ABB circuit breakers for direct current applications

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1. Introduction

Direct current, which was once the main means of distributing electric power, is still widespread today in electrical plants supplying particular industrial applications.

The advantages offered by the use of DC motors and supply through a single line make direct current supply a good solution for railway and underground systems, trams, lifts and other transport means.

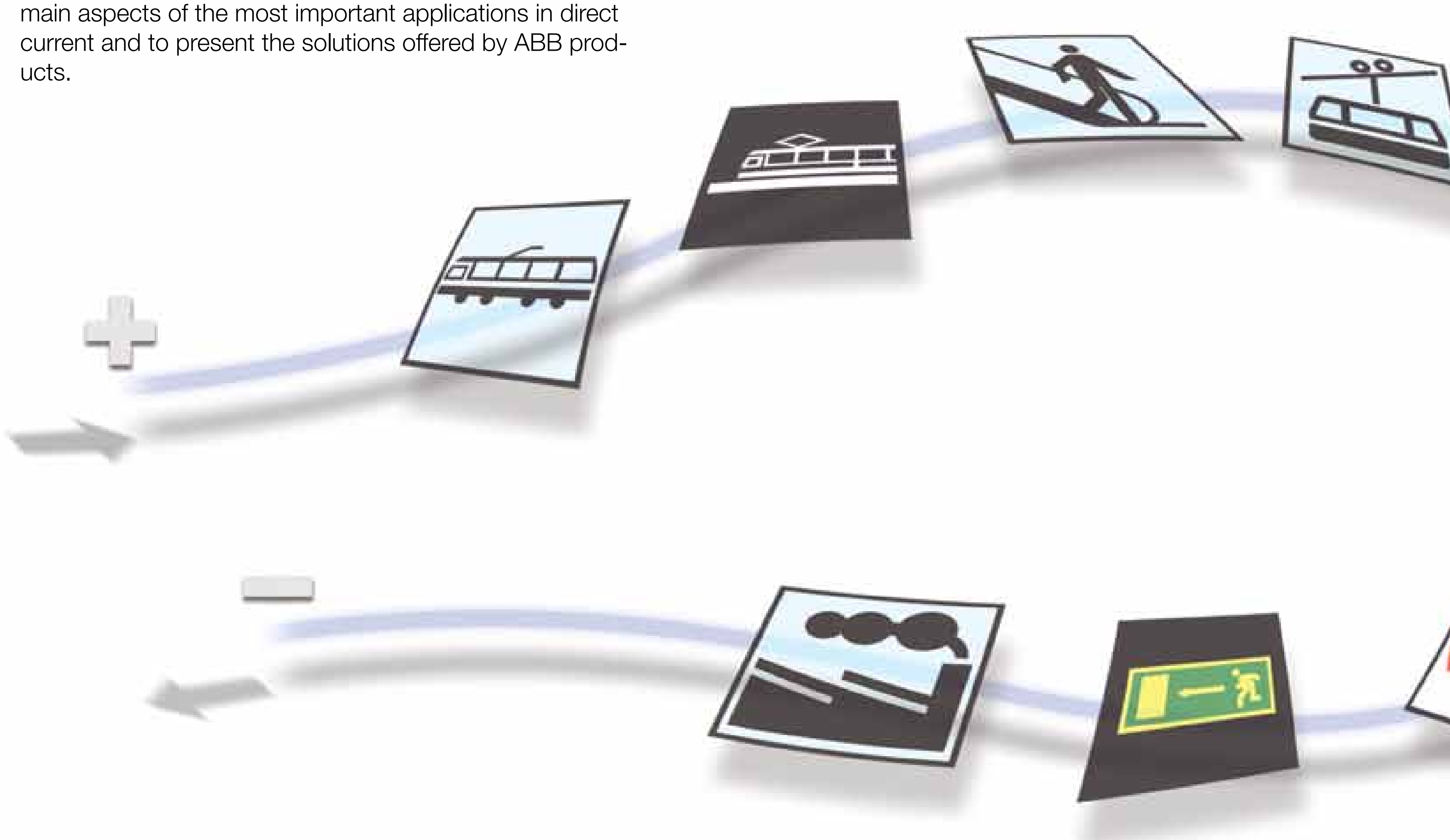
In addition, direct current is used in conversion plants (installations where different types of energy are converted into electrical direct energy, e.g. photovoltaic plants) and, above all, in those emergency applications where an auxiliary energy source is required to supply essential services such as protection systems, emergency lighting, wards and factories, alarm systems, computer centers, etc. Accumulators are the most reliable energy source for these services, both directly as direct current as well as by means of uninterruptible power supply units (UPS), where loads are supplied in alternating current.

This technical application paper is intended to explain the main aspects of the most important applications in direct current and to present the solutions offered by ABB products.

This paper also has the goal to give precise information to provide a rapid choice of the protection/disconnection device, paying particular attention to the installation characteristics (fault types, installation voltage, grounding arrangement).

There are also some annexes with further information about direct current such as:

- Information about distribution systems
- Guidelines on the calculation of DC short circuit currents as per IEEE 551, IEEE 141
- Circuit breakers and molded case switches for applications up to 1000 VDC



2. Generalities on direct current

Knowing the electrical characteristics of direct current and its differences with alternating current is fundamental to understand how to employ direct current.

By definition, direct current has a unidirectional trend constant in time. Analyzing the motion of the charges at a point crossed by a direct current, the quantity of charge (Q) flowing through a cross section is always the same.

Batteries or dynamos can provide direct current. It is also possible to convert alternating current into direct current through a rectifying process.

However, a “pure” direct current, a current which does not present any periodic fluctuation, is generated exclusively by batteries (or accumulators). In fact, the current produced by a dynamo can present small variations which do not make it constant in time. Nonetheless, from a practical point of view, this is considered a direct current.

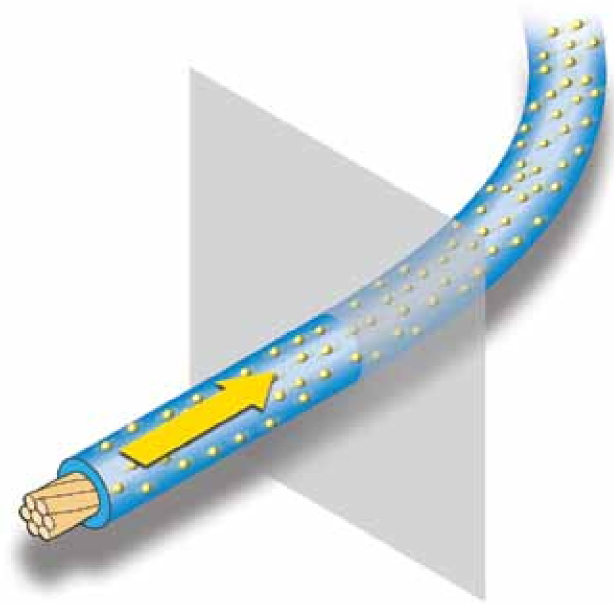
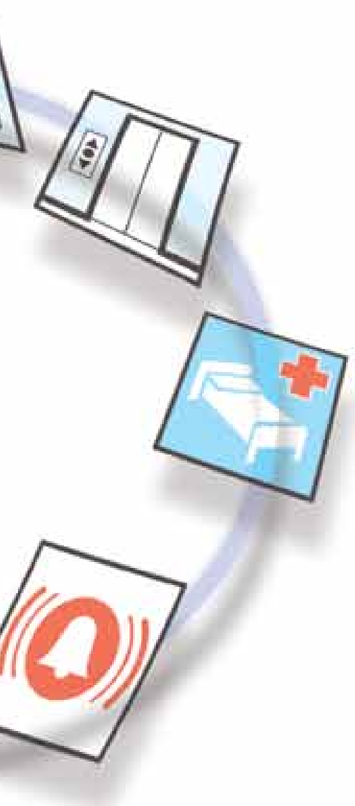


Figure 1
Quantity of charge flowing through the cross section of a conductor



In a DC system respecting the current direction has a remarkable importance. Therefore it is necessary to correctly connect the loads by respecting the terminals, as operation and safety problems could arise if the terminals should be connected incorrectly.

For example, if a DC motor were supplied by switching the terminals, it would rotate in reverse and many electronic circuits could suffer irreversible damage.

R.m.s. value of a sinusoidal quantity

The r.m.s. value is the parameter which relates alternating to direct current.

The r.m.s. value of an alternating current represents the direct current value that causes the same thermal effects in the same period of time. For example, a direct current of 100 A produces the same thermal effects of a sinusoidal alternating current with the maximum value of 141 A.

Thus the r.m.s. value allows alternating current to be treated as direct current where the instantaneous value varies in time.

$$I_{r.m.s} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt} \quad \text{(where T is the period)}$$

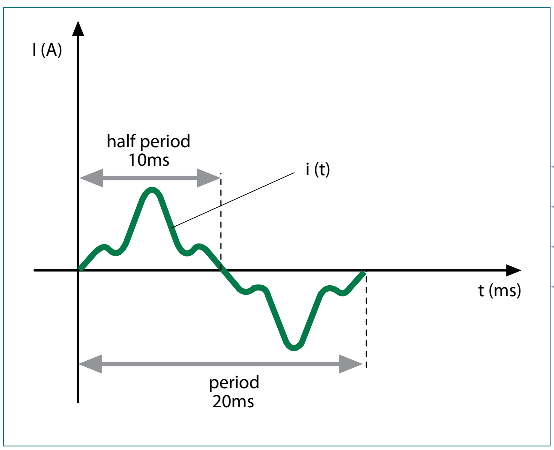


Figure 2
Periodic waveform

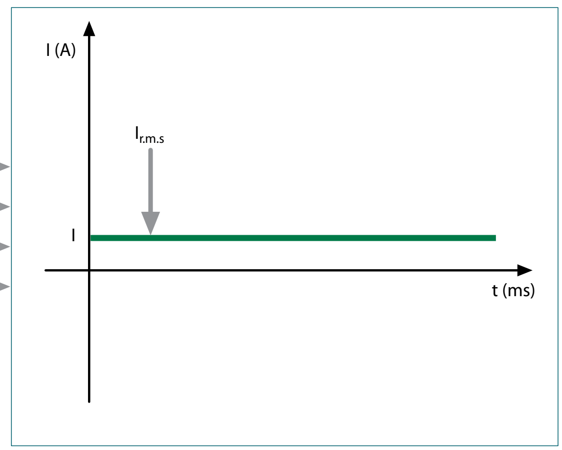


Figure 3
R.m.s. value (value of the equivalent direct current)

The r.m.s. value of a perfectly sinusoidal waveform is equal to:

$$I_{r.m.s} = \frac{I_{max}}{\sqrt{2}}$$

(where I_{max} is the maximum value of the amplitude of the sinusoidal waveform)

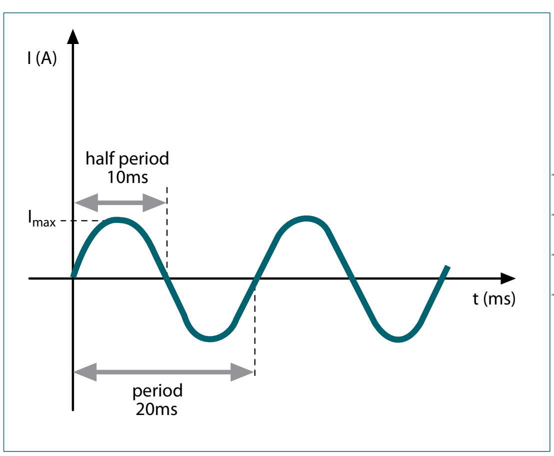


Figure 4
Sinusoidal waveform

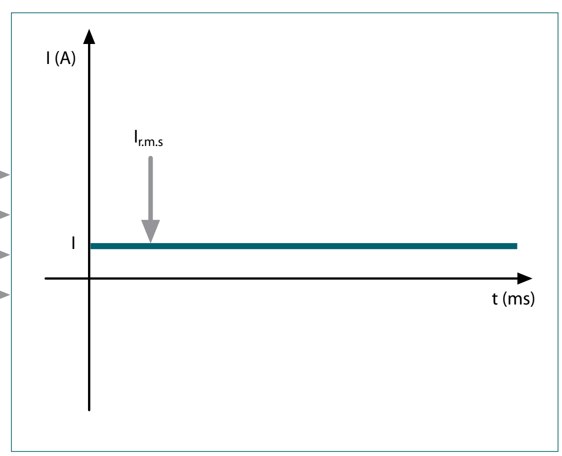


Figure 5
R.m.s. value (value of the equivalent direct current)

3. Applications

Low voltage direct current is used for different applications, which have been divided into four macrofamilies including:

- conversion into other forms of electrical energy (photovoltaic plants, above all where accumulator batteries are used);
- electric traction (tram-lines, underground railways, etc.);
- supply of emergency or auxiliary services;
- particular industrial installations (electrolytic processes, etc.).

