or hand to hand, then location insulation provides no protection.

## D9.3 Electric shock

An electric shock affects the nervous system, causing the muscles to contract and sometimes causes concussion.

An electric shock can be received either by direct or indirect contact with electricity:

- **Direct contact** is when a person or livestock makes contact with parts or conductors that are intended to be live in normal use.
- **Indirect contact** is when a person or livestock makes contact with exposed conductive parts that have become live under fault conditions.

### Removing persons

Great care needs to be taken when removing a person who has come in contact with live conductors. The following points should be considered:

- the rescuer must not put themselves in danger
- all necessary procedures must be undertaken as quickly as possible
- all necessary procedures must be carried out in a way that prevents further injury.

First, disconnect the electricity supply, wherever possible. Push the victim away from the live conductors using a piece of dry wood or similar (broom handle) so that they can be removed effectively and quickly.

Treatment

Summon assistance and **call for an ambulance**.

In the case of slight shock, reassure the patient and make them comfortable. Report the accident to the appropriate personnel.

If burns have been sustained, cool the areas with cold water or any other suitable non-flammable fluid at hand. Remove anything of a constrictive nature if possible, such as rings, belts and boots. If the burns are serious, cool the areas and send the patient to hospital without delay.

For severe cases of shock where the patient is unconscious and not breathing, clear the airway and administer mouth-to-mouth resuscitation. Remember, there is no time to waste because a lack of oxygen to the brain can cause damage within four minutes.

If the heart has stopped, then cardiac compression should be given and continued until further medical advice is given.

If the patient is breathing and has a heartbeat, after treatment, place them in the recovery position and send them to hospital without delay.

## D9.4 Electrical faults and protective measures against electrical faults

There are different types of electrical faults:

1. ***Short circuit***
   A short circuit means that there is a conductive connection, without a consumer load, between voltage carrying conductors intended to be at different voltages, due to an insulation fault.

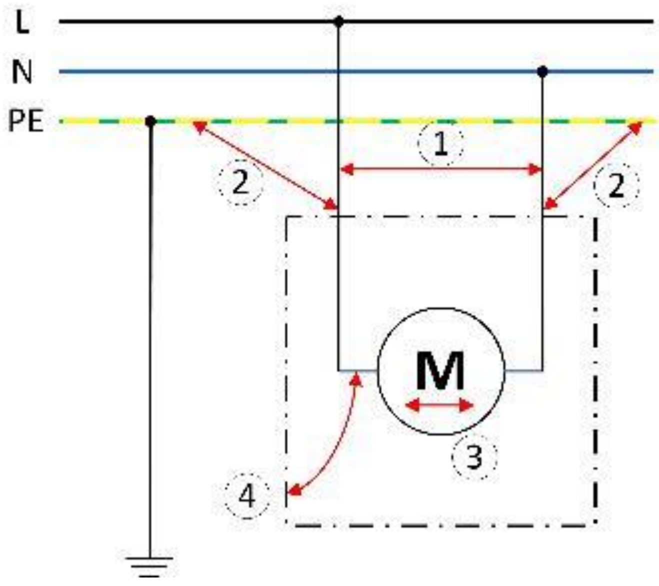
   This short circuit results in a very high short-circuit current which, without a protective measure, can destroy cables, switching devices and components.

2. ***Earth fault***
   An earth fault is a faulty conductive connection of a phase conductor or an operational insulated neutral conductor to earth or grounded parts.

3. ***Conductor short circuit***
   A conductor short circuit is a conductive connection created by a fault between operationally voltage carrying conductors when there is a consumer load in the fault circuit.

4. ***Short circuit to a housing***
   A short circuit to a housing (enclosure) is a faulty conductive connection between the housing and active parts of electrical equipment.

The following figure graphically illustrates the differences between the before mentioned types of electrical faults.




| | | |
|---|---|---|
| 1) | *Short circuit* | A low-resistance, direct connection between two live wires. |
| 2) | *Earth fault* | A low-resistance, direct connection of voltage-carrying lines to earth. |
| 3) | *Conductor short circuit* | Parts or the entire load-resistor are bridged in the event of a fault. |
| 4) | *Short circuit to a housing* | Insulation fault of live parts to the electrically conductive housing. |
| M | *Motor* | |
| L | *Line conductor* | |
| N | *Neutral* | |
| PE | *Protective Earth* | |

*Figure 9-3 Types of electrical faults (Source: HEAT GmbH)*

For the most common type of electrical faults, the short circuit, melting-fuses are the oldest protection device in electrical engineering. Nevertheless, plant construction without use of melting fuses is becoming increasingly important nowadays and replaced by state-of-the-art protection devices.

Melting fuse protection is based on the principle of allowing a piece of wire to melt through, as it were, at a predetermined breaking point within an electrical circuit. The functional classes of a fuse determine in which current ranges the fuse link can switch off. Class “g” stands for general purpose and “a” for accompanied fuse.

## Protection against electrical faults

In order to prevent electrical faults, three levels of protection can be distinguished for electrical engineering.

*Table 9-3 Main concept of electrical protection*

| **Designation** | | **Plant protection** | **Device protection** |
|---|---|---|---|
| Level 1 | Basic protection | Protection against direct contact of live (active) parts | Protection against direct contact and foreign bodies |
| Level 2 | Fault protection | Protection against indirect contact of active parts | Internal protective insulation, covers and housing as well as fuses and circuit breakers. |
| Level 3 | Additional protection | Measures to protect against direct contact with active parts, e.g. residual current device with nominal residual current of ≤ 30 mA | |

**Level 1: protection against direct contact by means of insulation**

Prevention of direct contact between live (active) parts and earth or active parts of different potentials is the baseline protection from electric shock. Examples are covers, sheathing, obstacles or the distance between parts, and protection against insertion of foreign bodies (e.g. metal pins).

Plant protection

- basic insulation
- covers
- housings
- obstacles
- distance (size of the distance depends on the voltage)

Device protection

- Protection from contact and protection from insertion of any foreign body

Full protection is mandatory for electrical equipment and systems used or operated by ordinary persons.
With partial protection, there is only protection against accidental contact, e.g. in closed electrical facilities.

In the case of a cascaded structure for the protection against dangerous contacts, the basic protection can also be referred to as the first protective measure.

Basic protection can fail by ageing, mechanical, thermal or chemical stress:

- If this happens to external insulation or covers, active parts can be touched directly. Damage is immediately visible, and repair is necessary for protection.
- If insulation inside the equipment fails, it may cause external conductive parts to receive fault voltages. In this case, it is not visible that touchable parts are carrying voltage. Measures must be taken to ensure that, in the event of a fault in the basic insulation, external conductive parts do not assume dangerous fault voltages (lower voltage, protective insulation, or protective separation) or that the faulty device shuts down automatically.

**Level 2: protection against indirect contact of active parts by protective insulation, cover, housing & protective earth**

Level 2, or fault protection, prevents harm in case basic insulation fails.

This includes internal protective insulation, covers and housing as well as fuses and circuit breakers.

Plant protection

- protection by switching off
- protective insulation
- protection by non-conductive spaces
- protection by local equipotential bonding (earthing)
- protective separation

Device protection

- protection class 1 - devices with protective conductor (earth) connection
- protection class 2 - devices with protective insulation
- protection class 3 - extra-low voltage

Protection class 3 - protective extra-low voltage: Experience has shown that even fault protection can fail. Protective earth conductors can break or be confused. Covers can go missing, making active parts accessible, or the equipment can fall into a tub of water.

These are often error events where the fault protection cannot take effect, e.g. if the dangerous contact current is not sufficient enough to break the faulty circuit in a timely manner. In such cases, a third level of protection can take effect, interrupting the fault currents or limiting them to harmless values.

**Protective measures with protective earth**

The protective earth establishes an electrical connection between accessible metallic housings (body of electrical equipment) and the main earthing bar either by means of a permanent connection or by means of the protective earth contacts in sockets.

The earthing wire connects the main earthing bar to a ground electrode (usually foundation earth or other earth electrodes such as ring-earther).
The protective equipotential bonding conductor serves to ensure equipotential bonding and connects extraneous conductive parts (water pipes, heating, air conditioning, railing, etc.) with the main earthing bar.

For equipment with flammable refrigerants:

- Electrical grounding is essential to prevent electrical discharge, which might result in sparks. Always check this is connected before leaving an installation/appliance.
- During commissioning, servicing and decommissioning of RACHP systems, equipment such as vacuum pumps, recovery units and recovery cylinder must be grounded (☛ *See Chapter A5 for safety requirements to avoid electrostatic discharge when working with flammable refrigerants and Chapter A9 on Installation and Commissioning*)
- Avoid man-made fibres as they can generate sparks caused by static electricity

Protective earth conductors, earthing conductors and protective equipotential bonding conductors must be properly laid and electrically connected. The connection and contact points must be protected against loosening or corrosion and should be accessible for inspection.

*Figure 9-4 Example of inadequate electrical cable insertion and earthing (Source: HEAT GmbH)*

*Figure 9-5 State of the art cable insertion and earthing within a control cabinet (Source: HEAT GmbH)*

Protective earth wire and protective earth connections must be marked according to standards. The protective earth, also called a PE (protective earth), is a conductor for the purpose of safety, for example to protect against electric shock in the event of a fault.

Connection points for the protective conductor are marked with the protective conductor symbol (grounding symbol in a circle). Protective conductors and neutral conductors may no longer be connected to each other from the first protective earth and neutral (PEN) separation in a system (and of course also not interchanged).

The neutral conductor is an active conductor and is able to contribute to the energy distribution. Active conductors must be protected against contact.

The protective earth contacts of sockets must always be in good condition. They must not be bent, dirty or painted over. There must be no switches in the protective earth wires.

**Level 3: additional protection**

Level 3 protection comprises supplementary measures to protect against dangerous touch currents if the basic protection and / or the fault protection fail or cannot protect due to the specific fault situation.

One example is the residual current circuit breaker technology (RCD), which makes it possible to protect even when the second barrier to electrical accidents has collapsed. It is described below in detail.

This creates a cascaded system of triple safety with the highest protection value (see Figure 9-6). The equipotential bonding also reduces the risk of contact, even if fault protection fails.

This also applies to insulating floors and walls.

## The use of residual-current protective devices


*Figure 9-6 Example of an RCD for 30mA application (Source: wylex)*

In normal operation, there should be the same current in the live and neutral wires (conductors). Any change in the current value due to an electrical anomaly indicates electrical leakage, which can cause an electrical shock and risk the human life. A residual-current device (RCD), or residual-current circuit breaker (RCCB), is a device that detects electrical leakages and instantly trips to disconnect an electric circuit ensuring protection against an electric shock.

They are also known as:

- United States and Canada: ground fault circuit interrupter (GFCI), ground fault interrupter (GFI) or an appliance leakage current interrupter (ALCI).
- United Kingdom: RCD
- Australia: Safety Switch or RCD

RCD Characteristics:

- In the event of high current (spikes or surges), RCDs do not provide protection against overheating, fire risks or short circuits
- In the event of excessive current in the circuit, RCDs are often used along with a circuit breaker such as a fuse or miniature circuit breaker (MCB). These are called residual circuit breaker with overcurrent protection (RCBO)
- RCDs are testable and resettable devices
- Some RCDs disconnect both the energized and return conductors upon a fault ('double-pole' design), while others only disconnect the energized conductor and rely upon the return conductor being at ground potential ('single-pole' design)
- If the fault has left the return wire "floating" or not at its expected ground potential for any reason, then a single-pole RCD will leave this conductor still connected to the circuit when it detects the fault

## Electrical safety devices in refrigeration control systems

**The thermal overcurrent trip**

In the event of danger, the thermal overcurrent trip disconnects the associated motor contactor and thus the connected motor via a built-in auxiliary switch. In this way, they effectively protect motors in the event of overload, damage in the event of a blocked rotor and guarantee undisturbed operation of electrical motors within the prescribed parameters.

**The motor-protective circuit-breaker (MPCB)**
Motor-protective circuit-breakers are manually operated switches that protect the motor against overloading and short-circuiting by self-opening in the main circuit. In addition, motor-protective circuit-breakers have in each current path a bimetal trip for overload protection and a magnetic quick release for short-circuit protection. In addition to opening in the main circuit, the switches can be attached with auxiliary contacts that signal the switching state or provide an interlocking to other electrical equipment. MPCBs can be installed at any point in the electrical circuit of the motor without back-up fuse.

**Thermistor protective relay**
Thermistor motor protection is the most effective and reliable state-of-the-art protection for electric motors against thermal overload. The compressor manufacturers (mainly semi-hermetic motor compressors) have included this motor protection in the basic electrical equipment. The thermistors are generally applicable for protection against thermal overloads. If these are embedded in the three windings of the motor in a three-phase compressor, they provide the protective function of the thermal overcurrent trip (bimetal).