3.1 Conversion of alternative energies into electrical energy

Photovoltaic plants

A photovoltaic plant converts the energy associated with solar irradiation into DC electrical energy. These plants are made up of semiconducting panels which can generate electrical power once exposed to the rays of the sun.

Photovoltaic plants can be grid-connected or supply a single load (stand alone plant). In this last case an accumulator battery is present to provide power in case of a lack of solar radiation.

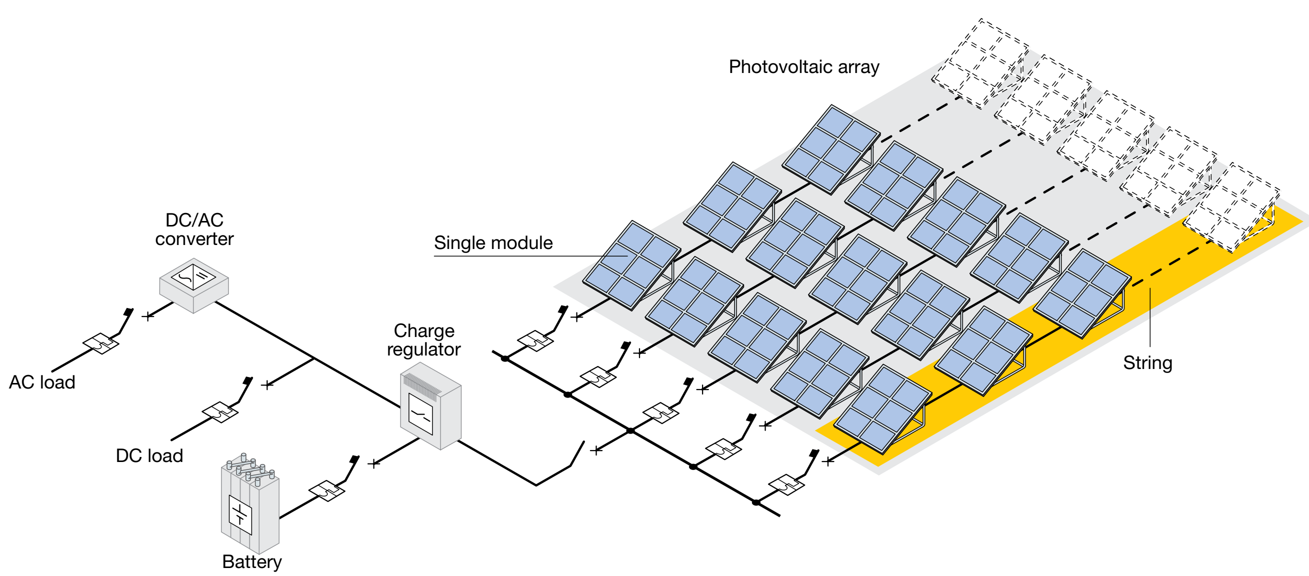
The basic element of a photovoltaic plant is the photovoltaic cell made of semiconducting material (amorphous silicon or monocrystalline silicon). Exposed to the rays of the sun, this cell is able to supply a maximum current I_{mpp} at a maximum voltage V_{mpp}, which corresponds to a maximum power called W_p. Photovoltaic cells are connected in series to form a string to raise the voltage level. By connecting several strings in parallel, the current level is increased.

For example, if a single cell can provide 5A at 35.5 VDC, in order to reach the level of 100A at 500 VDC, it is necessary to connect 20 strings in parallel, each one with 15 cells.

Generally speaking, a stand alone photovoltaic plant includes the following devices:

- Photovoltaic array: photovoltaic cells suitably interconnected and used for the conversion of sunlight energy into electrical energy;
- Charge regulator: an electronic device able to regulate charging and discharging of accumulators;
- Accumulator batteries: to provide power supply in case of lack of solar radiation;
- DC/AC inverter: to turn direct current into alternating current by controlling it and stabilizing its frequency and waveform.

The following figure shows a block diagram of a stand alone photovoltaic plant.

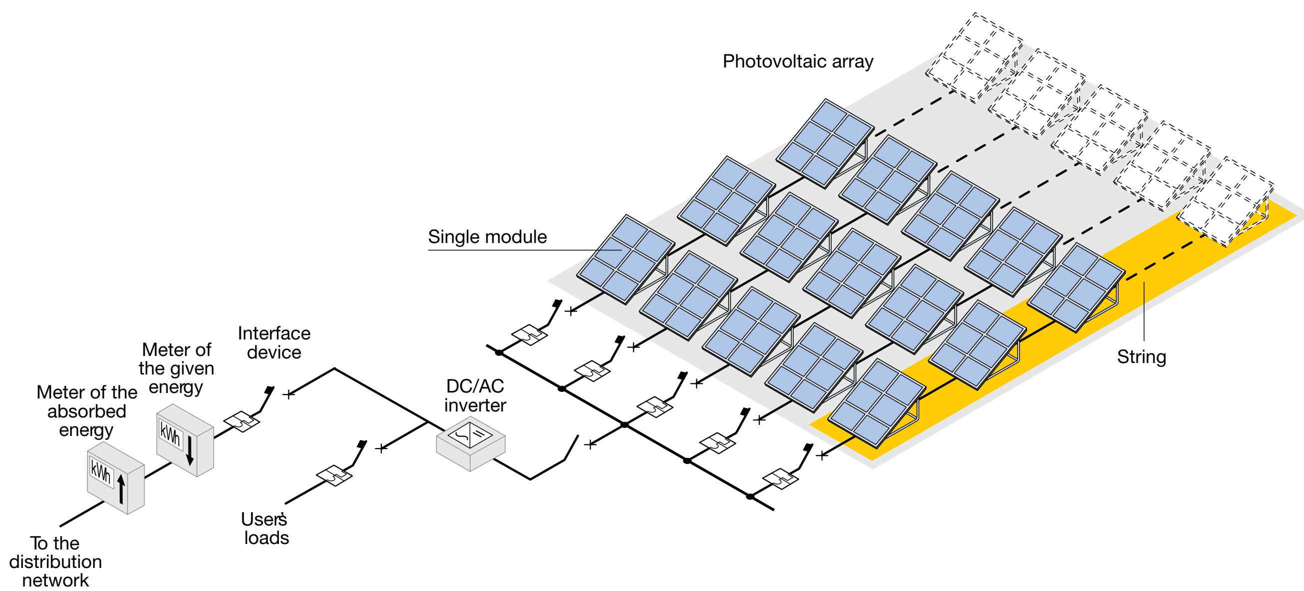


The general diagram of a grid-connected photovoltaic plant, unlike a stand alone one, may leave out the accumulator battery since the user is supplied by the network when solar irradiation is unavailable.

A photovoltaic plant of this type is made up of the following equipment:

- Photovoltaic array: the photovoltaic cells suitably interconnected and used for the conversion of sunlight energy into electrical energy;
- DC/AC inverter: to turn direct current into alternating current by controlling it and stabilizing its frequency and waveform;
- Interface device: a circuit breaker equipped with an undervoltage release or a molded case switch able to guarantee the total separation of the power generation units from the public utility network;
- Energy meters: to measure and invoice the energy supplied and absorbed by the distribution network.

The following figure shows the block diagram of a grid-connected photovoltaic plant.



Photovoltaic plants can supply currents from a few dozens of amperes (domestic applications and similar) up to several hundreds of amperes (service industry and small industry).

3.2 Electric traction

The particular torque/speed characteristic curve and the ease with which the speed itself can be regulated have led to the use of DC motors for electric traction.

Direct current supply also gives the great advantage of having the contact line consisting of a single conductor as the rails provide the return conductor.

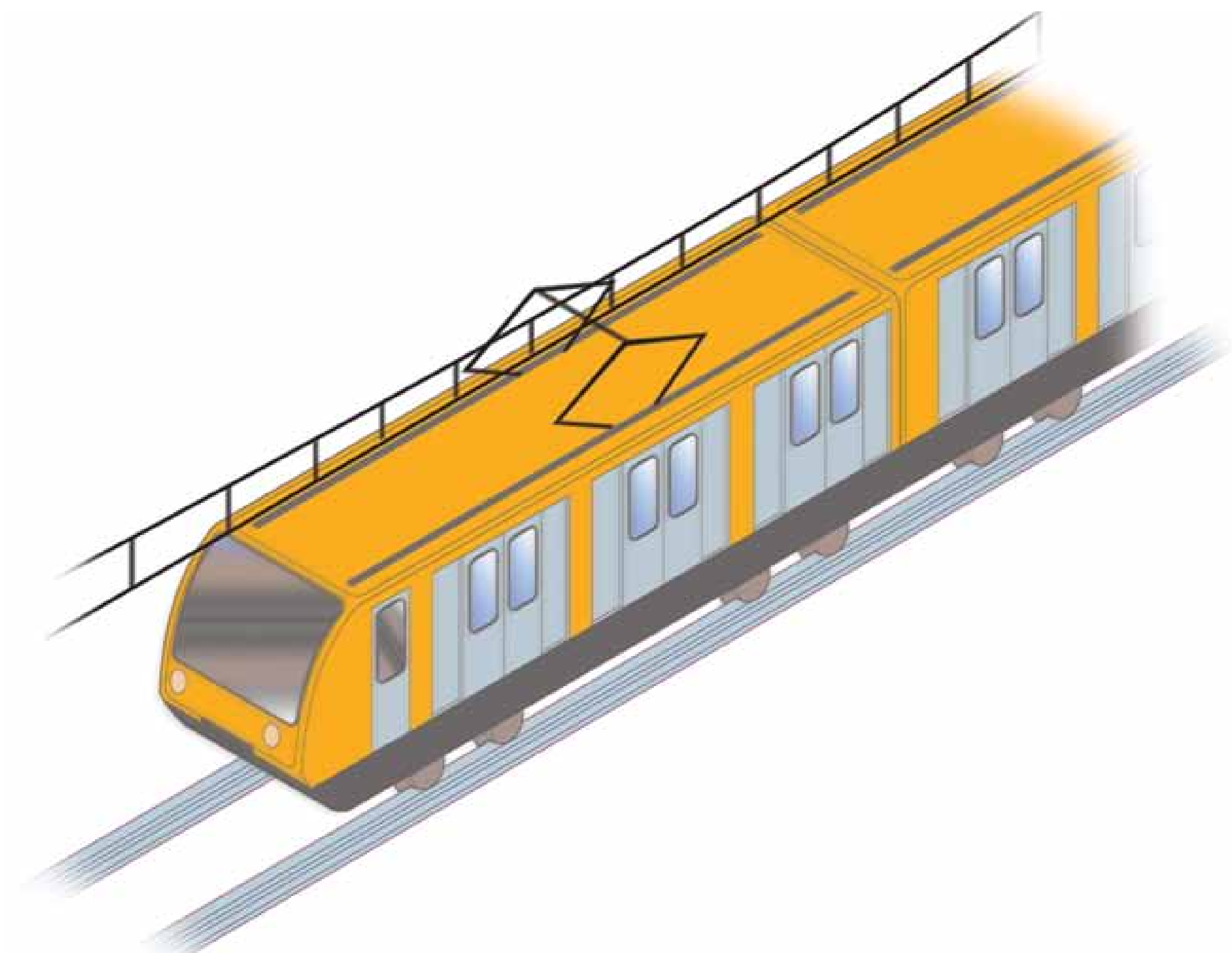
Currently, direct current is used primarily in urban transport like trolleybuses, trams and underground railways, with a supply voltage of 600 V or 750 V, up to 1000 V.

The use of direct current is not limited only to vehicle traction. Direct current represents a supply source for the auxiliary circuits on board vehicles as well. In this case, accumulator batteries are installed and constitute an auxiliary power supply source to be used if the external power supply should fail.

It is very important that this power supply be guaranteed since the auxiliary circuits may supply essential services such as air conditioning plants, internal and external lighting circuits, emergency brake systems or electrical heating systems.

The applications of circuit breakers in DC circuits for electric traction can be summarized as follows:

- Protection and operation of both overhead and rail contact lines;
- Protection of air compressors on board subway and train cars;
- Protection of distribution plants for services and signaling systems;
- Protection of DC supply sources (accumulator batteries)
- Protection and operation of DC motors.



3.3 Supply of emergency services or auxiliary services

Direct current is used (directly or indirectly through accumulator batteries) in those plants for which service continuity is fundamental.

Plants that cannot tolerate a power failure caused by a loss of energy need a ready-to-use supply source which is able to cover the time needed to start an emergency generating set.

Here are some examples of this type of user plant:

- industrial applications (process control systems);
- safety and emergency installations (lighting, alarms);
- hospital applications;
- telecommunication;
- applications in the data processing field (data centers, work stations, servers, etc.).

In these installations energy interruptions cannot be permitted. Therefore it is necessary to include systems to store energy when supplied that can give it back immediately if power fails.

Accumulator batteries are the most reliable electric energy source for the supply of such services, both directly in direct current (if allowed by the loads) as well as in alternating current by using an inverter able to develop an outgoing sinusoidal waveform starting from an incoming continuous one.

The above is carried out by uninterruptible power supply units (UPS):

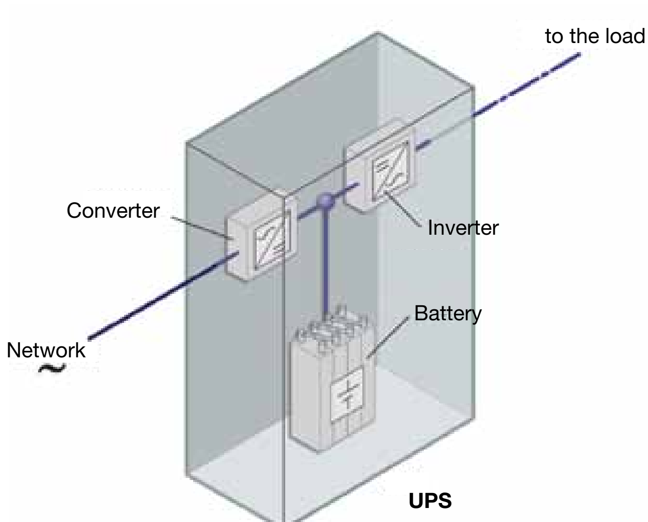


Figure 6
Principle diagram of a UPS

3.4 Particular industrial applications

The use of direct current is often required in many industrial applications such as:

- arc furnaces;
- electro welding plants;
- graphite manufacturing plants;
- metal production and refining plants (aluminum, zinc, etc.).

In particular, many metals such as aluminum are produced through an electrolytic process. Electrolysis is a process which converts electric energy into chemical energy. It is the opposite of what occurs in the battery process. In fact, with a battery, a chemical reaction is exploited to produce DC electric energy, whereas electrolysis uses DC electric energy to start a chemical reaction which otherwise would not occur spontaneously.

The procedure consists of immersing the metal to be refined, which acts as an anode, into a conductive solution, while a thin plate made of the same pure metal acts as a cathode. By applying a direct current from the rectifiers, it is possible to observe the metal atoms on the anode dissolve in the electrolytic solution and, at the same time, an equivalent quantity of metal settles on the cathode. In these applications, the service currents are very high, greater than 3000 A.

Another very common application is represented by galvanizing plants where processes are carried out to obtain the plating of metallic surfaces with other metals or alloys (chromium plating, nickeling, coppering, brass coating, galvanization zinc plating, tinning, etc.). The metallic piece to be plated usually acts as a cathode: by the current flow, the ions move from the anode and settle on the surface of the piece.

Also in these installations, the operations are carried out by an electrolytic cell with high service currents (up to 3000 A and over).

4. Generation

Direct current can be generated:

- by using batteries or accumulators where the current is generated directly through chemical processes;
- by the rectification of alternating current through rectifiers (static conversion);
- by the conversion of mechanical work into electrical energy using dynamos (production through rotating machines).

The following indications are not intended to be an exhaustive tool but are aimed at giving some brief information to help understand the main technologies for the production of direct current.

4.1 Storage batteries

A storage battery, or accumulator, is an electrochemical generator able to convert chemical energy into direct electrical current.

The structure of a storage battery is analogous to that of a normal battery. The main difference is that the discharging/ charging process for accumulator batteries is reversible. By using a DC generator, it is possible to restore the initial state of the electrodes which have been altered during discharge. This process cannot be carried out with a normal battery.

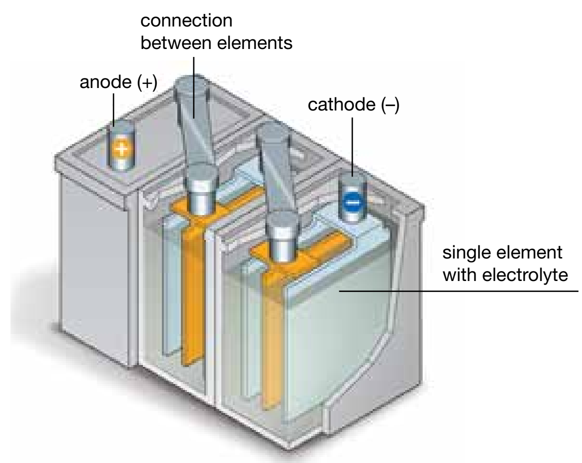
The main electrical characteristics of storage batteries are:

- Nominal voltage: potential difference existing between the negative and positive plates immersed in the electrolyte. The voltage value reported is usually related to each single cell (2V, 4V, 6V, 12V). To obtain the required voltage it is necessary to use several cells in series.
- Capacity: quantity of electricity which a battery can deliver for a defined time. Capacity is expressed in ampere-hours (Ah) and can be obtained by multiplying the value of the intensity of the discharge current (amperes) by the discharge time (hours).
- Internal resistance: the value of the internal resistance of the battery. This value is given by the manufacturer.
- Power: power which the battery can deliver. It is obtained from the average discharge voltage multiplied by the current and it is expressed in watts (W).

Structure of a storage battery

A stationary battery in its easiest form is made up of a recipient containing a sulfuric acid solution with distilled water (the electrolyte) where the two electrodes, positive and negative, are immersed. Each of them is formed of one or more plates connected in parallel. The terminals of these electrodes, where the loads are connected or where the connections in series or in parallel are made, are the anode (+) and the cathode (-).

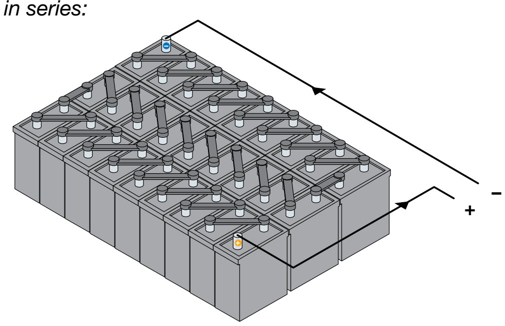
The following figure shows the possible structure of three elements connected in series:



In addition to these components, there are also current collectors and separators. The collectors direct the generated current towards the electrodes (discharging phase) and vice versa from the electrodes towards the elements (charging phase). The separators, usually made of insulating plates, avoid contact between anode and cathode to prevent short-circuits.

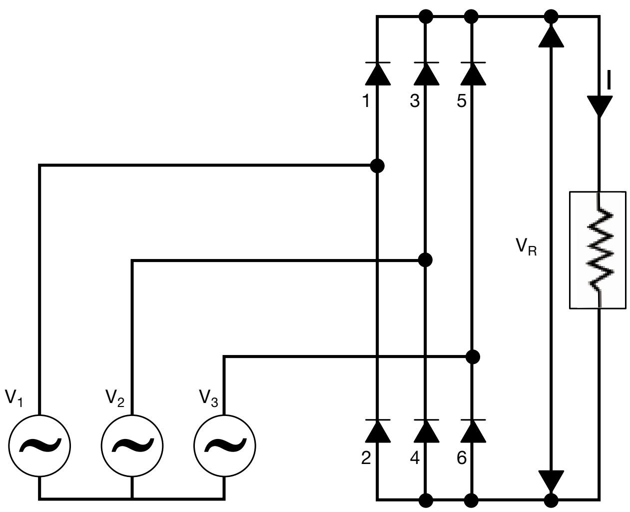
To obtain the voltage level needed, it is necessary to connect cells in series or in parallel to increase the voltage or the current level.

The following figure shows the possible structure of three elements connected in series:



4.2 Static conversion

Direct current can be supplied by using electronic devices (rectifiers) able to convert alternating current input into direct current output. These devices are also called static converters. The operating principle of rectifiers exploits the properties of the electronic components made of semiconductor materials (diodes, thyristors, etc.), their capacity of carrying currents only when positively polarized. The operating principle can be illustrated by the three-phase bridge rectifier (Graetz rectifier) shown in the figure:



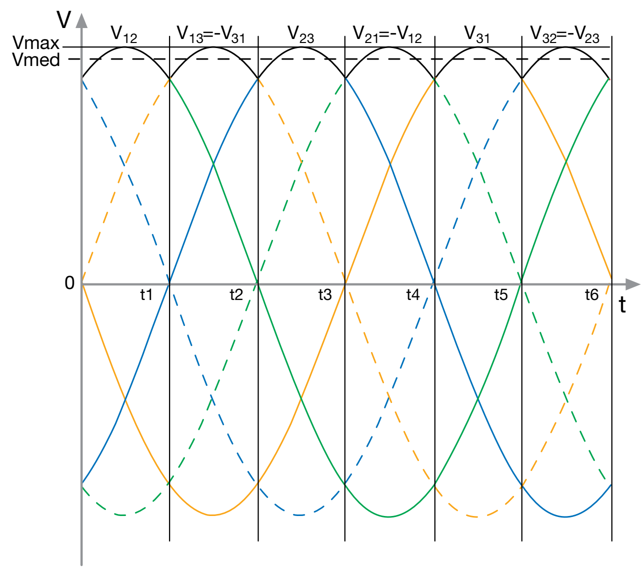
In this diagram it is possible to identify the three forward diodes (1,3,5) with the cathodes connected and the three backward diodes (2,4,6) which instead have the anodes connected.