**Klixon (bimetal switch)**
The Klixon (bimetal switch) serves as a self-resetting motor protection switch and is mainly used with hermetic compressors in refrigerators and freezers (inherently safe systems).
The bimetal is heated by a heating wire and the direct current flow through the wire from the motor load. It interrupts the contact if the motor current remains too high e.g. after starting. It thus protects the electric motor from overloading when the start-up mechanism fails or avoids hazards when the motor is damaged.

The bimetal of this switch is designed as a plate with concave curvature and therefore has a bounce behaviour with hysteresis (with overheating and cooling-down again).

## D9.5 Safety rules

“Live-line working” refers to activities where people or objects can get in contact with live/energised parts of a plant or can come close enough to be in a dangerous situation.

In the case of operating voltages above 50 V alternating voltage or 120 V direct voltage, work on live parts is only allowed if these parts cannot be switched off for important reasons, such as health risks, hazards, major economic damage, or during work on the public power supply.

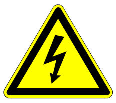
In fire-hazardous workplaces, it is generally forbidden to work on live parts.

Always follow the **five safety rules** when working on live parts.

Working on live parts is particularly dangerous. This work must only be carried out by specially qualified and certified personnel. While working on live parts, another employee trained in first aid should be present.

*The five safety rules for work with electric systems*

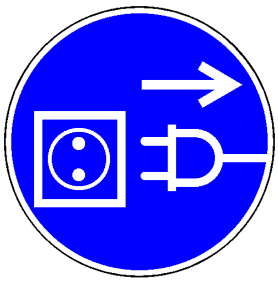
For safe work on electrical equipment, comply with the following safety rules in the given order! The rules make sure that active parts of appliances or systems are switched off before you start working and stay that way during your work.



1. Switch off power
2. Secure against reclosure of the electric circuit
3. Check that lines and equipment are dead
4. Ground and short circuit phases
5. Cover partitions or screen off neighbouring line sections

Note: Active parts are conductors or conductive parts intended to be voltage carrying during undisturbed normal operation, including the neutral conductor.

Depending on the system and the voltage, only steps 1 -3 may be necessary. This is for example the case for split ACs.

<table>
<tr>
<td>Rule 1: Switch off power<br><br>➢ For safety reasons, interrupt the circuit completely, e.g. by removing the fuses or by disconnecting the circuit breakers.<br><br>Switching off the equipment might not be enough! In some systems, voltage can still be present against earth.<br><br>➢ In circuits with capacitors, ensure that after switching off, the element is discharged by suitable devices, e.g. via built-in resistors. The voltage across the capacitors must drop to a value below 50 V within one minute.</td>
<td></td>
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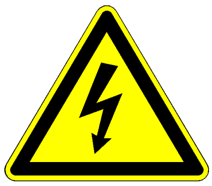
| | |
|---|---|
| **Rule 2: Secure against reclosure of the circuit**<br><br>➢ Prevent the system from restarting from reclosure of the electric circuit. This can for example be the case when someone plugs in a unit, inserts a fuse that has been intentionally taken out or this may happen automatically.<br>➢ Lock and protect safety devices and /or main switches against unintentional automatic switching on by using e.g. a padlock or taking away the fuses.<br>➢ Attach a warning sign for the duration of the work to the system to prevent unintentional restarting by others than the involved skilled persons. |  |
| **Rule 3: Check that lines and equipment are dead**<br><br>➢ Determine voltage free status by measurement before starting the work!<br>➢ Use a two-pole voltage tester.<br>**Note!**<br>Originally, in earlier regulations and standards, portable multimeters were also tolerated for determining the absence of voltage. In the last two decades, however, a number of serious and fatal accidents have occurred during this process. This was either because flashovers occurred in the multimeter for whatever reason, or because the measuring instruments with the current measuring range switched on have been inadvertently used as voltage detectors. | <br>*Figure 9-7 Voltage-free testing (Source: HEAT GmbH)* |
| **Rule 4: Ground and short circuit phases**<br><br>➢ If the voltage **is 1000 V or higher**, the earth must be grounded and must be connected to the active parts to be shorted.<br>➢ Determine voltage free status again.<br>This is **not** necessary in systems with voltages lower 1000 V. Rules 1-3 are sufficient in this case. |  |
| **Rule 5: Cover partitions or screen off neighbouring line sections**<br><br>➢ In the case of installations **below 1000 V**: cover active parts with insulating cloths, foils, plates or mouldings<br>➢ **Above a voltage of 1000 V:** additional safety boards, ropes and warning boards are necessary. In this case, the body must also be separately protected, e.g. through a protective helmet with face protection and highly insulated gloves. | <br>*Figure 9-8 Cover partitions (Source hongqi-zhang/123RF)* |

Only after the execution of all five (applicable) safety rules, the workplace may be released for normal operation by the supervisor!

For further information see EN 50110-1:2013; Operation of electrical installations - Part 1: General requirements

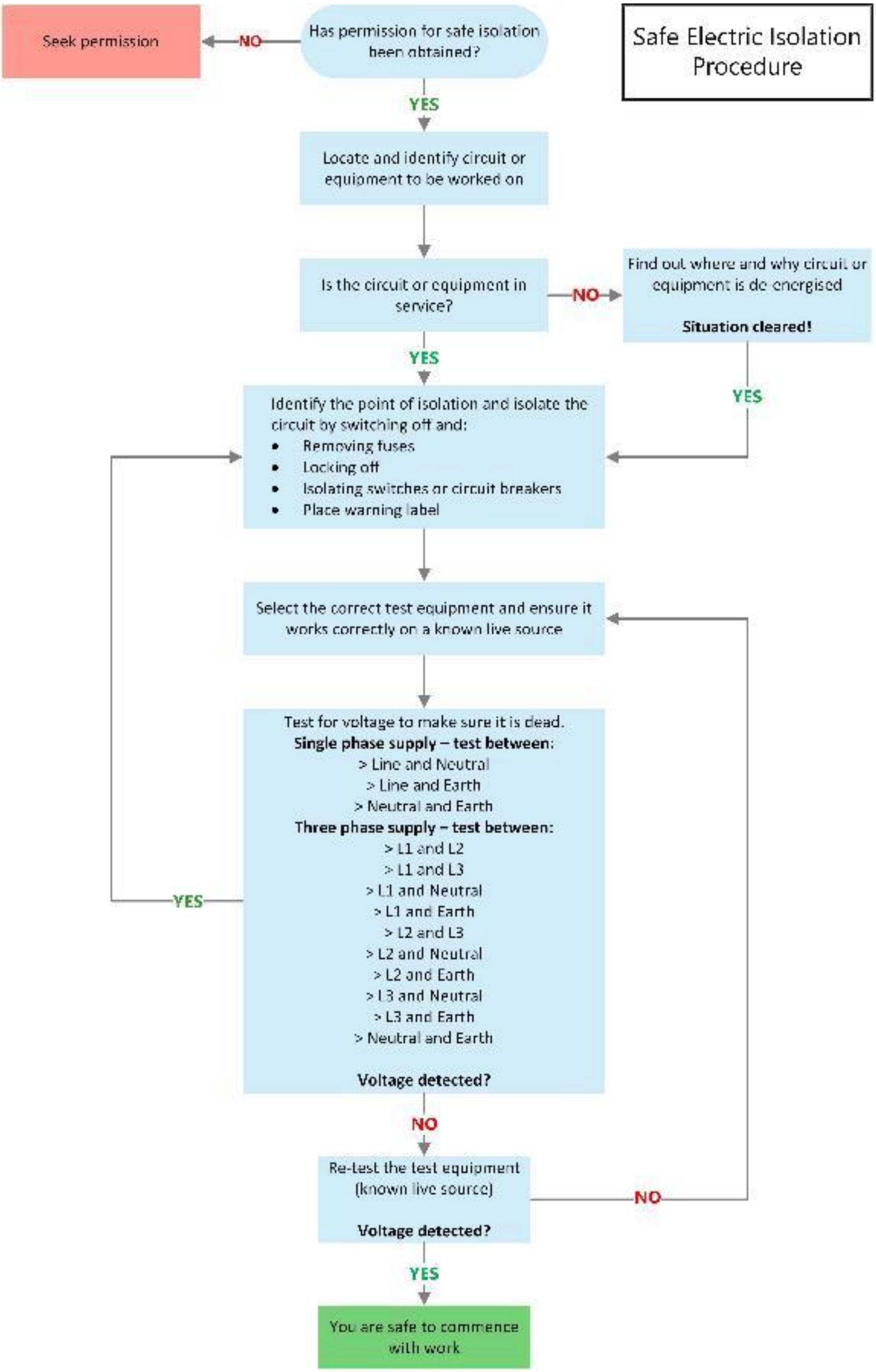



*Figure 9-9 Flow Chart for Rules 1 to 3 above. L stands for line conductor.*

Resetting in reverse order

Repealing the safeguard measures may only be started after:

- everyone included in the work has reported the completion of the work
- the workplace has been properly cleared, e.g. tools, equipment and ladders have been removed.

The system may only be restarted after:

- All persons have left the dangerous area
- approval by the supervisor

The system is made operational again by reversing the above-mentioned safety rules activities.

1. Remove the cover over partition or screens from neighbouring line sections.
2. Remove the short circuit lines and then the ground line.
3. Check that all lines are dead.
4. Remove the padlock and/or insert/activate the fuses.
5. Switch on the system.

*Voltage Indicating Devices*

Equipment used solely for detecting voltage fall into two categories:

1. Detectors which rely on an illuminated indication (e.g. a test lamp or similar) or a scale (e.g. a multimeter). Test lamps fitted with glass lamps should not give rise to danger if the lamp is broken. It may be protected by a guard. These detectors require protection against excess current. This may be provided by a suitable high-breaking capacity (hbc or hrc) fuse or fuses, with a low current rating (usually not exceeding 500 mA), or by means of a current-limiting resistor and a fuse. These protective devices are housed in the probes themselves. The test lead or leads are held captive and sealed into the body of the voltage detector (equipment which conforms to the requirements of EN 61243-3 has internal protection that meets this requirement),
2. Detectors which use two or more independent indicating systems (one of which may be audible) and limit energy input to the detector by the circuitry used. An example is a 2-pole voltage detector, i.e. a detector unit with an integral test probe, an interconnecting lead and a second test probe. These detectors may be designed and constructed to limit the current and energy which can flow into the detector. The limitation is usually provided by a combination of circuit design, using the concept of protective impedance, and current-limiting resistors built into the test probes. These detectors may be provided with inbuilt test features to check the functioning of the detector before and after use. The interconnecting lead and second test probe are not detachable components. These types of detector do not require additional current limiting resistors or hbc fuses to be fitted provided that they conform to EN 61243-3.


*Figure 9-10 Example of CE approved digital multifunctional tester (Source: Benning Duspol)*

# D10 Safety precautions when handling live circuit plant sections, electrical power tools, line and plug connections, machinery and equipment

Safety precautions when working near live circuit plant sections

When working on a part of a plant, it is sometimes not possible to deactivate neighbouring active parts. These parts might also not be protected against direct contact. In this case, particular care must be taken to select the suitable tools and work at a safe distance.

The protective distance for systems up to 1000 V mains rated voltage is **0.5 m**

Persons who have neither been trained as qualified electrician or electrically instructed personnel may only work under expert supervision near live circuit plant sections.

Safety precautions when working on live circuit plant sections

Working on live circuit plant sections requires a high level of knowledge, skills and responsibility from the worker as well as from the supervisor.

Always use appropriate personal protective equipment (PPE), tools, devices and instruments for the type of work, the voltage level and the surrounding conditions.

If working on live circuits components or sections is necessary, always use insulated safety tools. They offer increased protection against live wire contact and electrical shock.

Conduct risk assessment before decision to work and get permission by supervisor (if applicable, this may include obtaining a permit to work.).

Table 10-1 lists conditions for working on live circuit system parts up to a voltage of 1000 V.

Table 10-1 Permitted work conditions on live circuit components

| **Working on live circuit plant sections - Distinctions** | |
|---|---|
| Up to AC 50 V<br>Up to DC 120 V | **Skilled electrician, electrically trained person (according to IEC 60364 and EN 60204-1) and electro-technical layperson:**<br>- All works, as far as a danger, e.g. by arcing, is impossible. |
| Above AC 50 V or DC 120 V<br><br>Up to 1000 V AC and DC | **Skilled electrician, electrically trained person (according to IEC 60364 and EN 60204-1):**<br>- Use of suitable testing, measuring and adjusting devices, e.g. voltage testers and suitable tools for moving smooth-running parts.<br>- Prepare suitable tools and consumables for cleaning and install suitable covers and barriers.<br>- Removal or insertion of non-direct-touch fuse-links, e.g. NH fuses, with suitable aids if this is possible without danger.<br>- Sprinkling of live circuit parts during firefighting.<br>- Work on batteries taking appropriate precautions. |
| | **Skilled electrician only:**<br>- Fault location in auxiliary circuits, e.g. signal tracking, as well as the functional testing of devices and circuits.<br>- Other work, if there is a compelling reason and in addition the instruction of a responsible person is present. |

Professional insulated safety tools are identified by a symbol on the insulation. The year of manufacture, a type abbreviation and a mark of origin are required as additional information.


*Figure 10-1 Example electrician plier (side-cutter) 1000 Volts tested (Source: Knipex) and Pictogram and voltage testing level of safety tools (right)*

Safety precautions when working with electrical power tools, line and plug connections, machinery and equipment:

Handling electrical power tools can be dangerous. There are hazards caused by the electric current, but also hazards that occur when handling tools and equipment in conjunction with working fluids such as refrigerants (specifically flammable and toxic substances), lubricants and other heat transfer media and construction materials.

**Safety rules for the use of power tools**

Rules to prevent accidents with power tools:

1. Keep tools in good condition with regular maintenance
2. Use the right tool for the job
3. Examine each tool for damage before use
4. Operate according to the manufacturer’s instruction
5. Provide and properly use the right PPE

Incorrect tool selection can result in, e.g. damage to connecting elements and tools and thus to a significant risk of injury, e.g. by slipping with the tool whilst handling.

Hand-held power tools are a common cause of accidents and therefore require special care. Power tools should be visually inspected for external damage (e.g. broken housing) before use.

- Preventive maintenance should also be performed regularly on daily used hand tools:
- Drilling and cutting tools must always be kept sharply,
- Chisel heads must be burr-free.
- The hammer must be firmly wedged with the handle.
- Wrenches and screwdrivers are to match the corresponding nuts and bolts in use.

Machinery has to be selected according to the specific work demand, the approval of any device must be carefully examined (recovery unit, recovery cylinder, vacuum pump, etc.). Specifically, the use of equipment for handling of flammable refrigerants must be approved and carefully maintained.

Machinery, tools and equipment in the workshop or the service vehicle should be stored carefully and in order. This makes them easy to find and prevents damage.

Refrigerating system components, such as functional parts, flammable refrigerant transfer tubes, filters, strainers etc. must not be removed from the system (e.g. during servicing) with the use of power-tools (cutters, drillers, grinders, saws etc.) or by brazing (hot work), if it is not safe to do so (If a permit to work has been issued)!

Fatal accidents, resulting in death, physical damage and/or destruction of property may be the result. Wherever possible, cut-out components with a tube cutter or similar equipment.

Otherwise use inertisation.

*Figure 10-2 Example of cold work (Source: Rothenberger)*

*Figure 10-3 Example of hot works that must not be conducted if systems are not inerted (Source: Rothenberger)*

**Inertisation**

The system, application or part of the installation, to be worked on, should be first recovered / vented and then thoroughly flushed with Oxygen Free and Dry Nitrogen (OFDN) in order to remove residual flammable refrigerant content.

☛ *See chapter A5 for more information on OFDN, and chapter A6 on inertisation.*

*Figure 10-4 Hydrocarbon R290 refrigerating system accident (fire and explosion) by fatal human mistake due to wrong use of tools (hot works at copper tubing without inertisation) (Source: HEAT GmbH)*

Dangerous situations may also be generated by:

- defective plug-in devices,
- improper or incomplete repair,
- broken or missing parts of the casing or cover,
- exposed single wires on cable entries, e.g. at the bend protection or cable glands,
- frayed, porous, kinked or cut insulation of the connection cable.

**Testing by electrician**

Regular testing by a qualified electrician is required for electrical equipment. After the inspection, the device receives a test sticker with the test date and the date of the next inspection (see Figure 10-5).

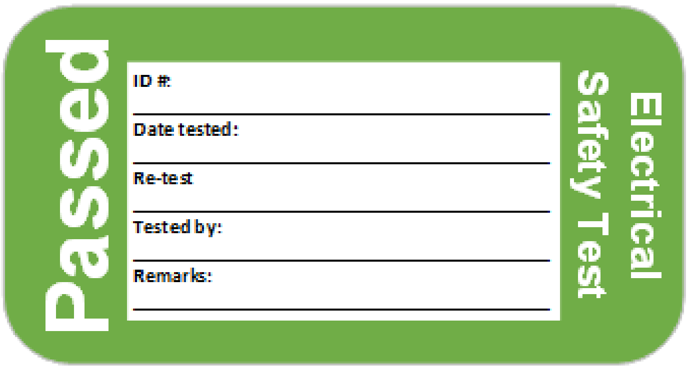



*Figure 10-5 Label: Electrical test sticker (Source: HEAT GmbH)*

Equipment should be checked regularly and at least once a year. National requirements might differ. It is the employer's responsibility to make sure that all portable power tools and equipment are checked according to best electro-technical practice. It is advised to keep a logbook of checks as proof.

**User checks**

Each time you use the equipment, ask yourself the following questions:

- **Is it suitable for the PURPOSE?** Electrical equipment is no different from any other tool in this respect. Ask yourself the question - is this the right tool for the job? Do not be tempted to use improvised tools that may not be up to the job.
- **Is it suitable for the LOCATION?** Where are you using the equipment? Even simple battery-operated equipment can present a hazard if used in the wrong environment - a spark from a torch could cause a gas explosion, for example.
- **Is it UNSAFE?** A simple visual check should be carried out to verify that the equipment has not been damaged since the last time it was used. If it has been damaged, do not be tempted to carry out a temporary repair; get it fixed properly or withdraw it from service. Even new equipment cannot be relied upon to remain in a safe condition - it may have been damaged in transit, for example. It is estimated that up to 95 of electrical faults can be found by a visual inspection.
- **Is there a GREEN STICKER?** This might seem strange, but many companies operate a system of regular portable appliance testing (PAT). Appliances that have passed the PAT test are often identified by a green sticker indicating that, at some time, they passed an electrical safety test. Look for the green sticker.
- **Is the SUPPLY OK?** Is the supply you are connecting to of the right type (i.e. is it the right voltage, current and frequency)? Is the socket undamaged? Is it overloaded?

PLUGS
To help you remember these checks, notice that the first letters of the words in capital letters above spell the mnemonic **PLUGS** - PURPOSE, LOCATION, UNSAFE, GREEN STICKER, SUPPLY.
So before you plug in, use **PLUGS!**

## D11 Electrical protection classes and ratings

The term "Electrical protection class" is often used to describe two different systems.

1) The electrical appliance manufacturing industry has defined four IEC protection classes (IEC 61140: 2016 Protection against electric shock – common aspects. Applies to the protection of persons and livestock against electric shock) to differentiate between protective-earth connection requirements of devices against contact-hazard voltages.
2) Ingress protection (IP) is defined in another IEC standard (IEC 60529 Degrees of protection provided by enclosures) The IP Code, International **Protection** Marking, **IEC** standard **60529**, sometimes interpreted as Ingress **Protection** Marking, classifies and rates the **degree of protection provided** by mechanical casings and electrical **enclosures** against intrusion, dust, accidental contact, and water.

*Relevant IEC standards:*

- IEC 61140: 2016 Protection against electric shock – common aspects for installation and equipment
- IEC 60529 Degrees of protection provided by enclosures
- ISO 7000/IEC 60417 Graphical symbols for use on equipment

## D11.1 Protection classes against electric shock

In electrical engineering, protection classes are used to classify and label electrical equipment such as devices and installation components with regard to the existing safety measures and to prevent electric shock or malfunctions of the refrigerating system, which may lead to generation of sparks. There are four protection classes for electrical equipment, with protection classes I-III being the most common.

Generally, the appliances must have their chassis connected to electrical earth.

*Protection class "0" – no special protection*

Apart from the basic insulation, there is no special protection against electric shock. The connection to the protective earth conductor system is not possible. The protection must be ensured by the surrounding area of the equipment. If permitted at all, **Class 0** items are intended for use in dry areas only.

For protection class 0, there is no symbol, a marking is not provided. It is forbidden in many countries, such as Germany, Austria, UK, and New Zealand.

However, equipment of this class is still common in many countries, whether it is permitted officially or not.

Equipment that is not professionally grounded is dangerous when used with flammable refrigerants!

*Protection class "I" – protective earth*

In protection class "I", devices or appliances, conductive housing parts of the equipment are connected to electrical earth (also called electrical ground) by a separate earth conductor.

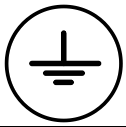
Generally, exposed metal and conductive parts in a house are connected to each other to be at ground potential. In case of a fault, a person touching these parts will therefore be protected from an electrical shock (☛ see also H18 equipotential bonding).

**In most countries the earth conductor is green/yellow; in the US, Canada and Japan it is green only.**

Movable devices of protection class "I" have a plug connection with protective conductor contact, a plug with protective contact or a three-pole plug. The protective conductor connection is designed in a way that it is the first contact to be maintained when plugging in the plug and is the last to be disconnected in the event of damage (first-to-make, last-to-break contact).

The insertion of the connecting cable into the device must be mechanically “strain relieved”, when the cable is torn out; the protective conductor must tear off last.

The earth connection is achieved with a 3-conductor wired mains cable, typically ending with an AC three-pole connector, which plugs into a corresponding AC outlet. The basic requirement is that no single failure can result in dangerous voltage becoming exposed so that it might cause an electric shock and that if a fault occurs the power supply will be disconnected automatically (this is sometimes referred to as ADS = Automatic Disconnection of Supply).

| | |
|---|---|
| Grounding symbol in protection class “I”, for the protection class “I” itself there is no symbol. |  |

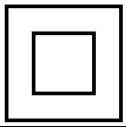
*Protection class “0I”*

In protection class “0I”, the chassis is connected to earth via a separate terminal and not via the mains cable. In Class 01 appliances, there is provision for an Earth connection, but it is wired with either twin core cable or only has a 2-pin plug, so an Earth cannot be connected. As in Class 0 equipment, there is only one level of protection. For this reason, Class 0I appliances are also prohibited from sale. The protection is equivalent to class “I”.

*Protection class “II” - Protection by double or reinforced insulation*

Equipment with protection class “II” has reinforced or double insulation in the amount of the rated insulation voltage between active and touchable parts. They have no connection to the protective conductor. Even if they have electrically conductive surfaces, they are protected by reinforced or double insulation, which ensures complete protection against dangerous contact currents even when the basic insulation is bridged by an insulation fault.

For the power connection of movable devices of protection class “II”, power cable and plugs are used which have no connection to the protective earth conductor.

| | |
|---|---|
| **Symbol for double insulation.** Appliances can also be labelled class “II” |  |

Insulated AC/DC power supplies, such as sniffers for leakage detection and cell-phone chargers are typically designated as class “II”

*Protection class “III” – Extra low safety voltage*

Class “III” equipment may only be connected to separated extra-low voltage (SELV) power sources, including:

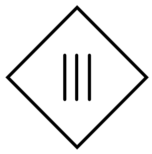
- Safety transformer according to DIN EN 61558-2-6
- Electrochemical power source (battery, accumulator)
- A separated feeder of the supply network that is effectively independent of the normal feeder

The device is operated with a voltage which corresponds to a maximum of the permissible contact voltage.

Maximum contact voltages are:

| | |
|---|---|
| Normal | DC: U ≤ 120 V =<br>AC: U ≤ 50 V ~ |
| In stables / animal husbandry | DC: U ≤ 60 V =<br>AC: U ≤ 25 V ~ |
| For children's toys | U ≤ 25.0 V |
| In wet rooms | U ≤ 12.0 V |
| In medical technology | U ≤ 6.0 V |

Protective class “III” equipment is commonly used for the application of flammable refrigerants.

| | |
|---|---|
| Symbol for protection class III |  |

## D11.2 Ingress protection (IP)

In RACHP applications, electrical and electronic equipment must operate safely under harsh environmental conditions for many years. One important point to guarantee this is to prevent the ingress of foreign bodies, such as wires and dust and the mechanical stress caused by impact.

The standard allows an objective comparison of the characteristics, rather than marketing terms such as “waterproof”.