Having established that a diode carries current only if positively polarized by supplying the bridge circuit with a set of three-phase voltages:

a) During the first sixth of a period, the line-to-line voltage V12 is the prevailing voltage; consequently, diodes 1 and 4 shall carry the current.

b) During the second sixth of a period, the line-to-line voltage V13 is the prevailing voltage; consequently, diodes 1 and 6 shall carry the current.

The same occurs in the subsequent fractions of a period. The voltage U_R at the terminals of the load R is the voltage represented by the envelope of the line-to-line voltages as shown in the figure.



The continuous lines represent the three sine waves of the line-to-line voltages (V_{12}; V_{23}; V_{31}), whereas the dotted lines represent the sine curves of the same voltages but reversed ($V_{13} = -V_{31}$; $V_{21} = -V_{12}$; $V_2 = -V_{23}$).

The resulting output voltage (represented by the continuous black line) takes the waveform of a ripple voltage with average value greater than zero.

Therefore, the direct current which flows through the resistance R is equal to:

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

The electronic circuit of a rectifier is more complex than the circuit just shown. A capacitor which "smooths" the output voltage is often present to reduce ripple. Thyristors can also be used instead of diodes. Thyristors, thanks to the possibility of controlling their switching-on time in relation to their switching instant, allow varying the output voltage value at the bridge. In this case, this device is referred to as a controlled bridge rectifier.

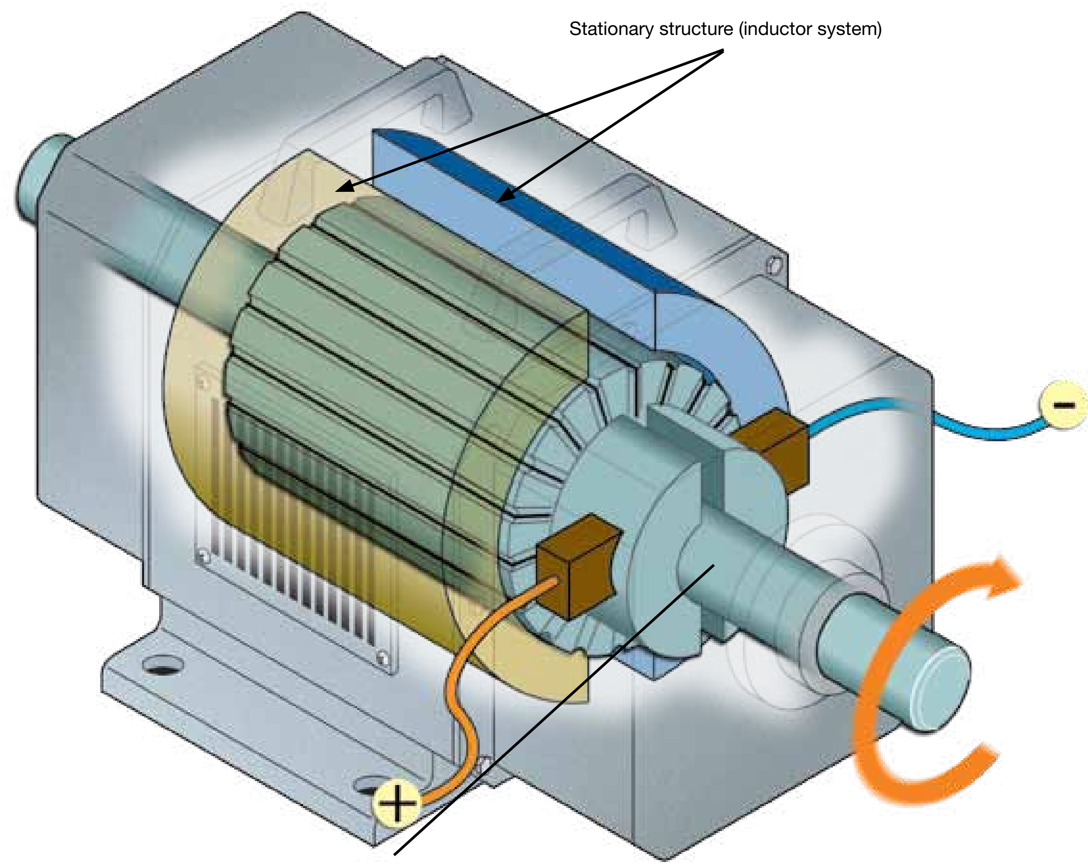
4.3 Dynamo

A dynamo is a direct current generator used to convert kinetic energy into direct electrical current.

As shown in the figure, these devices consist primarily of a stationary structure (called the inductor system), which generates a magnetic field, and of a moving part (called the rotor), made up of a system of conductors, which are "struck" by the magnetic field generated by the inductor.

Assume that a straight-line conductor (positioned along a cylinder rotating at constant speed), cutting the lines of force of the magnetic field, becomes the seat of an induced electromotive force (emf) variable in time. With more conductors suitably connected (so that the positive and negative values of the electromotive forces induced in the conductors are compensated), it is possible to obtain a resulting emf of constant value having always the same direction.

The following figure shows the structure of a dynamo:



5. Interrupting direct current

Interrupting direct current presents different problems than alternating current as the arc extinction is particularly difficult.

As Figure 7 shows, with alternating current there is natural passage of current through zero at each half cycle, which corresponds to the quenching of the arc during the circuit opening. With direct current there is no such natural passage and therefore the current must decrease to null to guarantee arc extinction (forcing the current passage through zero).

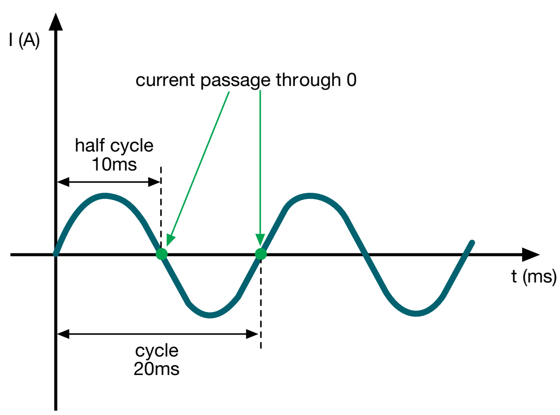


Figure 7
Alternating current

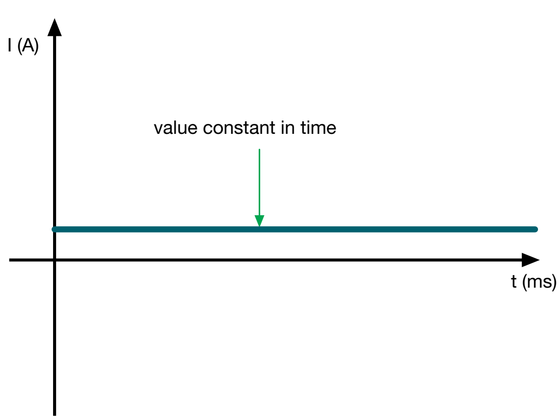
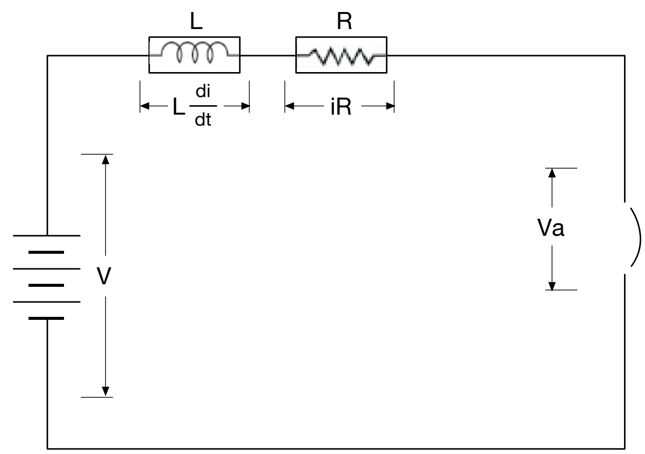


Figure 8
Direct current

To illustrate, reference the circuit shown in the figure:



In this case:

$$V = L\frac{di}{dt} + Ri + Va$$

where:

V is the rated voltage of the supply source

L is the inductance of the circuit

R is the resistance of the circuit

Va is the arc voltage.

The formula can be written also as:

$$L\frac{di}{dt} = V - Ri - Va \quad (1)$$

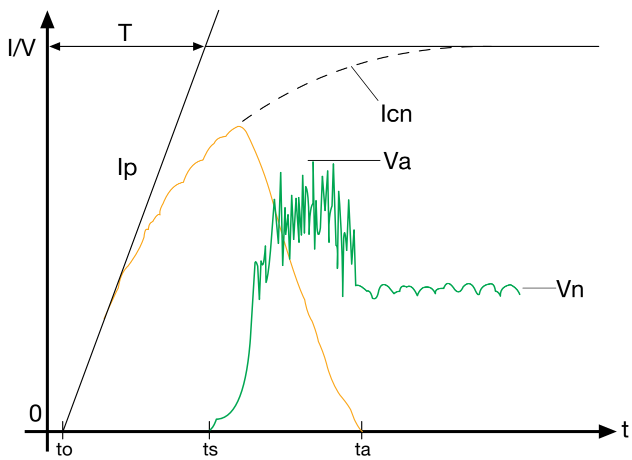
To guarantee arc extinction, it is necessary that:

$$\frac{di}{dt} < 0$$

This relationship shall be verified when the arc voltage (Va) is so high that the first part of the formula (1) becomes negative. It is possible to conclude that the extinction time of a direct current is proportional to the time constant of the circuit T = L/R and to the extinction constant.

The extinction constant is a parameter depending on the arc characteristic and on the circuit supply voltage.

The following figure shows an oscillogram of a short-circuit test carried out in the ABB power testing laboratories.



Ip = short-circuit making current

Icn = prospective short-circuit current

Va = maximum arc voltage

Vn = network voltage

T = time constant

to = instant of beginning of short-circuit

ts = instant of beginning of separation of the circuit breaker contacts

ta = instant of quenching of the fault current

When a short-circuit occurs in correspondence to the instant *to*, the current starts rising according to the time constant of the circuit. The circuit breaker contacts begin to separate, thus an arc starts from the instant *ts*.

The current keeps on rising for a short period after the beginning of contacts opening, then decreases depending on the increasing value of the arc resistance progressively introduced in the circuit. As can be seen in the graph, the arc voltage remains higher than the supply voltage of the circuit during the interruption. In correspondence of ***ta***, the current is completely quenched.

As the graph shows, the short-circuit current represented by the red line is extinguished without abrupt interruptions which could cause high voltage peaks.

As a consequence, to obtain a gradual extinction (the graph represents the descent of Ip), it is necessary to cool and extend the arc, so that increasing arc resistance is inserted in the circuit (with the consequent increase of the arc voltage Va). This extinction involves energetic phenomena which depend on the voltage level of the plant (Vn) and require circuit breakers to be connected in series to optimize performance during short circuit conditions. The higher the number of contacts opening the circuit, the higher the breaking capacity of the circuit breaker.