The IP code contains 2 characteristic numerals (for example, IP 67)

*Table 11-1 IP protection class*

| IP | First digit – Ingress of solid objects | Second digit- Ingress of liquid objects |
|---|---|---|
| **0** | No protection | Not protected |
| **1** | Protection against solid foreign objects (≥50 mm in diameter) | Protection against vertically falling drops of water or condensation |
| **2** | Protection against solid foreign objects (≥12.5 mm in diameter) | Protection against sprays of water up to 15° on either side of vertical |
| **3** | Protection against solid foreign objects (≥2.5 mm in diameter) | Protection against sprays of water up to 60° on either side of vertical |
| **4** | Protection against solid foreign objects (≥1 mm in diameter) | Protection against splash water from any direction |
| **5** | Limited protection against dust ingress | Water protected in low-pressure jets against enclosure from any direction |

| | | |
|---|---|---|
| **6** | Total protection against dust ingress | Water protected in high-pressure jets against the enclosure from any direction |
| **7** | N/A | Temporary immersion in water (1 m of for 30 min) |
| **8** | N/A | Protected against continuous immersion under water for short period (2m for 60 min) |
| **9** | N/A | Stream directed at a high pressure against the enclosure from any direction |

For the use with flammable refrigerant, IP 67 is recommended as a minimum to guarantee gas tightness.

IP67: total protection against dust ingress and temporary immersion in water.

# D12 Electrical check of appliances and systems

Electrical systems and appliances have to be tested before commissioning, both after installation and modification. This has to be carried out by a person with the appropriate qualification and approved equipment and tools.

Electrical inspections generally include the following steps:

- The equipment is looked at, touched, shaken or pulled
- Check firm hold of cables and electrical components
- Check the correct connection
- Check the correct dimensioning, e.g. of cables and fuses
- Check if cable lugs are fixed properly
- Test fault-current circuit breakers, protective measures (such as enclosures) and the correct connection of the protective conductors

In case of negligence or carelessness, danger to life may exist for all individuals who come into contact with the appliance or plant, and those that have to work with it.

<u>General Inspection</u>

First, a rough visual inspection is performed:

1. Does the equipment have to be protected from external influences? How is this managed? Examples for external influences are other electrical systems causing vibrations or potential contact with water. Fastening of equipment, protective cases or finding a different space can be solutions to exclude hazards.

2. Are the overcurrent protection devices, such as fuses and MCBs dimensioned according to the weakest point of the circuit?

| |
|---|
| Example: Cable 1.5 mm² = 18 A; Socket = 16 A; Switch = 10 A; |
| Conclusion: Choose a 10 A fuse. |

3. Are all individual circuits labelled correctly?
   Main circuits, control circuits and circuits with low voltage have to be marked clearly, e.g. by cables in different colours.
4. Are wiring diagrams available (if applicable)?
   Circuit diagram documents are located on the machine itself or provided separately. It has to be checked that the diagram belongs to the plant.

## D13 Instrumentation

Unsuitable electrical test equipment can cause serious burns or electric shock. Arcing or 'flashover' caused by the use of inadequate test probes can result in burn injuries. Contact with inadequate test probes can result in shock injuries.

Arcs, once drawn, ionise the surrounding air and cause further 'flashovers' to occur. These can rapidly engulf the working area, before anybody can escape.

Systems where voltages are below 50 V AC or 120 V DC (extra low voltage) reduce the risk of electric shock to a low level. If system energy levels are low, arcing is unlikely to cause burns. It is recommended that, where reasonably practicable, tests are carried out at reduced voltages to help reduce the risk of injury.

Equipment should be constructed with suitably insulated and shrouded terminals to minimise the risk of short-circuits, which could cause danger.

Always use suitable test probes, leads, lamps, voltage indicators and multimeters, as unsuitable equipment can cause electrical arcing due to:

- inadequately insulated test probes (typically having an excessive length of bare metal at the contact end) accidentally bridging a live conductor and adjacent earthed metalwork; or
- excessive current drawn through test probes, leads and measuring instruments. This can happen when a multimeter is set to the wrong function, e.g. set to measure a current or resistance range when measuring voltage.

*Suitable test probes, clips and leads*

The test probes, clips and leads used in conjunction with electrical test equipment should be selected to prevent danger.

Modern test probes, clips and leads should:

- conform to the requirements of EN 61010-031 or in the case of a 2-pole voltage detector to EN 61243-3,
- be marked with the rated installation category – CAT II, III, or IV (see below),

- be marked with the manufacturer’s name or identifying mark,
- and have probes, and clips, which:
  - have finger barriers or are shaped to guard against inadvertent hand contact with the live conductors under test,
  - are insulated to leave an exposed metal tip not exceeding 4 mm measured across any surface of the tip. Where practicable it is strongly recommended that this is reduced to 2 mm or less, or that spring-loaded retractable, screened probes are used,
  - when used with a multimeter, should have suitable high-breaking capacity (hbc), sometimes known as hrc, fuse, or fuses, with a suitable current rating (usually not exceeding 500 mA), except when used with a loop impedance or RCD tester where a value of 10 A is typically used or a current-limiting resistor and a fuse.

Leads which:
- are adequately insulated (the choice of insulating material may be influenced by the environment in which the leads are to be used),
- are coloured so that one lead can be easily distinguished from the other (voltage detectors tend not to have different coloured leads),
- are flexible and of sufficient capacity for the duty expected of them,
- are sheathed to protect against mechanical damage,
- are long enough for the purpose, while not too long that they are clumsy or unwieldy,
- do not have accessible exposed conductors other than the probe tips, or have live conductors accessible to a person’s finger if a lead becomes detached from a probe or equipment when in use.

*EN 61010 CAT II, III and IV*

EN 61010 defines measurement categories (CAT) as below; these reflect the level of overvoltage that can be expected at the point of measurement:
- measurement category IV is for measurements performed at the source of the low voltage installation (e.g. meters, primary overcurrent protection devices etc.),
- measurement category III is for measurements performed in the building installation (e.g. measurements on distribution boards, socket outlets, permanently connected equipment, etc.),
- measurement category II is for measurements performed on circuits directly connected to the low voltage installation (e.g. appliances, portable tools, etc.).

Regulations permit few circumstances where it is acceptable for live working activities to be carried out on electrical equipment or systems, this includes electrical testing and fault finding. Wherever possible, all work on electrical systems should be carried out with the system dead. This includes electrical testing where dead tests are often as effective as live measurements.
This information is aimed at people who use electrical test equipment on low voltage electrical systems and equipment.

It provides advice on the selection and use of:
- test probes;
- leads;
- lamps;
- voltage detecting devices; and
- measuring equipment for circuits with rated voltages not exceeding 1000 V AC.

Below are the main requirements when carrying out electrical testing.

Equipment should be, so far as is reasonably practicable:

- constructed,
- maintained,
- and used in a way to prevent danger.

There must be no live working unless it is unreasonable to work dead and it is reasonable to work live and suitable precautions are taken to prevent injury.

Work must be carried out in a safe manner. Things to consider when developing safe working practices include:

- control of risks while working,
- control of test areas,
- use of suitable tools and clothing,
- use of suitable insulated barriers,
- adequate information,
- adequate accompaniment,
- adequate space, access and lighting,
- precautions to prevent people not carrying out the testing coming into contact with exposed live parts.

People at work must prevent danger and injury, be competent for the work they are carrying out, by having adequate training, skills and experience to avoid injury to themselves and others, and have adequate supervision when appropriate.

# D14 The multimeter

## D14.1 Measurement of voltage, current and resistance

A very widely used measuring instrument is the 'multimeter'. This instrument is sometimes referred to as an AVO because it can measure Amps, Volts and Ohms.

Depending on what the meter is being used for, the multimeter has very different characteristics, and care must be taken whichever function it is being used for. There is, therefore, clearly a need for caution when using a multimeter.

*Figure 14-1 Typical Digital Multimeter (Source: pixabay)*

*Figure 14-2 Example of a typical Analogue Multimeter (Source: pixabay)*

There are many different makes and models of multimeter, but they usually fall into one of two categories - analogue or digital.

Analogue meters has a moving needle against a scale that has to be interpreted by the user. So care has to be taken when reading the scales.

Digital meters display a result in numbers. Take care with where the decimal point is placed.

*Selection of correct function and range*

The selector switch allows the user to choose the electrical unit and range you wish to measure:

- DC voltage (V)
- DC current (A)
- AC voltage (V)
- AC current (A)
- Resistance (Ω)

## Instrument preparation

Prior to use, check:

- that it is calibrated by reading the calibration label that is attached to the instrument,
- battery condition,
- and the instrument test leads should be checked to make sure they are in good order and fit for purpose.

Ensure when measuring voltage, fused test leads conform to the requirements of EN 61010-031 or in the case of a 2-pole voltage detector to EN 61243-3

When an arc is created, this ionises the surrounding air, introducing further flashovers that can quickly engulf the working area and that can prove fatal.

**NOTE**: When the over rated current flows through the fuse element of a **High Rupturing Capacity Fuse** (HRC) the element is melted and vapourized. The filling powder is of such a quantity that the chemical reaction between the silver vapour and the filling powder forms a high resistance substance, which helps in quenching the arc.

*Correct calibration*

Set the range switch to the lower value of DC voltage and touch the test leads together; the needle should read zero. If the value is not zero, the accuracy of the readings will be affected. In order to adjust the reading to zero, the adjustment screw must be turned until zero is obtained.

*Battery condition and continuity of test leads*

To test the battery, select the lower ohms range and touch the test probes together. If the battery is charged and the test leads are satisfactory, you will be able to zero the reading on the ohms scale using the adjuster. No movement of the pointer indicates the test leads or connections are faulty. Where movement is detected but you cannot zero the pointer, then the battery is suspect.

To save the battery – always turn off the meter when finished.

**Digital multimeter**

Digital multimeters are often 'auto ranging'. This means that for measuring resistance, you would only have to select the ohms (Ω) range and the instrument would then measure from zero up to its maximum value (e.g. 1 mega ohms (1 MΩ)).

Always check the resistance of the test leads first, as this will have to be taken away from any resistance readings taken.

Always check that:

- the meter is in good order and calibrated,
- the test leads are in a good condition and that the continuity is correct,
- the battery is in good condition.

Prior to the measurement of voltage, resistance and low values of current, always select the correct function and the correct range.

If you are unsure which range to select, then start at the highest range and change progressively to a lower range to achieve a reasonable reading and to prevent overloading.

## D14.2 Measuring voltage

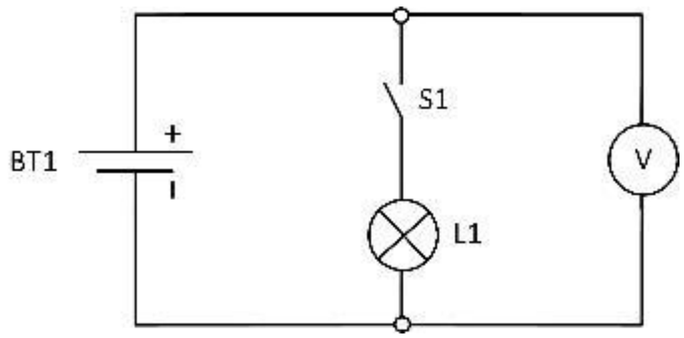



*Figure 14-3 Using a multimeter to measure voltage (potential difference) (Source: HEAT GmbH)*

When measuring voltage, the meter leads are placed either side of the component to determine the potential difference across that component.

All safety measures must be taken prior to measuring voltage. High risk activity.

## D14.3 Measuring resistance

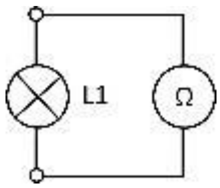



*Figure 14-4 Using a  Ohm-meter to measure resistance (Source: HEAT GmbH)*

To measure the resistance of a component the leads of the multimeter are placed either side of the component as in Figure 14-4 above.

When you are using a multimeter to measure resistance, remember the following so that you obtain accurate readings and prevent damage to the meter:

- never connect the meter into a circuit with voltage present or current flowing and
- always make sure the component or circuit you are checking is isolated from any other components or circuit.

## D14.4 Measuring current

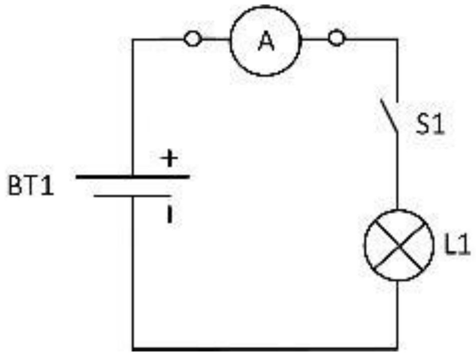



*Figure 14-5 Using a multimeter to measure current (Source: HEAT GmbH)*

When measuring current, the meter leads have to be placed in circuit to be able to measure the current flowing through the component as in Figure 14-5.

All safety measures must be taken prior to measuring current. The cables and surrounding terminals will be live. High risk activity.

This is only suitable for measuring small currents, because this method is limited by the current carrying capacity of the meter and its associated test leads. Therefore this method of measuring current is rarely used.

The majority of current measurements will be taken by using a clamp-meter, where the clamp of the meter is placed around the live wire (only) supplying the current to the component. When more current flows in the live wire, a stronger magnetic field will be created around that wire. The strength of the magnetic field is measured by the clamp part of the meter and converted in to a current reading which is then displayed by the meter

*Figure 14-6 Using a clamp-meter to measure current (Source: Fluke)*

**Instrument safety**

- Always ensure that the instrument is set correctly to the required function and range.
- When measuring voltage, use fused test leads.
- Exercise great care when measuring voltages greater than 50 V.
- For measuring resistance or if using a buzzer/diode test function, the circuit or equipment under test must be de-energised.
- Do not use the instrument on voltages or currents in excess of the instrument's capability
- Instrument test leads must be in good order and fit for the purpose, as in EN 61010-031

## D14.5 Measuring insulation resistance

Insulation deteriorates over time, caused by thermal, chemical and mechanical stress. Deteriorating insulation is one of the main causes for faults in electrical systems. The insulation resistance should therefore be measured regularly. This is done by measuring the insulation between the active conductors and the protective conductor. Insulation resistance measurements can be done for specific refrigerated appliances and components such as compressors, fans, and heaters.

Ensure no flammable refrigerants or other flammable substances are within the measuring environment. Inert the equipment if necessary and make sure there are no residues. In spaces where explosive atmospheres might occur, all conductors are measured against each other.

**Measuring insulation resistance**

- Connect two leads across the insulation barrier you want to test
- Apply a voltage higher than the operating voltage
- Use a regulated and stabilised DC as AC could produce capacitive or inductive reactance, falsifying the measurement result
- Disconnect devices that can be damaged by the measuring voltage or falsify the measurement (e.g. transformers)
- Keep the whole system voltage free
- If possible/necessary, switch on fuses and switches to measure the whole system in the voltage free system
- Measure the flow of leakage current and calculate a resistance measurement (in mega-ohms)

By carrying out an insulation resistance test, the meter pushes a higher than normal voltage into the component under test to check if any of the voltage leaks out to earth. This is similar to carrying out a strength pressure test on an air conditioning system, where the system is pressurised to a higher pressure than it would normally work at, using OFDN.

The insulation resistance shall be measured between live conductors and the protective conductor connected to the earthing arrangement. Where appropriate during this measurement, line and neutral conductors may be connected together.

The insulation resistance measured with the test voltages indicated in Table 14-1 shall be considered satisfactory if the component (in refrigeration and air conditioning, this is usually the compressor) has an insulation resistance not less than the appropriate value given in Table 14-1.

*Table 14-1 Minimum values of insulation resistance*

| Circuit nominal voltage (V) | Test voltage DC (V) | Minimum insulation resistance (MΩ) |
|---|---|---|
| SELV (Separated extra low voltage) | 250 | 0.5 |
| Up to and including 500V with the exception of the above systems | 500 | 1.0 |
| Above 500 V | 1000 | 1.0 |

Insulation resistance values are usually much higher than those of Table 14-1

**NOTE:** Additional precautions, such as disconnection, may be necessary to avoid damage to electronic devices.


*Figure 14-7 Typical insulation resistance test meter (Source: Fluke)*

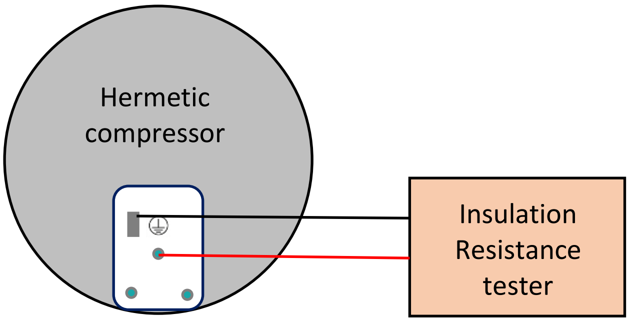



*Figure 14-8 Testing insulation resistance on a typical hermetic compressor (Source: HEAT GmbH)*

To measure the insulation resistance between the motor windings and earth:

- Connect one lead to the earth terminal and
- the other lead to the motor windings terminal (preferable the common terminal, see below how to identify compressor terminals)
- Set the test voltage and
- Press the test button on the insulation resistance tester

Then note the reading on the insulation resistance tester and compare it to Table 14-1.

## D14.6 How to identify single phase compressor electrical terminals

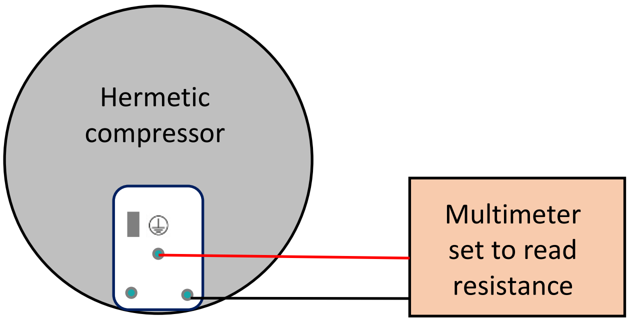



*Figure 14-9 Using a multimeter to identify the electrical terminals on a single phase hermetic compressor (Source: HEAT GmbH)*

1) Set the multimeter to read resistance on the lowest ohms range,
2) Turn the multimeter on,
3) Ignoring the earth terminal, select any two of the remaining terminals and measure the resistance between them,
4) Select a different pair of the remaining terminals and measure the resistance between them,
5) Select the last pair of the remaining terminals and measure the resistance between them,
6) By using the three resistance readings you can determine the terminal (see below).

Referring to Figure 14-9 above, if you first reading was between the top terminal and the bottom right terminal and the resistance reading was 5 Ω.

Then your second reading was between the top terminal and the bottom left terminal and the resistance reading was 3 Ω.

Finally your third reading was between the two bottom terminals and the resistance reading was 8 Ω.

What these results tell you is that because the first and second readings add up to give the third reading, the top terminal is the **common**. Also because the first reading was higher than the second, then the bottom right terminal is connected to the **start** winding.

The reason for the start winding to produce a higher reading is that the start winding is manufactured from thinner copper wire, hence producing a higher resistance. Therefore the bottom left terminal is connected to the **run** windings.

The three terminals are referred to as **C (common), S (start) and R (run)** and normally compressor terminals are marked as such, either on the compressor or on the electrical connection cover.

## D15 Electrical regulations and standards

The regulations and standards that cover electrical installations and practices associated with plumbing, gas, heating and ventilation, and refrigeration installations will vary from country to country, but below are some international standards of importants that have also been referred to throughout these notes:

**EN 60204-1** - Safety of machinery- Electrical equipment of machines- Part 1: General requirements

**IEC 60364-8-1:2019** Low-voltage electrical installations. Functional aspects. Energy efficiency

**IEC 60364-1:2005** Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions

**IEC 60529:2019** Degrees of protection provided by enclosures

**EN 61010-2-030** defines measurement categories (CAT) (Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 2-030: Particular requirements for testing and measuring circuits)

**EN 61010-031:2015** Safety requirements for electrical equipment for measurement, control and laboratory use. Safety requirements for hand-held probe assemblies for electrical measurement and test

**IEC 61140: 2016** Protection against electric shock – common aspects for installation and equipment

**EN 61243-3:2014** Live working. Voltage detectors. Two-pole low-voltage type

**IEC 61557-8:2014** specifies the requirements for insulation monitoring devices (IMD) which permanently monitor the insulation resistance (Rf) to earth of unearthed a.c IT systems.

**IEC 61558-2-6:2014-04** Safety transformer for supply voltages up to 1,100 V

**ISO 7000/IEC 60417** Graphical symbols for use on equipment

# D16 Earthing arrangements and protective conductors

## D16.1 Earthing

The Earth is a large conductor which is at zero potential. The reason for connecting the metalwork of electrical components to earth (other than that which is intended to carry current) is so that dangerous potential differences cannot exist either between different metal parts or between metal parts and Earth.

*Purpose of earthing*

For safety reasons the non-current-carrying metalwork within buildings is generally connected to Earth; this ensures that there is a route provided for any leakage current which can be detected and, if necessary, interrupted by one or more of the following:

- fuses,
- circuit-breakers,
- residual current devices (RCDs).

*Connections to Earth*

The earthing arrangements shall be such that:

1) The value of impedance from the consumer's main earthing terminal to the earthed point of the supply for TN systems, or to Earth for TT and IT systems, is in accordance with the protective and functional requirements of the installation, and considered to be continuously effective, and
2) Earth fault currents and protective conductor currents which may occur are carried without danger, particularly from thermal, thermomechanical and electromechanical stresses, and
3) They are adequately robust or have additional mechanical protection appropriate to the assessed conditions of external influence.

> Impedance: In electrical engineering, electrical impedance is the measure of the opposition that a circuit presents to a current when a voltage is applied.

The installation should be so installed as to avoid risk of subsequent damage to any metal parts or structures through electrolysis.

*Main earthing terminals or bars*

A main earthing terminal must be provided in every installation to enable the earthing conductor to connect to:

- circuit protective conductors,
- protective bonding conductors
- lightning protection system bonding conductors

Provision must be made for disconnection of the earthing conductor for test measurement of the earthing arrangements.

The method of disconnecting the earthing terminal from the means of earthing must be such that it can only be affected with the use of tools, and may conveniently be combined within the main earthing terminal or bar.

## D16.2 Protective conductors

### Cross-sectional areas

The minimum cross-sectional area of protective conductors can be obtained by using Table 16-1. This establishes the minimum cross-sectional area of the protective conductor in relation to the cross-sectional area of the associated phase conductor.

*Table 16-1 Determining cross sectional area of protective conductors (earth) (Source: IET Wiring regulation Part 5 (BS 7671))*

| Cross sectional area of phase conductor SIZE (S) $mm^2$ | Minimum cross sectional area of the protective conductor if it is of the same material as the phase conductor SIZE (S) $mm^2$ |
|---|---|
| $S \leq 16$ | S |
| $16 < S \leq 35$ | 16 |
| $S > 35$ | $\frac{S}{2}$ |

If the protective conductor not an integral part of a cable, is not a conduit, ducting or trunking, and is not contained in an enclosure formed by the wiring system, the cross- sectional area should not be less than:

- 2.5 $mm^2$ if sheathed, or otherwise provided with mechanical protection
- 4 $mm^2$ where mechanical protection is not provided.

### Types of protective conductor

A protective conductor may consist of one or more of the following:

- A single-core cable
- A conductor in a cable
- An insulated or bare conductor in a common enclosure with insulated live conductors
- A fixed bare or insulated conductor
- A metal covering, for example, the sheath, screen or armouring of a cable
- A metal conduit, metallic cable management system or other enclosure or electrically continuous support system for conductors
- an extraneous-conductive part.

Where the protective conductor is formed by metal conduit, trunking or ducting or the metal sheath and/or armour of a cable, the earthing terminal of each accessory shall be connected by a separate protective conductor to an earthing terminal incorporated in the associated box or other enclosure.

# D17 Equipotential bonding

## D17.1 Main equipotential bonding

Equipotential bonding prevents life-threatening potential differences or voltages between conductive parts and the protective earth in the event of an insulation fault. This means that all conductive materials are connected together and to earth. The following building systems and their conductive material are directly integrated:

- Telecom networks
- Data system
- Power utility cables
- Internal gas pipe
- Metal water supply pipe
- Metal drain pipe
- Central heating system
- Central chilled water piping system
- Foundation earth electrodes or lightning protection earth electrodes
- Earthing conductor for antennas (if any)
- Earthing conductor for telecommunication systems (if any)
- Protective conductors of the electrical installation in accordance with VED0100-100:2009-06 series (PEN conductor for TN systems and PE conductors for TT systems or IT systems)
- Main equipotential bonding conductor
- Metal shields of electrical and electronic conductors
- Metal cable sheaths of high-voltage current cables up to 1000 V
- Conductive parts of the building structure (e.g. lift rails, steel skeleton, ventilation and air conditioning ducting)

Installations with cathodic corrosion protection are indirectly integrated via isolating spark gaps.