This means that when the voltage rises it is necessary to increase the number of current interruptions in series, so that a rise in the arc voltage is obtained and consequently a number of poles for breaking operations proportional to the fault level.

To summarize: in order to guarantee breaking of a short-circuit current in a DC system it is necessary to employ circuit breakers that can ensure:

- rapid tripping with adequate breaking capacity;
- high fault current limiting capacity;
- overvoltage reduction effect.

6. Types of DC networks

As previously explained, in order to break a short-circuit current in a DC system, it is necessary to connect the circuit breaker poles in a suitable way.

To do this, it is necessary to know the grounding type of the plant.

This information allows any possible fault condition to be evaluated and consequently the most suitable connection type to be selected (short-circuit current, supply voltage, rated current of the loads, etc.).

The following pages shall give the following for each network type:

- Description of the network
- Fault types

(Pole connection and the relevant breaking capacity discussed in Chapter 7: ”Choice of the protective device”)

6.1 Network insulated from ground

This type of network represents the easiest connection to carry out as no connection between the battery terminals and ground is provided.

These types of systems are widely used in those installations where grounding is difficult, but above all where service continuity is required after an initial ground fault.

However, because no terminals are grounded, the risk with this connection is that dangerous overvoltages could occur between an exposed conductive part and ground due to static electricity. These hazards can be limited by overload dischargers.

Common solution

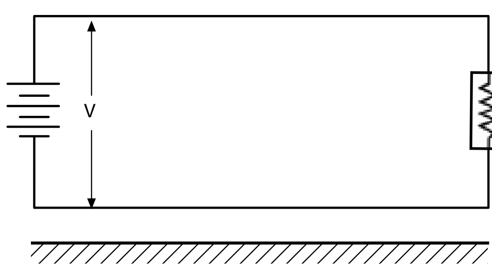


Figure 9
Network insulated from ground

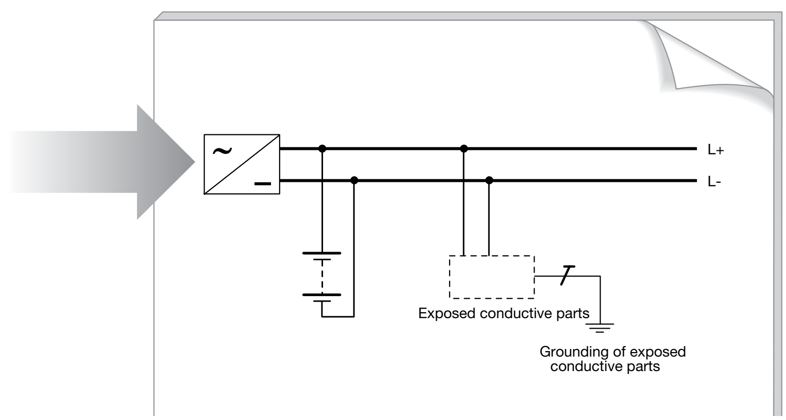
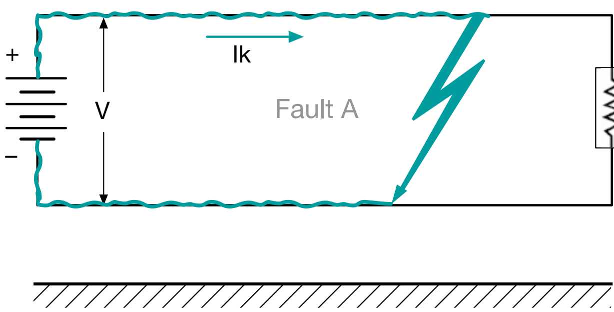


Figure 10

Fault types in a network insulated from ground

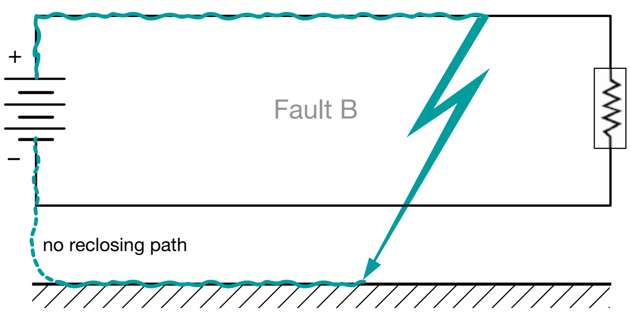
Fault A:

The fault between the two terminals is a short-circuit current fed by the full voltage U. The breaking capacity of the circuit breaker shall be sized according to the short-circuit current relevant to such fault.



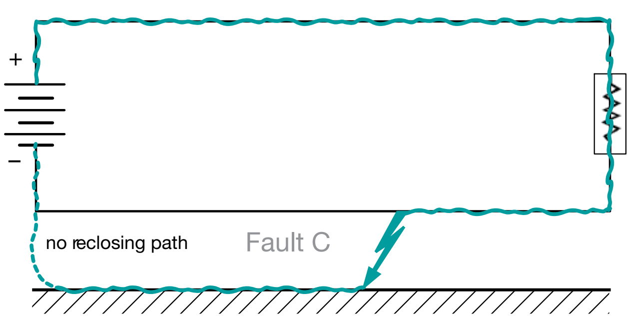
Fault B:

The fault between a terminal and ground has no consequences to plant operation since such current has no reclosing paths and consequently it cannot circulate.



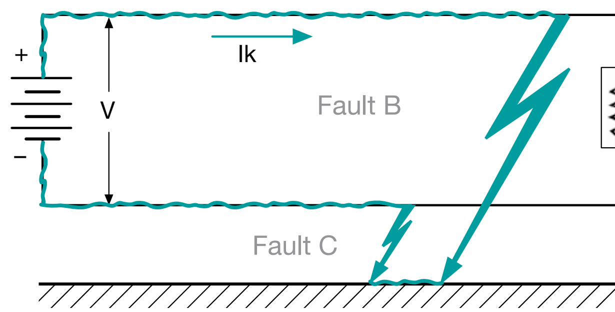
Fault C:

Like fault B, this fault between a terminal and ground has no consequences to plant operation.



Double fault (fault B + fault C):

In the case of a double fault as shown in the figure, the current might circulate and find a reclosing path. Therefore, it is advisable that a device capable of signaling a ground fault or a decrease of the insulation to ground of a terminal be installed in the plant. In this way, the fault is eliminated in good time to prevent the occurrence of a second ground fault on the other terminal. The consequent total inefficiency of the plant due to the tripping of the circuit breaker caused by the short-circuit generated on the two terminals to ground is also avoided.



Conclusion:

With this type of network, the fault type which affects the version and connection of the circuit breaker poles is fault A (between the two terminals).

In an insulated network it is necessary to install a device able to signal the presence of the first ground fault so that it can be eliminated to avoid any problem arising from a second ground fault. In fact, in case of a second ground fault, the circuit breaker could have to interrupt the fault current with the full voltage applied to a single terminal and consequently with an insufficient arc voltage (see figure).

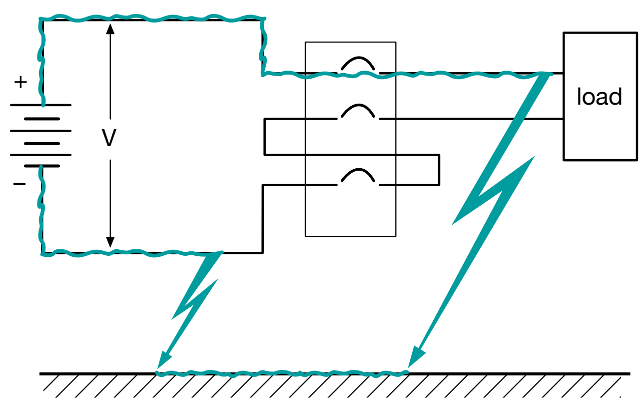


Figure 11
Double fault in a network insulated from ground

6.2 Network with one terminal grounded

This type of network is obtained by connecting one terminal to ground.

This connection type allows the overvoltages due to static electricity to be discharged to ground.

Common solution

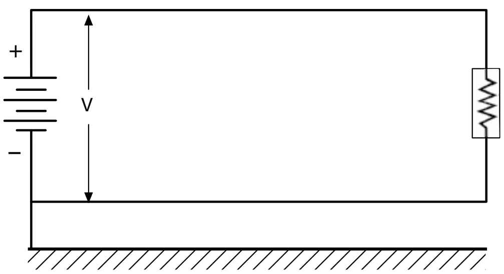


Figure 12
Network with one terminal grounded

Figure 13

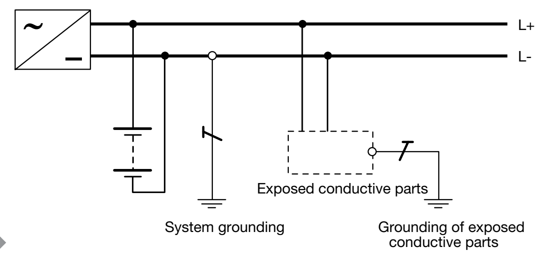
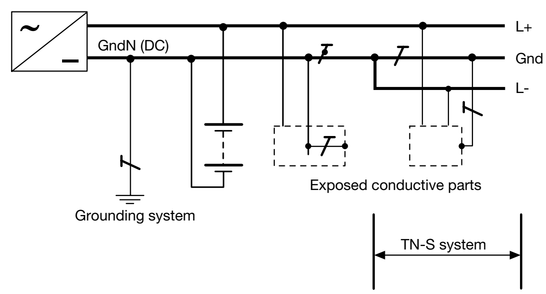


Figure 14

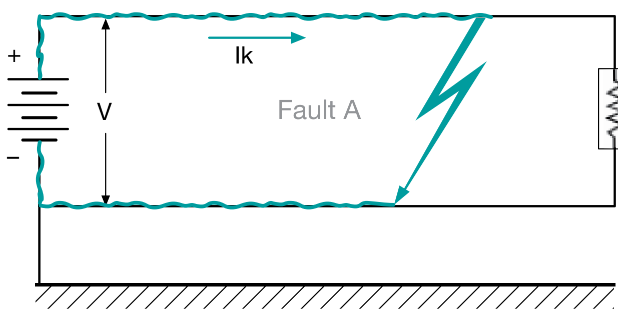


Fault types in a network with one terminal grounded

In the following examples the grounded terminal is the negative one.

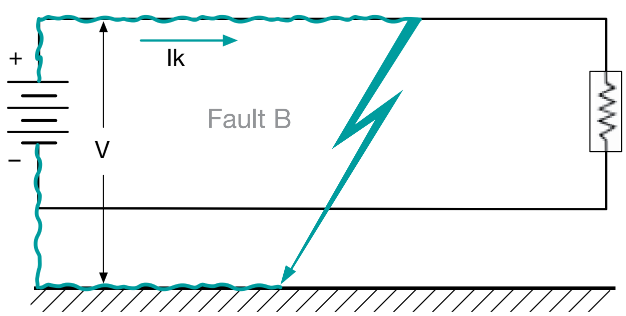
Fault A:

The fault between the two terminals is a short-circuit current fed by the full voltage V. The breaking capacity of the circuit breaker shall be sized according to the short-circuit current relevant to such fault.



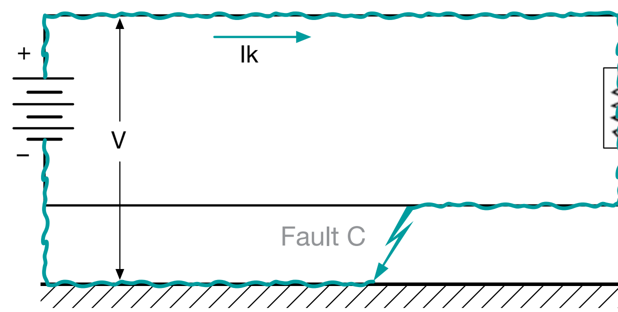
Fault B:

The fault on the non-grounded terminal sets up a current involving the overcurrent protections as a function of the soil resistance.



Fault C:

The fault on the grounded terminal sets up a current which affects the overcurrent protections as a function of the soil resistance. This current presents an extremely low value because it depends on the impedance of the soil and the V is next to zero because the voltage drop on the load further reduces its value.



Conclusions

With this type of network, the fault type which affects the version of the circuit breaker and the connection of the poles is fault A (between the two terminals). However it is also necessary to take into consideration the fault between the non-grounded terminal and the ground itself (fault B) because as described above, a current could flow at full voltage. For this reason, all the circuit breaker poles necessary for protection must be connected in series on the non-grounded terminal.

6.3 Network with the middle point of the supply source connected to ground

This type of network is obtained by connecting the middle point of the battery to ground.

This type of connection reduces the value of static overvoltages, which could otherwise be present at full voltage in an insulated plant.

The main disadvantage of this connection, if compared with other types, is that a fault between a terminal and ground gives rise to a fault current at a voltage $\frac{V}{2}$.

Common solution

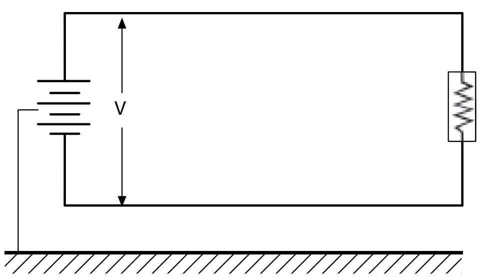


Figure 15
Network with the middle point connected to ground

Figure 16

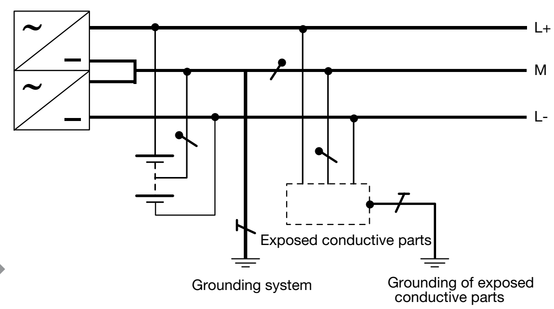
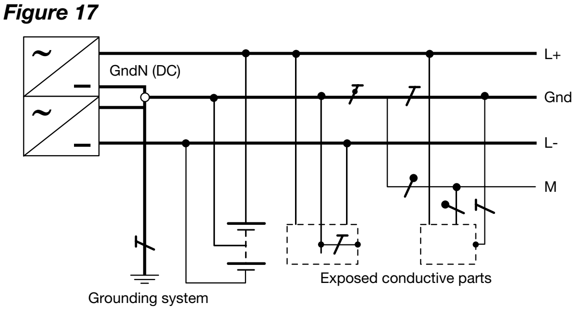


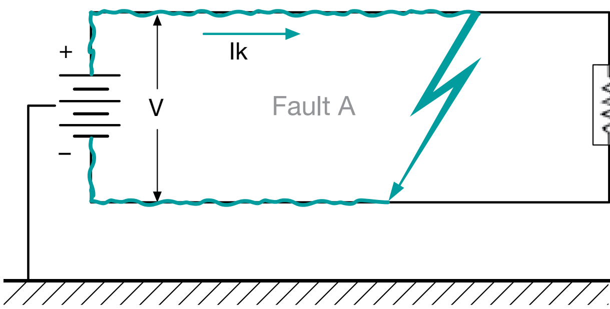
Figure 17



Fault types in a network with the middle point connected to ground

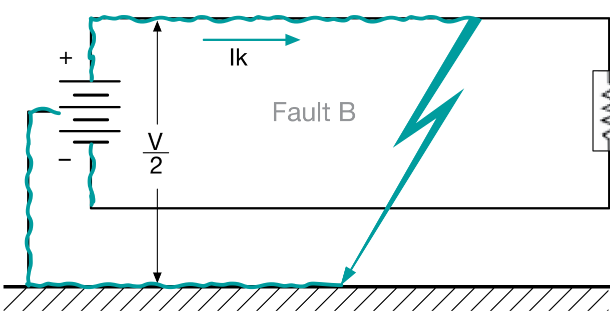
Fault A:

The fault between the two terminals is a short-circuit current fed by the full voltage V. The breaking capacity of the circuit breaker shall be sized according to the short-circuit current relevant to such a fault.



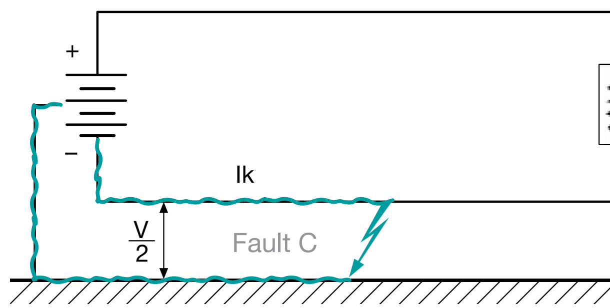
Fault B:

The fault between the terminal and ground sets up a short-circuit current lower than the fault between the two terminals as it is supplied by a voltage equal to $\frac{V}{2}$ depending on the soil resistance.



Fault C:

In this case, the fault is analogous to the previous case but it involves the negative terminal.



Conclusion

With this type of network, the fault which affects the version of the circuit breaker and the connection of the poles is fault A (between the two terminals). However, the fault between a terminal and ground should also be taken into consideration because a current could flow at a voltage equal to:

$$\frac{V}{2}$$

In a network with the middle point of the supply connected to ground, the circuit breaker must be connected on both terminals.

7. Choice of the protective device

For the correct sizing of a circuit breaker in a direct current network, some electrical parameters which characterize the device itself must be evaluated.

Here is a short description of these parameters, which are discussed in the following pages.

Rated operational voltage Ve

This represents the value of the application voltage of the equipment and to which all the other equipment parameters are referred.

Rated uninterrupted current Iu

This represents the value of current which the equipment can carry for an indefinite time (uninterrupted duty). This parameter is used to define the size of the circuit breaker.

Rated current In

This represents the value of current of the trip unit mounted on the circuit breaker and determines the protection characteristic of the circuit breaker itself according to the available settings of the trip unit.

This current is often referred to the rated current of the load protected by the circuit breaker itself.

Rated ultimate short-circuit breaking capacity Icu

The rated ultimate short-circuit breaking capacity of a circuit breaker is the maximum short-circuit current value which the circuit breaker can break twice (in accordance with the sequence O – t – CO) at the corresponding rated operational voltage. After the opening and closing sequence the circuit breaker is not required to carry its rated current.

Rated service short-circuit breaking capacity Ics

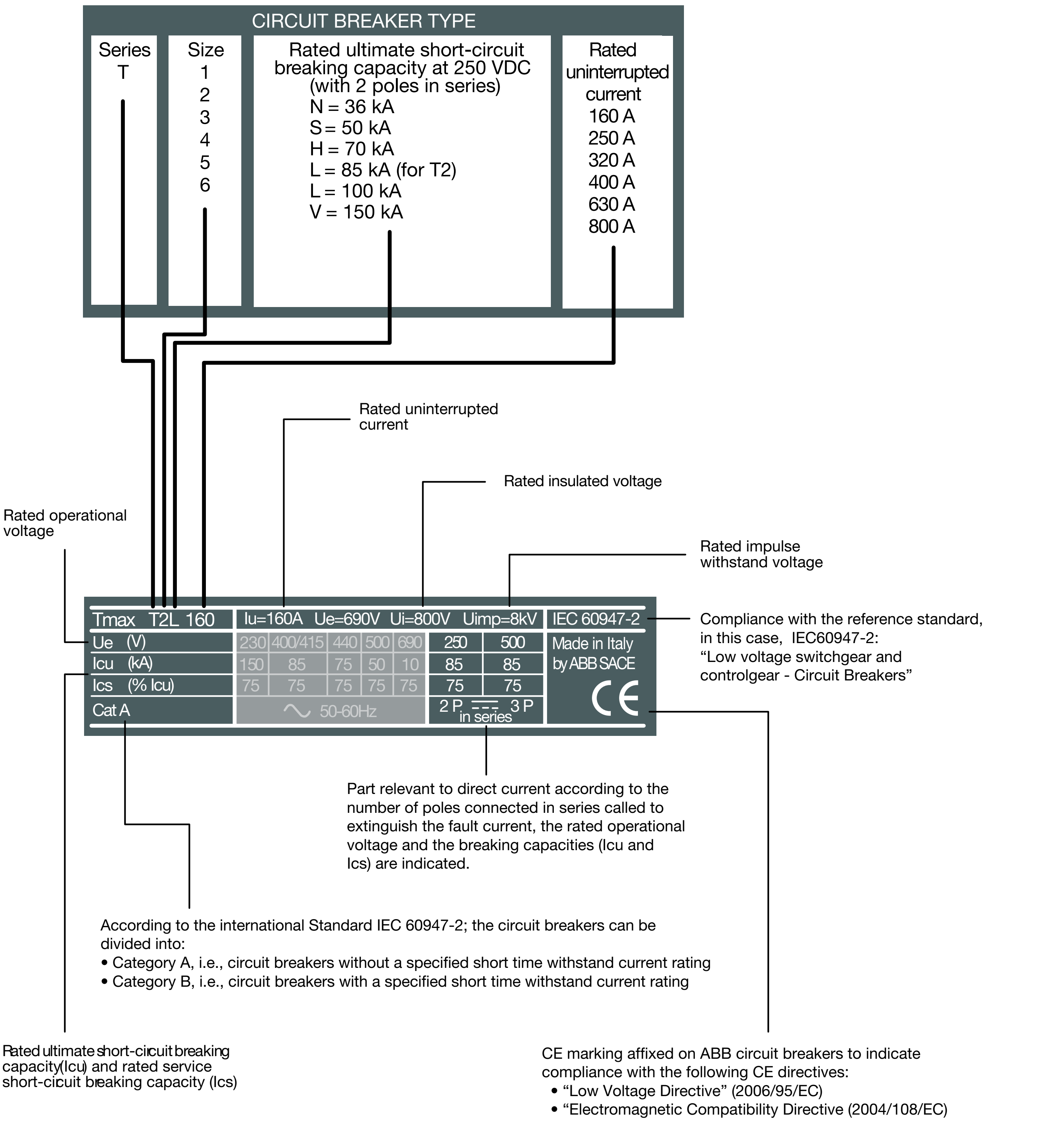
The rated service short-circuit breaking capacity of a circuit breaker is the maximum short-circuit current value which the circuit breaker can break three times, in accordance with a sequence of opening and closing operations (O - t - CO - t – CO), at a defined rated operational voltage (Ve) and at a defined time constant (for direct current). After this sequence the circuit breaker is required to carry its rated current.

Rated short-time withstand current Icw

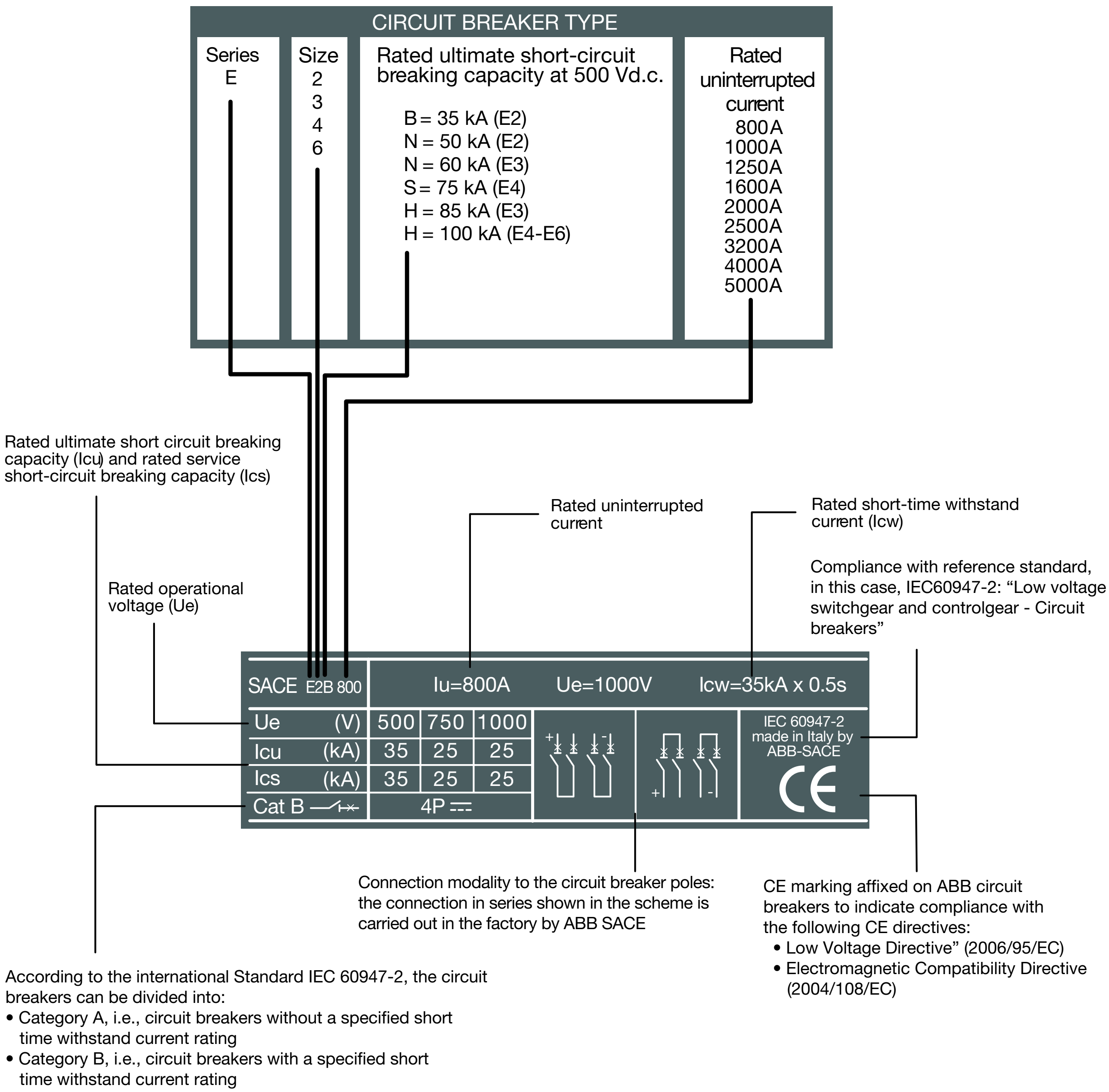
The rated short-time withstand current is the current that the circuit breaker in the closed position can carry during a specified short time under prescribed conditions of use and behavior. The circuit breaker shall be able to carry this current during the associated short-time delay in order to ensure discrimination between the circuit breakers in series.

Rating plates of the circuit breakers

Tmax molded-case circuit breakers for direct current



Emax air circuit breakers for direct current



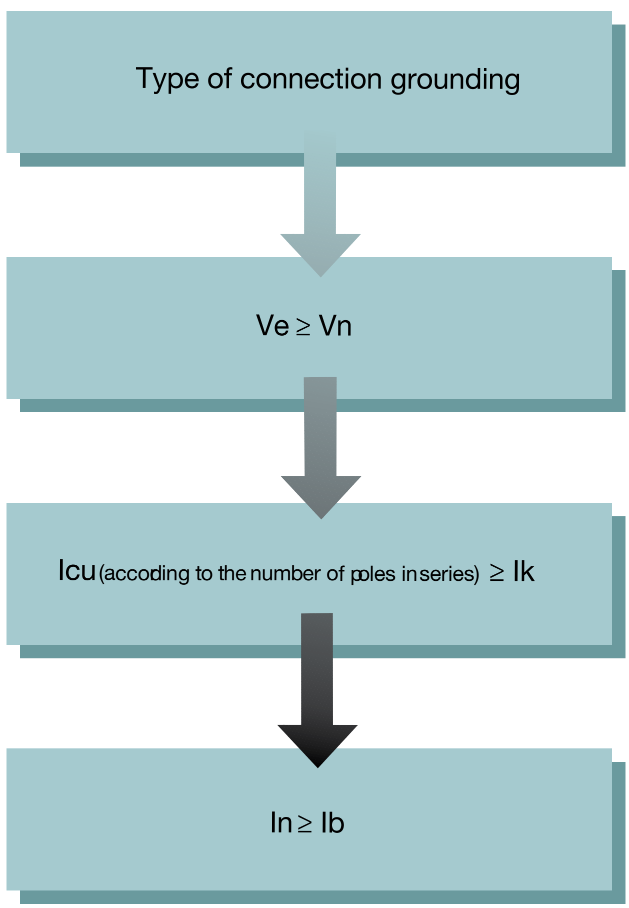
Sizing circuit breakers

In the previous pages, the main electrical characteristics needed to choose the correct circuit breaker have been defined so that protection of the plant is guaranteed.

To size the circuit breaker, it is necessary to know the following characteristics of the network:

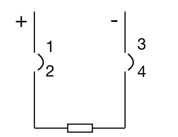
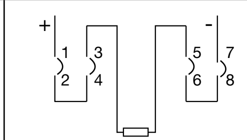
- The type of network (see Chapter 6), to define the connection of the circuit breaker poles according to the possible fault conditions;
- The rated voltage of a plant (Vn), to define the operational voltage (Ve) depending on the pole connection by verifying the relation: Vn≤ Ve;
- The short-circuit current at the installation point of the circuit breaker (Ik), to define the circuit breaker version (depending on the connection of the poles) by verifying the relation Ik ≤ Icu (at the reference rated operational voltages Ve);
- The rated current absorbed by the load (Ib), to define the rated current (In) of the thermal-magnetic trip unit or of the DC electronic trip unit by verifying the relation Ib≤ In.

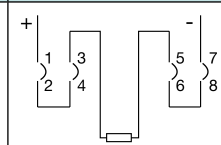
The following diagram summarizes the choices for a correct sizing of the circuit breaker in relation to the characteristics of the plant.



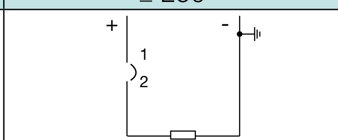
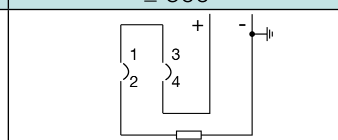
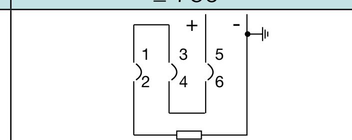
The values given in the following tables indicate the performance of circuit breakers under the heaviest fault conditions for the type of network under consideration (see Chapter 6: "Types of DC networks").

Tables 1-2. Pole connection (for IEC MCBs type S280 UC-S800S UC) in an insulated network

UNGROUNDED NETWORK			
Rated voltage (Vn)		≤ 500	≤ 750
Protection + isolation function			
S800S UC	In = 10…125 A	50	50

UNGROUNDED NETWORK		
Rated voltage (Un)		≤ 440
Protection + isolation function		
S280 UC	In = 0,5…2 A	50
	In = 3…40 A	6
	In = 50…63 A	4,5

Tables 3-4. Pole connection (for IEC MCBs type S280 UC-S800S UC) in a network with one terminal grounded

NETWORK WITH ONE TERMINAL GROUNDED				
Rated voltage (Vn)		≤ 250	≤ 500	≤ 750
Protection function				
S800S UC	In = 10…125 A	50	50	50

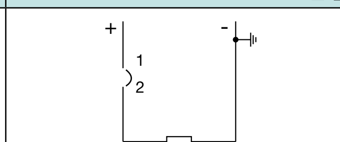
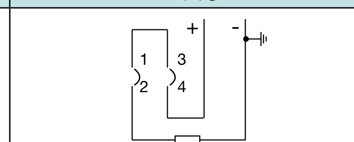
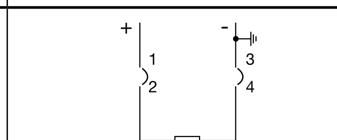
NETWORK WITH ONE TERMINAL GROUNDED				
Rated voltage (Vn)		≤ 220		≤ 440
Protection function				
Protection + isolation function				
S280 UC	In = 0,5…2 A	50	50	50
	In = 3…40 A	6	10	6
	In = 50…63 A	4,5	6	4,5

Table 5. Connection of poles (for IEC S280 UC MCBs) in a network with the middle point grounded

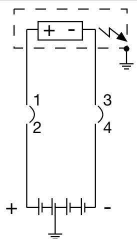
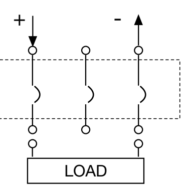
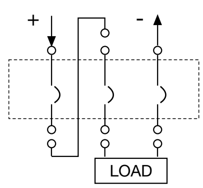
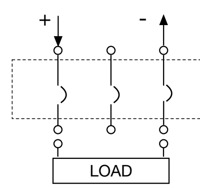
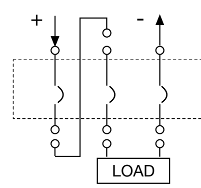
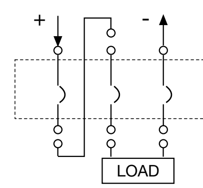
NETWORK WITH THE MIDDLE POINT CONNECTED TO GROUND		
Rated voltage (Vn)		≤ 220
Protection + isolation function		
S280 UC	In = 0,5…2 A	50
	In = 3…40 A	10
	In = 50…63 A	6

Table 6. Connection of poles (for IEC Tmax MCCBs) in an insulated network ①

UNGROUNDED NETWORK						
Rated voltage (Vn)		≤ 250		≤ 500		≤ 750
Protection + isolation function						
T1 160	B	16	20		16	
	C	25	30		25	
	N	36	40		36	
T2 160	N	36	40		36	
	S	50	55		50	
	H	70	85		70	
	L	85	100		85	
T3 250	N	36	40		36	
	S	50	55		50	
T4 250/320 T5 400/630	N	36		25		16
	S	50		36		25
	H	70		50		36
	L	100		70		50
	V	150		100		70
T6 630/800	N	36		20		16
	S	50		35		20
	H	70		50		36
	L	100		65		50

The positive pole (+) can be inverted with the negative pole (-).

① with these types of pole connection the possibility of a double fault to ground is considered unlikely (see Chapter 6: “Types of DC networks”)

Table 7. Connection of poles (for IEC Tmax MCCBs) in a network with one terminal grounded (in the considered connections, the grounded terminal is negative)

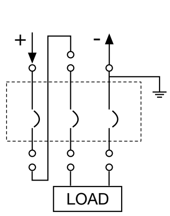
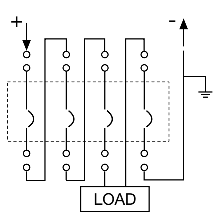
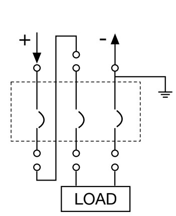
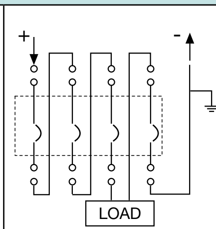
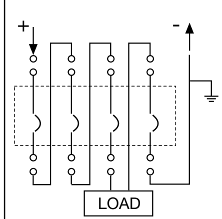
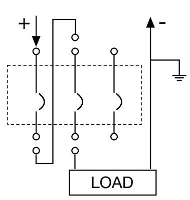
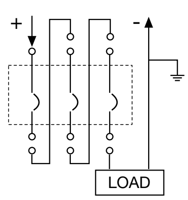
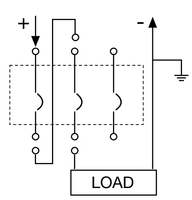
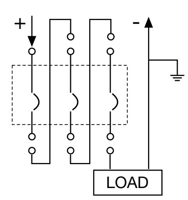
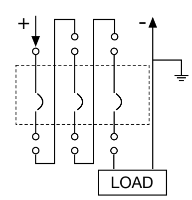
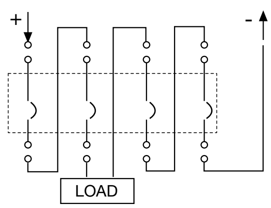
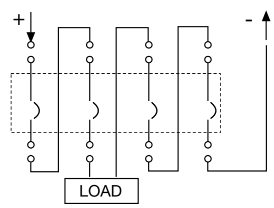
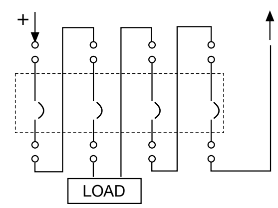
NETWORK WITH ONE TERMINAL GROUNDED						
Rated voltage (Vn)		≤ 250		≤ 500		≤ 750
Protection + isolation function						
Protection function						
T1 160	B	16	20		16	
	C	25	30		25	
	N	36	40		36	
T2 160	N	36	40		36	
	S	50	55		50	
	H	70	85		70	
	L	85	100		85	
T3 250	N	36	40		36	
	S	50	55		50	
T4 250/320 T5 400/630	N	36		25		16
	S	50		36		25
	H	70		50		36
	L	100		70		50
	V	150		100		70
T6 630/800	N	36		20		16
	S	50		35		20
	H	70		50		36
	L	100		65		50

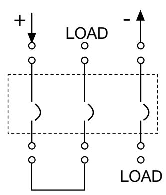
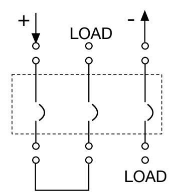
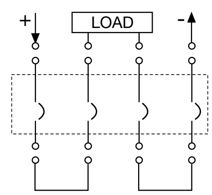
Table 8. Connection of poles (for IEC Tmax MCCBs) in a network with the middle point grounded

NETWORK WITH THE MIDDLE POINT CONNECTED TO GROUND				
Rated voltage (Vn)		≤ 250 ①	≤ 500 ②	≤ 750
Protection + isolation function				
T1 160	B	20	16	
	C	30	25	
	N	40	36	
T2 160	N	40	36	
	S	55	50	
	H	85	70	
	L	100	85	
T3 250	N	40	36	
	S	55	50	
T4 250/320 T5 400/630	N	36	25	16
	S	50	36	25
	H	70	50	36
	L	100	70	50
	V	100	100	70
T6 630/800	N	36	20	16
	S	50	35	20
	H	70	50	36
	L	100	65	50

① for the use of three-phase circuit breakers please ask ABB
② for the use of three-phase circuit breakers (T4-T5-T6) please ask ABB

The values given in the following tables indicate the performances of circuit breakers under the heaviest fault conditions for the type of network under consideration (see Chapter 6: "Types of networks".)

Tables 9-10. Pole connection for (ACBs type Emax) in an insulated network and with one terminal grounded (in the considered connections, the grounded terminal is negative)

INSULATED NETWORK ①				
Rated voltage (Vn)		≤ 500	≤ 750	≤ 1000
Protection + isolation function		3-pole circuit breaker 	3-pole circuit breaker 	4-pole circuit breaker 
E2	B	35	25	25
	N	50	35	35
E3	N	60	50	35
	H	85	65	65
E4	S	75	65	50
	H	100	85	65
E6	H	100	85	65

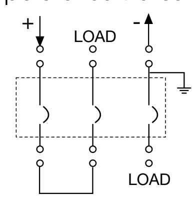
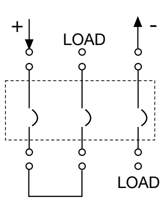
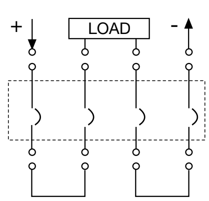
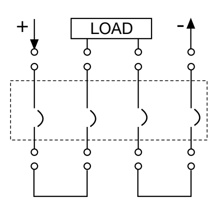
NETWORK WITH ONE TERMINAL GROUNDED		
Rated voltage (Vn)		< 500 ②
Protection + isolation function		3-pole circuit breaker 
E2	B	35
	N	50
E3	N	60
	H	85
E4	S	75
	H	100
E6	H	100

Table 11. Pole connection for (ACBs type Emax) in a network with the middle point grounded

NETWORK WITH THE MIDDLE POINT CONNECTED TO GROUND				
Rated voltage (Vn)		< 500	< 750	≤ 1000
Protection + isolation function		3-pole circuit breaker 	4-pole circuit breaker 	4-pole circuit breaker 
E2	B	35	25	25
	N	50	35	35
E3	N	60	50	35
	H	85	65	65
E4	S	75	65	50
	H	100	85	65
E6	H	100	85	65

① With these types of pole connection the possibility of a double fault to ground is considered unlikely (see Chapter 6: "Types of DC networks")
② For higher voltages please ask ABB

The following tables show the pole connections of Tmax molded case switches according to the installation voltage. The connections shown in the table shall be carried out by the customer.

Table 12. Pole connection for IEC Tmax molded case switches

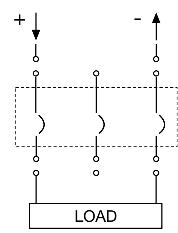
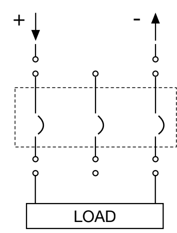
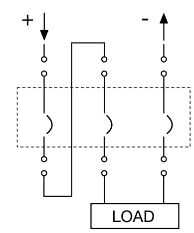
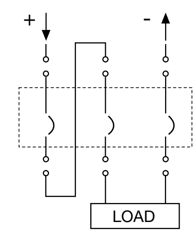
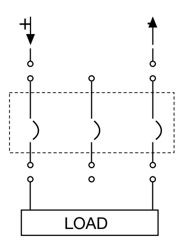
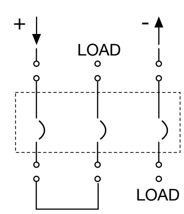
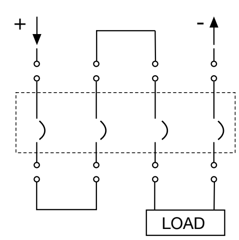
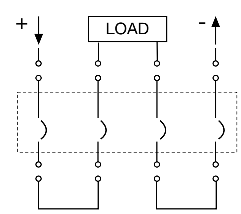
Rated voltage (Vn)	≤ 250	≤ 500		≤ 750
Pole connection				
T1D 160	■	–	■	–
T3D 250	■	–	■	–
T4D 250/320	■	■	–	■
T5D 400/630	■	■	–	■
T6D 630/800/1000	■	■	–	■
T7D 1000/1250/1600	■	■	■	■

Table 13. Pole connection for IEC Emax switch disconnectors

Rated voltage (Vn)	≤ 500	≤ 750	≤ 1000	
Pole connection				
X1-E1…E6 / MS	■	–	–	–
E1…E6 E/ MS	■	■	■	■

Tmax molded case circuit breakers

Example:

Characteristics of the plant:

- Type of network: one terminal grounded (the negative one)
- Network voltage: Vn = 250 VDC
- Rated voltage absorbed by the loads (Ib): 450 A
- Short-circuit current: 40k A

Choice of the circuit breaker

According to the indications on page 23, to correctly size the circuit breaker, the following must be complied with:

- Ve ≥ Vn
- Icu ≥ Ik
- In ≥ Ib

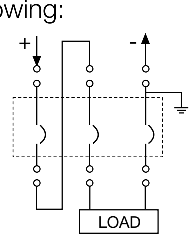
With reference to the type of network, the suitable table shall be identified from tables 6-7-8. In this case, the table for a network with one grounded terminal (Table 7) shall be chosen.

The column with the performances for a network voltage higher than or equal to the plant voltage shall be identified, in this example Vn≥ 250 VDC.

The load current is used to identify the row of the table for circuit breakers with uninterrupted rated current Iu higher than or equal to the load current. In this case, a Tmax T5 with Iu=600 A circuit breaker can be used.

The interrupting rating is chosen according to the relation Icu≥Ik. In this example, since Ik=40 kA, version S can be used.

With these limitations, two possible schemes for the pole connection can be identified. Assuming that the grounded terminal is to be disconnected also, the connection scheme to be used is the following:



A 500 A T5S thermal magnetic circuit breaker shall be chosen. To summarize, a three-pole thermal magnetic T5S600 TMA 500 circuit breaker shall be used connected as shown in the figure, i.e. with two poles in series on the terminal insulated from ground and the other one connected to the grounded terminal.

Emax air circuit breakers

Example:

Characteristics of the plant:

- Type of network: insulated
- Network voltage: Vn = 500 VDC
- Rated voltage absorbed by the loads (Ib): 1800 A
- Short-circuit current: 45 kA

Choice of the circuit breaker

According to the indications on page 23, to correctly size the circuit breaker, the following must be complied with:

- Ve ≥ Vn
- Icu ≥ Ik
- In ≥ Ib

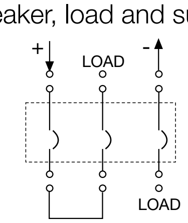
With reference to the type of network, the suitable table shall be identified from tables 9-10-11. In this case, the table for an insulated network (Table 9) shall be chosen.

The column with the performances for a network voltage higher than or equal to the plant voltage shall be identified, in this example Vn≥ 500 VDC.

According to the column considered, the circuit breaker which would seem suitable under short-circuit conditions is an E2N (N=50kA>Ik). However, according to the table of the rated uninterrupted current (page 39), it is necessary to pass to an E3N since it has Iu= 2000 A which is higher than the current absorbed by the loads. In this way, the third relationship is complied with.

Therefore the suitable circuit breaker is a three-pole E3N 2000 circuit breaker with PR1122-123/DC In=2000 A. The connection of the poles is carried out in the factory by ABB.

The solution of the table shows the connections between three-pole circuit breaker, load and supply source.