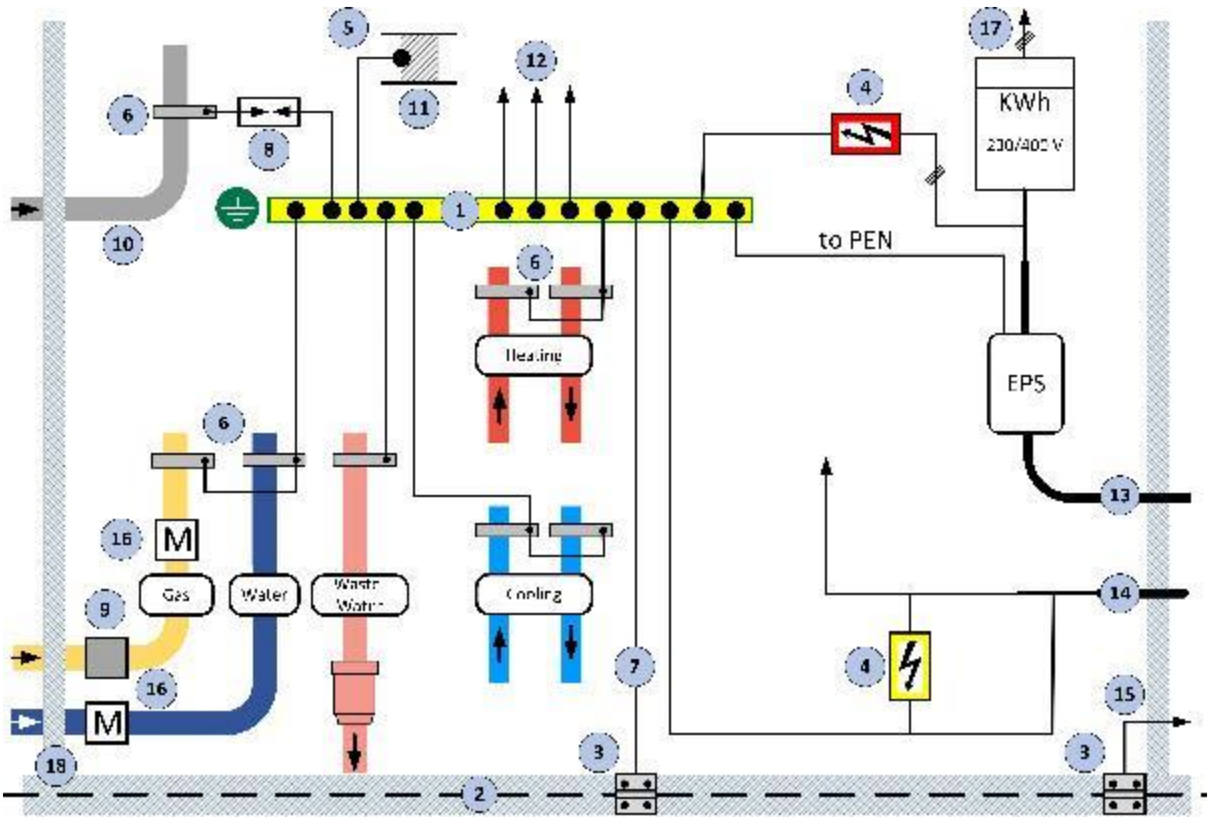
The grounding conductor must meet the following conditions:

- Resist all external influences during normal operation
- Does not cause fire hazards
- Does not influence the operation of other equipment
- Be as short as possible, without sharp bends, unnecessary arcs and loops
- Overground parts must be controllable
- Outside parts must be suitably protected, e.g. by panelling or placing them into tubes (e.g. in places where they might be damaged

Conductive construction elements of metal constructions can be used as random grounding conductors. They create a continually connected complex, as for example cable trays, cable frames, pillars, rails of crane, steel poles, reinforcement of columns made of flow spinning concrete, metal conduits, ducting and machine housings.

Connections of grounding conductors and ground electrodes must be correctly carried out and must be selectively dimensioned. While using clamps, the principle implies that the used clamp must neither mechanically damage the ground electrode (e.g. conduit) nor the grounding conductor.

The principle equipotential bonding including lightning protection within a building structure and its generic elements is laid out in Figure 17-1.




| | | | | | |
|---|---|---|---|---|---|
| 1 | Equipotential bonding / main earthing terminal | 7 | Terminal lug foundation earth | 13 | Electricity supply & distribution network |
| 2 | Foundation & lightning earth electrode | 8 | Insulation spark gap | 14 | IT system |
| 3 | Foundation & lightning earth electrode connector | 9 | Insulating element | 15 | Terminal lug for external lightning protection |
| 4 | Lightning current arrestor | 10 | Buried installation, operational isolated (e.g. cathodic protected tank installation) | 16 | Meter |
| 5 | Terminal | 11 | Metal element going through the building (e.g. metal framework, lift rails, etc.) | 17 | Buildings electrical installation |
| 6 | Pipe clamp | 12 | - Antenna<br>- Remote signalling system<br>- Equipotential bonding of bath room | 18 | Building foundation and structure |

*Figure 17-1 Example of equipotential bonding (Source: HEAT GmbH)*

## D17.2 Supplementary bonding conductors

A supplementary bonding conductor used to connect exposed conductive parts must have a cross-sectional area not less than the smallest protective conductor connected to the exposed conductive parts, subject to a minimum of:

- 2.5 mm² if sheathed or mechanically protected
- 4 mm² if mechanical protection is not provided

In situations where a supplementary bonding conductor connects two extraneous conductive parts, neither of which are connected to an exposed conductive part, the minimum cross-sectional area of the supplementary bonding conductor shall be:

- 2.5 mm² if sheathed or mechanically protected
- 4 mm² if mechanical protection is not provided

Where supplementary bonding is to be applied to a fixed appliance which is supplied via a short length of flexible cable from an adjacent connection unit or other accessory, incorporating a flex outlet, the circuit protective conductor within the flexible cable shall be deemed to provide the supplementary bonding connection to the exposed-conductive-parts of the appliance, from the earthing terminal in the connection unit or other accessory.

# D18 Terminating cables and flexible cords

## D18.1 Basic types of cable / flex and factors for their selection

**Definitions**

**Cable: Fixed wiring that is usually hidden in walls, floors (ground) and ceilings** is done using cable, which is oval in cross-section and contains three or more wires.

**Flex: Portable appliances and lights are connected to the fixed wiring system with flex**, which is round in cross-section and contains two or three wires.

In a two-core flex, there is a sheathed live (brown) and neutral (blue) wire. These flexes contain no earth wire and should therefore be used only to connect double insulated appliances.

In a two-core flex, there is a sheathed live (brown) and neutral (blue) wire. These flexes contain no earth wire and should therefore be used only to connect double insulated appliances.

The entry of a cable end into an accessory is known as a **termination**. In the case of a multi-stranded conductor, the strands should be twisted together before terminating.

Where possible, any single strand conductors should be folded to ensure an effective connection. However, be careful not to damage the conductors.

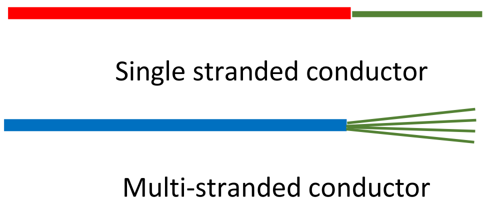



*Figure 18-1 Basic types of cable / flex (Source: HEAT GmbH)*

A cable termination of any kind should securely anchor all the strands of the conductor and not impose any appreciable mechanical stress on the terminal or socket or any undue strain on the conductor itself.

A termination under mechanical stress is liable to loosen or disconnect. When current is flowing, heat is developed, and the consequent expansion and contraction may be sufficient to allow a conductor under stress, particularly one under tension, to loosen or be pulled out of the terminal or socket.

Unless the equipment manufacturer's instructions state otherwise, all conductors should preferably be of sufficient length to allow them to be terminated at least one more time.

**For any specific selection of installation material, installation requirements and application specifications, national regulations have to be followed. These national regulations can differ from the following described technical content.**

A large range of cables and wires is available. Table 18-1 shows a variety of factors leading to the right selection of cables or wires for a specific situation.

*Table 18-1 Factors for selection of cables*

| Factors | Results for selection |
|---|---|
| • Installation location?<br>  ○ Outside or inside building<br>  ○ According to safety regulations for this installation<br>• Fixed or flexible installations | Type of cable |
| • Which equipment must be supplied with electricity?<br>• Type of electrical circuit?<br>  ○ Single phase, three-phase, with or without neutral conductor | Number of wires |
| • Minimum diameter of the conductor according to the requirements of the standards<br>• Minimum current load capacity according to the requirements of the standards<br>• Necessary protection for the operating equipment to be supplied<br>• Current carrying capacity to prevent fires<br>• Circuit breaking condition of the protective measures<br>• Voltage drop | Diameter of the conductor |
| • Types of installations<br>  ○ Maximum mounting distances<br>  ○ Maximum bending radius<br>  ○ Strain relief | Distance between fixing points |

## D18.2 Standardised electrical cables

### CENELEC harmonised system in Europe

Electrical cables were harmonized and standardized in Europe by CENELEC in 1976. The labelling of electrical cables gives information about the permissible voltage and the structure of the cable.

Exemplarily recommended cable applications (also for the use in RACHP installations) as defined in the harmonization standards are as follows:

| | |
|---|---|
| PVC cable (flex) (YSLY-JB)<br>• Universally applicable: Flexible power, process control and instrumentation cable for industrial applications and mechanical engineering for indoor applications.<br>• For installation in dry and damp rooms.<br>• The cable is resistant to most usual chemicals, oil and grease.<br>• Not suitable for constant motion. | <br>*Figure 18-2 Cable YSLY-JB example (Source: La Triveneta Cavi)* |
| Rubber cable (flex) (H05RR-F / H07RN-F),<br>• For use when cable is subjected to mechanical stress in dry or damp areas.<br>• May be used as power supply cable for portable motors, appliances, domestic electric and electrical tools, and agricultural and utility water equipment.<br>• May be installed on plaster or directly on structural parts of heavy machinery. | <br>*Figure 18-3 Cable H05RR-F example (Source: Foerch)* |
| PVC cable (flex) (H05VV-F),<br>• For use in offices and domestic premises. Generally used for household appliances such as washing machine and refrigerators.<br>• Permitted for cooking and heating applications, provided cable does not contact hot parts and is not subjected to radiation.<br>• Not suitable for outdoor use and constant motion. | <br>*Figure 18-4 Cable H=5VV-F example (Source: Zhengzhou Jinyuan Wire and Cable Co., Ltd)* |

## Use of wire colours

For most cables, the wires are colour coded.

*Table 18-2 General colour coding of wires*

| Wire | Europe, China, Singapore, Russia, Ukraine, Belarus, Kazakhstan, Argentina | US, Canada, South America and Japan, Thailand | Australia, New Zealand |
|---|---|---|---|
| Phase conductors | black, brown, grey | red, black | Red, white, others |
| Neutral | blue | white | Black, blue |
| Protective earth conductor and protective equipotential bonding conductor | green-yellow | green | Green-yellow, green |

If cables have more than 5 wires, these are usually numbered. In addition to these numbered wires, one conductor is coloured in green-yellow. If neutral conductors are routed in these lines, this wire can be used with any chosen numbering. However, this wire additionally has to be marked blue at the point of clamping, e.g. with blue sleeving (or blue insulating tape) and to be marked as neutral conductor.

## D18.3 Cable (flex) laying and fixing

Cable laying conditions and fixing distances for cables and wires depend on the type of material used. Local connection provisions, regulations and standards must be observed, especially for the laying of cables in buildings.

Cables fixed to the surface should be neatly run and secured at regular intervals in accordance with the cable manufacturer's instructions (therefore some consultation may be required in order to obtain specific technical information). In addition, it is compulsory to use fixings that can withstand high temperatures.

Movable cables are to be provided with a strain relief directly at the insertion point. This happens either with the cable gland or in the device or machine.

Cables are to be inserted into electrical components and machines using appropriate cable glands, which provide the required IP protection, vibration elimination and strain relief.

Usually flexible (chemical and oil resistant) cables are used and can be laid and installed within specific cable ducts, protective tubes or on appropriate cable racks.


*Figure 18-5 Electrical installation example for a RACHP application (Source: HEAT GmbH)*

## Cable entry systems (Cable glands)

Cable glands are used to insert and guide electrical cables as well as corrugated hoses and pneumatic hoses in control cabinets, distribution boxes, terminal boxes, machines or vehicles.

Cable glands provide a certain degree of protection against:

- Ingress of water or dust
- Contact
- Sharp metallic edges
- Strain relieve when equipped with a lock nut

*Figure 18-6 Inadequate insertion of more than one cable into a compressor terminal box (Source: HEAT GmbH)*

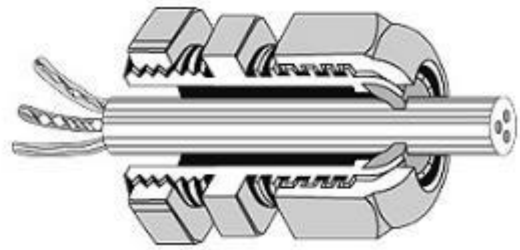
*Figure 18-7 State of the art cable laying and insertion into compressor terminal box (Source: HEAT GmbH)*

The IP protection classification and strain relief are only secured if **one** cable is inserted! Passing of more than one cable through a cable gland is not permitted and voids the given certification (IP protection certification).

Cable entries are available in various sizes. Common sizes are those that are congruent with both the required punching and hole pattern of attachment points with those of heavy industrial connectors (10-pin, 16-pin or 24-pin).

Round cable entries usually correspond to the sizes of standard metric cut outs (M16-M63). As such systems are used in the most versatile applications, the fulfilment of numerous standards is very important. These include, for example, IP classification, the UL approval or the ATEX approval for installation in potentially explosive atmospheres. The latter is in some cases important for the application of flammable refrigerants.

*Table 18-3 Examples of cable entry systems (cable glands)*

| | |
|---|---|
| Thermoplastic-based cable gland for universal use and for functional safety in installation of machines and equipment. Vibration protection and strain relief and locknut, large variable clamping ranges. Most commonly used, recommended for RACHP<br>*IP67 - 5 bar, test according to IEC 60529.*<br>*Suitable for unprotected outdoor installation according to DIN VDE 0100 Part 737* | <br>*Figure 18-8 PVC cable gland IP67 (Source: Superlec)* |
| Example: Drawing (side-cut) of a IP67 cable gland with vibration protection, strain relief and locknut | <br>*Figure 18-9 Cable gland (IP67) cut-away drawing (Source: Hensel Electric)* |
| Brass, nickel-plated cable gland for universal use and for functional safety in installation of machines and equipment.<br>Vibration protection and strain relief and locknut, large variable clamping ranges.<br>Recommended for RACHP<br>*IP 68 – 10bar / 30min for M12x1,5 to M50x1,5 according to EN 60529*<br>*No ingress of dust, full protection against body contact, protected against the effects of continuous immersion in water.*<br>*Suitable for unprotected outdoor installation according to DIN VDE 0100 Part 737* | <br>*Figure 18-10 Brass and nickel-plated cable gland IP68 (Source: Bossard)* |
| ATEX plus, metric plastic cable gland with high degree of protection and reducing seal insert, explosion proof. Vibration protection and strain relief and locknut, with large variable clamping ranges.<br>Recommended for RACHP and where ATEX regulation must be met.<br>*Certifications: CE 0637, Ex II 2G, Ex eb IIC, Ex II 1D, Ex ta IIIC, IECEx IBE 13.0027X*<br>*Suitable for unprotected outdoor installation according to DIN VDE 0100 Part 737* | <br>*Figure 18-11 Cable glands ATEX for the use in flammable zones (Source: ABB)* |

| | |
|---|---|
| Thermoplastic based cable bushing for universal use and for large variable clamping ranges.<br>No strain relief and limited vibration protection.<br>Most common used for electrical building installation, limited/restricted for RACHP<br>*IP54 test according to EN 60529*<br>*Dust protection, full protection against body contact, protected against water sprayed from all directions, limited ingress permitted* | <br>*Figure 18-12 Simple cable bushing IP54 (Source: Spelsberg)* |
| Stepped PVC nipple for cable 5 to 16 mm<br>No strain relief and limited vibration protection.<br>*IP54 test according to EN 60529*<br>*Dust protection, full protection against body contact, protected against water sprayed from all directions, limited ingress permitted* | <br>*Figure 18-13 Stepped cable nipple IP54 (Source: Spelsberg)* |
| Rubber made cable bushings for universal use. No vibration protection and strain relief.<br>Large variable application range.<br>Regularly used, limited/restricted for RACHP.<br>No specified protection classification. | <br>*Figure 18-14 Rubber cable bushing (Source: Vital Parts Ltd.)* |

## Terminating a plug to flexible cord

*Figure 18-15 Example of a well terminated plug (Source: HEAT GmbH)*

One or more strands, or wires, left out of the terminal or socket will reduce the effective cross-sectional area of the conductor at that point. This may result in overheating because further resistance has been introduced into the circuit. The same effect could occur with a loose connection.

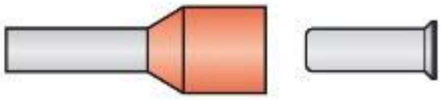
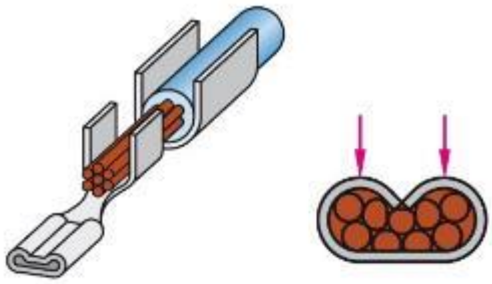
### Terminating flexible cords or cables

Just the minimum amount of insulation should be removed to achieve an effective connection, with the terminal screw firmly clamping the conductor.

Insulation should be removed using appropriate stripping tools; doing this will avoid damaging the conductor, its insulation and sheath.

## D18.4 Cable insulation stripping tools

| | |
|---|---|
| <br>*Figure 18-16 Wire stripper for the use of cable connection preparation (Source: Knipex)* | For the preparation of flexible cable connections, use a wire-stripper plier.<br><br>**Side cutter plier or knifes should not be used!**<br><br>They can damage the thin individual copper wires. Damaged copper wires will cause arcing and scorching, and this may lead to the generation of sparks.<br><br>Any of the wire strands cut and removed during the insulation stripping process reduces the cross sectional area of the conductor. This reduces the current carrying capacity of the cable and also will increase the conductor resistance. |
| <br>*Figure 18-17 Crimping plier example (Source: Knipex)* | Example of crimping plier for cable cutting, wire stripping and crimping of insulated and uninsulated cable lugs and connectors, with threaded holes for cutting copper or brass set screws with M 2.6; M 3; M 3.5; M 4 and M 5 diameter. |

| | |
|---|---|
|  *Figure 18-18 Wire-end sleeves for flexible wire connections (Source: Knipex)* | Wire-end sleeves should be used where applicable (contactors, controls, etc.) to provide reliable electrical contact. |
|  *Figure 18-19 Crimping cable lugs for the use with flexible wire connection (Source: Knipex)* | Crimping cable lugs formed as an eyelet or a fork allow for a clamping connection to electrically conductive components with a screw, which is connected to this component and connects one or more cable lugs. The third cable lug allows for a push fit connection. |
|  *Figure 18-20 Producing a crimping connection of a cable lug (Source: Knipex)* | With the use of crimping cable lugs, the crimping cable lug is formed by a metal sheet, which is bent laterally upwards. During crimping, this area including the wire end is inserted into a crimping tool or machine. This bends the metal tabs in and down on the wire end, so that there is a kidney-shaped cross-section.<br>Often, two more metal tabs are present at the end of the wire insulation, so that it is possible to produce in the same way a strain relief and kink protection. |
|  *Figure 18-21 Insulated compression cable lugs (Source: Knipex)* | Compression cable lugs have a thicker, sleeve-shaped conductor sleeve closed at the cable lug, which is deformed with crimping plier so that a force and form connection is maintained with the conductor.<br>These electrical connectors, professionally prepared, will provide the best reliable connection and avoid arcing and scorching. |
|  *Figure 18-22 Example of wire end ferrules (Source: Knipex)* | For specific connections, the use of wire end ferrules ensures long-lasting electrical connections and avoid arcing and scorching. |

In order to terminate conductors effectively, crimp terminals are extensively used.

This type of connection is often used in the termination of bonding conductors to Earth clamps. The terminals are usually made of tinned sheet copper with silver-brazed seams. The colour-coded crimp terminals represent the cable sizes they are designed for use with, and they are typically:

- RED = $0.75\ mm^2 – 1.5\ mm^2$
- BLUE = $1.5\ mm^2 – 2.5\ mm^2$
- YELLOW = $4\ mm^2 – 6\ mm^2$

> Loose cable ends (in specific flexible wires) can present a danger as they may cause arcing and scorching, which are possible sources of ignition in presence of a flammable refrigerant and result in system malfunction or hazardous situations (fire and explosion)

In order to prevent this, it is crucial to install permanent fixed and reliable crimping cable lugs and wire sleeves. Cable lugs allow electrical connection of cables or strands by screws (eyelet, fork) or plug (flat connector).

In contrast, wire end ferrules are often required for fastening cables in terminals. Solid conductors can also be bolted directly to a loop by bending the wire. For the screw fastening of stranded cables crimp rings are used, where the stranded wire is inserted in a ring shape.

A heavy-duty crimping tool is made with special steel jaws which are adjustable in order that a range of cables and terminals can be crimped.

The ratchet crimping tool (see below) must be fully closed before the jaws will open to release the crimp terminal. This is to ensure that the crimp termination is correctly clamped on to the cable.

## Ratchet crimping tool

*Figure 18-23 Ratchet type crimping tool with wire sleeves (Source: Knipex)*

To use the ratchet type crimping tool:

1) Remove sufficient insulation from the wire to be crimped, so that when the wire is inserted in the crimp, 1-2 mm extends out from it.
2) Insert the wire into the crimp, making sure all strands are in, and none are left straying.
3) Carefully place the crimp and the inserted wire in to the tool (you may find it easier to put the crimp into the tool prior to the wire with some crimps), and ensure the wire is seated home.
4) Cycle the tool until the tool releases.
5) Remove and inspect the crimp - ensure that the wire is in the correct position, and the insulation is gripped successfully.
6) Hold the crimp lug and give the wire a tug to ensure fully secured.

## D18.5 Types of terminations

There is a wide variety of conductor terminations. The typical methods of securing conductors in accessories are pillar terminals, screw heads, and nuts and washers. Push-in connectors are also increasingly common.

A pillar terminal has a hole through its side into which the conductor is inserted and then secured by a set screw. If the conductor is small in relation to the hole, it should be doubled back. Care should be taken not to damage the conductor by excessive tightening.

### Strip connectors

The conductors to be terminated are clamped by means of grub screws in connectors which are usually made of brass and mounted in a moulded, insulated or porcelain block.

*Figure 18-24 Typical Electrical strip connector (Source: Reichelt)*

Just the minimum amount of insulation should be removed to achieve an effective connection so that the terminal screw firmly clamps the conductor. A good, clean, tight termination is essential in order to avoid a high-resistance connection that could result in overheating of the joint.

Strip connectors are rated for the amount of current they are safely able to carry. Ensure you use one with a suitable current rating.

# D19 Electrical safety tests

If you are involved in connecting and reconnecting electrical equipment you will need to carry out more formal electrical safety tests as part of the commissioning process.

These tests must be performed in the order given and, unless the test requires it, with the equipment isolated from the electrical supply.

## D19.1 Inspection

The following items (where applicable) should be inspected to make sure that the work has been carried out correctly, using the appropriate materials:

- ✓ connection of conductors - are all connections mechanically sound and in the right terminals?
- ✓ identification of conductors - are the cores the correct colours and suitably labeled?
- ✓ routing of conductors - are these subject to mechanical damage?
- ✓ selection of conductors - are these the right size?
- ✓ insulation - are all live parts suitably covered?
- ✓ enclosures - are all live parts inaccessible?
- ✓ protective conductors - is everything earthed that needs to be?
- ✓ bonding conductors - is everything bonded that needs to be?
- ✓ external influences - is there protection against water, heat, smoke, fumes, dust, etc.?

Please note that this is intended to be a guide only. There may be other factors that need to be taken into account because each situation will be different.

## D19.2 Earth continuity check

This check is carried out after safe isolation. It ensures that all the metallic parts of the system are satisfactorily earthed and that all Earth connections are good.

Set the multimeter on the lowest ohms range. Connect one lead of the test meter to the Earth pin on the plug or, if not connected by a plug, then the main incoming Earth terminal. The other test meter lead should now be moved around the system to make a connection with all the Earth terminals and the metallic components involved (for example, compressor housing, pipework, pump, etc.) In all instances the resulting reading should be less than one ohm. A reading in excess of one ohm indicates a poor Earth connection, and this must be investigated.

## D19.3 Short circuit check

This check is also carried out after safe isolation. It ensures that there are no short circuits between live and neutral.

Set the multi meter on the lowest ohms range and ensure that all switches and controls are selected for cooling. Connect one meter lead to the main incoming neutral terminal. The other lead should now be connected, in turn, to all the live connections on the terminal strip (this ensures that all the components are tested even if they are not switched in). A reading of less than one ohm indicates a short circuit.

## D19.4 Resistance to earth check

This check is again carried out after safe isolation. It tests the quality of the insulation of the wiring and components in the system. A failure on this check means the system is dangerous and therefore it must not be connected to the electrical supply until the problem has been rectified.

Set the multi meter on the highest ohms range and ensure that all switches and controls are selected for cooling. Connect one meter lead to the main incoming Earth terminal. The other lead should now be connected, in turn, to all the live connections on the terminal strip (this ensures that all the components are tested even if they are not switched in). An infinitely high reading should be achieved in all instances. Any reading less than 2 MΩ must be investigated.

Once all of the above tests have been carried out with successful results, the system can now be energized and the live testing can begin.

## D19.5 Measuring the earth fault loop impedance

This test is used to test if the fuse or circuit breaker works fast enough in case of a fault in the installation to prevent fires. The loop impedance measured must satisfy local regulations.

- The loop impedance ($Z_s$) is the sum of all the resistances of the distribution network, ($Z_e$) and the conductors in the final circuit ($R_1$ resistance of the **line** conductor plus $R_2$ resistance of the **circuit protective conductor** {earth}). i.e. $Z_s = Z_e + R_1 + R_2$
- The resistance must be low enough to allow enough current to flow in the event of a short circuit to trip the fuses. In practice, the loop impedance is a maximum of 1 Ω.

- The loop impedance can also be greater than 1 Ω, as long as the short-circuit current is still large enough to trip the circuit protector.

It is usually determined with multi-function measuring devices (e.g. Fluke), which directly display the short-circuit current and the loop impedance.


*Figure 19-1 Typical multi-function measuring device (Source: Fluke)*

## D19.6 Measuring the operating voltages

All safety measures must be taken prior to measuring voltage. High risk activity.

Measure all required voltages after switching on the system to ensure safe operation. Use an approved two-pole voltage tester or multimeter.

For example, in the household networks common in the EU:

- Line conductor against line conductor 400 V,
- Line conductor against neutral conductor 230 V,
- Line conductor against protective conductor 230 V,
- Neutral conductor against protective conductor 0 V.

## D19.7 Testing of protection systems

Protection and alarm systems such as RCDs, insulation monitors and emergency stop devices have to be tested regularly to make sure they operate properly.

Examples for these tests are:

- Operation of the test buttons on RCDs and insulation monitoring devices
- Proof of the function of emergency stop devices (using the test button)
- Functional check of signalling units

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| By pressing the test button of an RCD device, only the function of the device itself is tested. The function of the protective measure as a whole and its effectiveness cannot be proved hereby; measurements are absolutely necessary for this purpose. |   *Figure 19-2 Test button on RCD device (Source: wylex)* |
| IEC 61557-8:2014 specifies the requirements for insulation monitoring devices (IMD) which permanently monitor the insulation resistance (Rf) to earth of unearthed a.c. IT systems. |  *Figure 19-3 Example of an insulation monitoring device (Source: Legrand 043501)* |

## D20 Fixed laying of cables and connections to the public electricity grid network

Only certified and registered electricians may install electrical equipment. A skilled RACHP worker does not usually have the qualification to lay cables in an electro-technical system. They may however, if they are appropriately trained, wire RACHP machines according to national standards and regulations.

As a general rule, the laying of cables is always subject to national standards and regulations. Regulations regarding the strength of cables, their protection and fastening must be followed.

## D20.1 Examples of suitable electrical connections

Figure 20-1 shows the electrical connections at split air-conditioner outdoor unit (ODU) / indoor unit (IDU):

- Manually made electrical connections must be prepared and connected with the use of the correct cable lugs and crimping tools
- Provision of earthing contacts as foreseen from the original equipment manufacturer (OEM)
- Check that plug-in modules are fitted correctly (if applicable)
- Reliable strain relief (cable grip) is essential
- Connection compartment cover must be installed after electrical connections are made and fitted tightly.

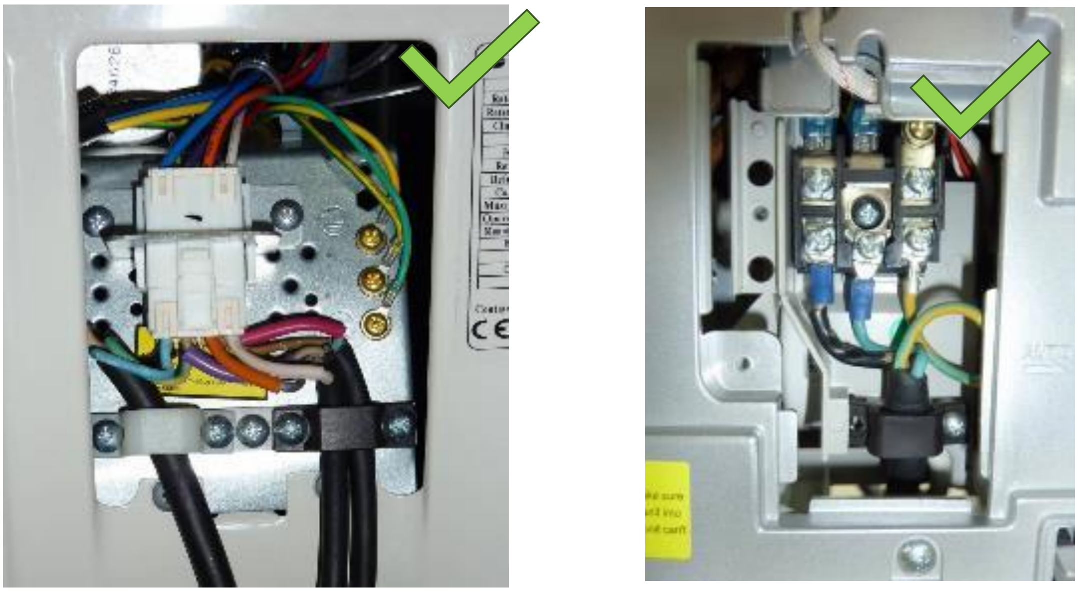

*Figure 20-1 Example of Split AC – ODU electrical connections (left) – IDU electrical connections (right) (Source: HEAT GmbH)*

General precautions and installation requirements for mains plug

- Use appropriate mains plug and cable
- Choose the correct protection class (see section H10)
- Wire end ferrules must be prepared and connected with the use of the correct crimping tools
- Reliable strain relief (cable grip) is essential
- Plug cover must be installed after electrical connections are made and fitted tightly.

*Figure 20-2 Example of mains plug – electrical connections (Source: HEAT GmbH)*

Earthing wire must be longer than phase and neutral wires, so if mains cable is pulled out by uncontrollable circumstances, the earth wire will be disconnected last!

Before commissioning of the refrigerant circuit and operation of the appliance, all electrical connectors (screws) must be fastened and checked for reliable contact and fixation. In particular, the electrical grounding must be ensured always.

## D20.2 Inappropriate examples from field installations

Inadequately installed wire lugs do not provide a reliable electrical connection and lead to malfunction of the system.

*Figure 20-3 Example - Inadequate installed cable lug (Source: HEAT GmbH)*

Made off with very poor connections at a circuit breaker. Blank wire strands connected and fixed with screws will break wires and consequentially cause arcing and scorching and finally create sparks and overheat.

*Figure 20-4 Missing wire sleeves at power conductor (Source: HEAT GmbH)*


Inadequately fixed cable lugs lead to contact scorching and finally malfunction of the compressor.

*Figure 20-5 Example – Inadequate (loose) cable lugs lead to arcing and scorching (Soure: HEAT GmbH)*

# D21 Electrical safety checks

When it is properly used and maintained, electrical equipment has a high degree of safety but, as with any other technical equipment, misuse and neglect can lead to unnecessary safety hazards. For this reason, it is essential to check electrical equipment before it is used. The extent to which you must check equipment will depend on the type of equipment you are about to use and the nature of the work you are about to carry out.

If you use electrical equipment in a variety of situations or at various customers' sites, or if you are involved in installing equipment that needs an electricity supply, there are two useful precautions you can take in addition to the user checks.

## D21.1 Supply check

On a strange site you may feel that the supply has not been wired correctly and therefore that it is not in a safe condition. The use of a socket outlet tester can provide a very quick and easy check of the supply simply by plugging it in.

This is no substitute for a full electrical test, but it does at least show that all three wires are connected and that they are in the right places. If the supply fails this test, you or anyone else must not use it until a competent person has corrected the fault. It is a good idea to label the outlet as being unsuitable for use before reporting it to the appropriate person.

*Note: These devices are not capable* of *identifying neutral-Earth reversals.*


*Figure 21-1 Example of a socket outlet tester (Source: HEAT GmbH)*

## D21.2 RCD protection

When you use portable equipment, a 30 mA residual current device (RCD) can provide additional protection against electric shock, and an RCD must be used to protect equipment that is being used outdoors. The portable plug-in type (example illustrated below) provides the most flexibility for on-site use. The device must be regularly tested to ensure that its effectiveness is maintained. Pressing the RCD test button is an easy way to check that the mechanism is operational, and the device should also be tested electrically on regular occasions to ensure that its electrical performance is within limits.


*Figure 21-2 Example of a plug in RCD (Source: HEAT GmbH)*

<u>*How an RCD works*</u>

An RCD constantly monitors the electric current flowing through one or more circuits it is used to protect. If it detects electricity flowing down an unintended path, such as through a person who has touched a live part, the RCD will switch the circuit off very quickly, (typically within 40 ms), significantly reducing the risk of death or serious injury.

The RCD device monitors the out-going current and compares it to the return current.

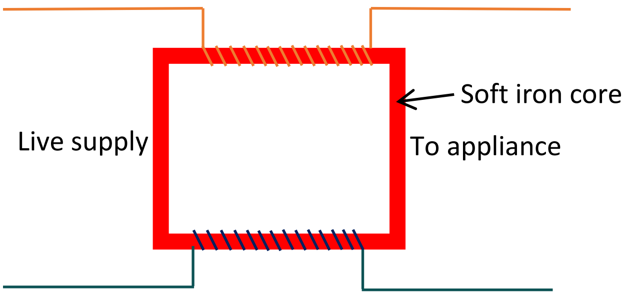


*Figure 21-3 Schematic drawing of an RCD (Source: HEAT)*

Inside an RCD is a soft iron core (see Figure 21-3 above), and the live supply is connected to coils of copper wire wound around that core. Those windings create magnetic fields and so long as the strength of the magnetic created by the live supply wire equals the strength of the magnetic field created by the neutral supply wire, then electricity will be allowed to supply the appliance.

If the strengths of the two magnetic fields are no longer balanced (e.g. the user has cut through the appliance flex), then the RCD will stop supplying the appliance typically within 40 ms.

This will ensure that the user does not receive a significant electric shock.

Further information provided with chapter D9.4 (Level 3 Protection).

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Standards referred to in this module:

BS 7671:2018 Requirements for Electrical Installations. IET Wiring Regulations

EN 50110-1:2013; Operation of electrical installations - Part 1: General requirements

EN 13313 Refrigerating systems and heat pumps – Competence of personnel

EN 60204-1: 2018 Safety of machinery- Electrical equipment of machines- Part 1: General requirements

EN 60617 Graphical symbols for diagrams - Part 2: Symbol elements, qualifying symbols and other symbols having general application

EN 61010-031 Safety requirements for electrical equipment for measurement, control and laboratory use - Part 031: Safety requirements for hand-held probe assemblies for electrical measurement and test

EN 61010-2-030 Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 2-030: Particular requirements for testing and measuring circuits

EN 61010-031:2015 Safety requirements for electrical equipment for measurement, control and laboratory use. Safety requirements for hand-held probe assemblies for electrical measurement and test

EN 61243-3:2014 Live working. Voltage detectors. Two-pole low-voltage type

EN 61558-2-6 Safety transformer for supply voltages up to 1,100 V

IEC 60027-4 Letter symbols to be used in electrical technology - Part 4: Rotating electric machines

IEC 60364-1:2005 Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions

IEC 60364-8-1:2019 Low-voltage electrical installations. Functional aspects. Energy efficiency

IEC 60417 Graphical symbols for use on equipment

IEC 60529:2019 Degrees of protection provided by enclosures

IEC 61140:2016 Protection against electric shock – Common aspects for installation and equipment

IEC 61557-8:2014 specifies the requirements for insulation monitoring devices (IMD) which permanently monitor the insulation resistance (Rf) to earth of unearthed a.c IT systems.

ISO 7000 Graphical symbols for use on equipment - Index and synopsis

ISO/DIS 22712 Refrigerating systems and heat pumps - Competence of personnel

DIN VDE 0100 Part 737 Erection of power installations with nominal voltages up to 1000 V; humid and wet areas and locations; outdoor installations

DIN VDE 0100-100:2009-06 Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions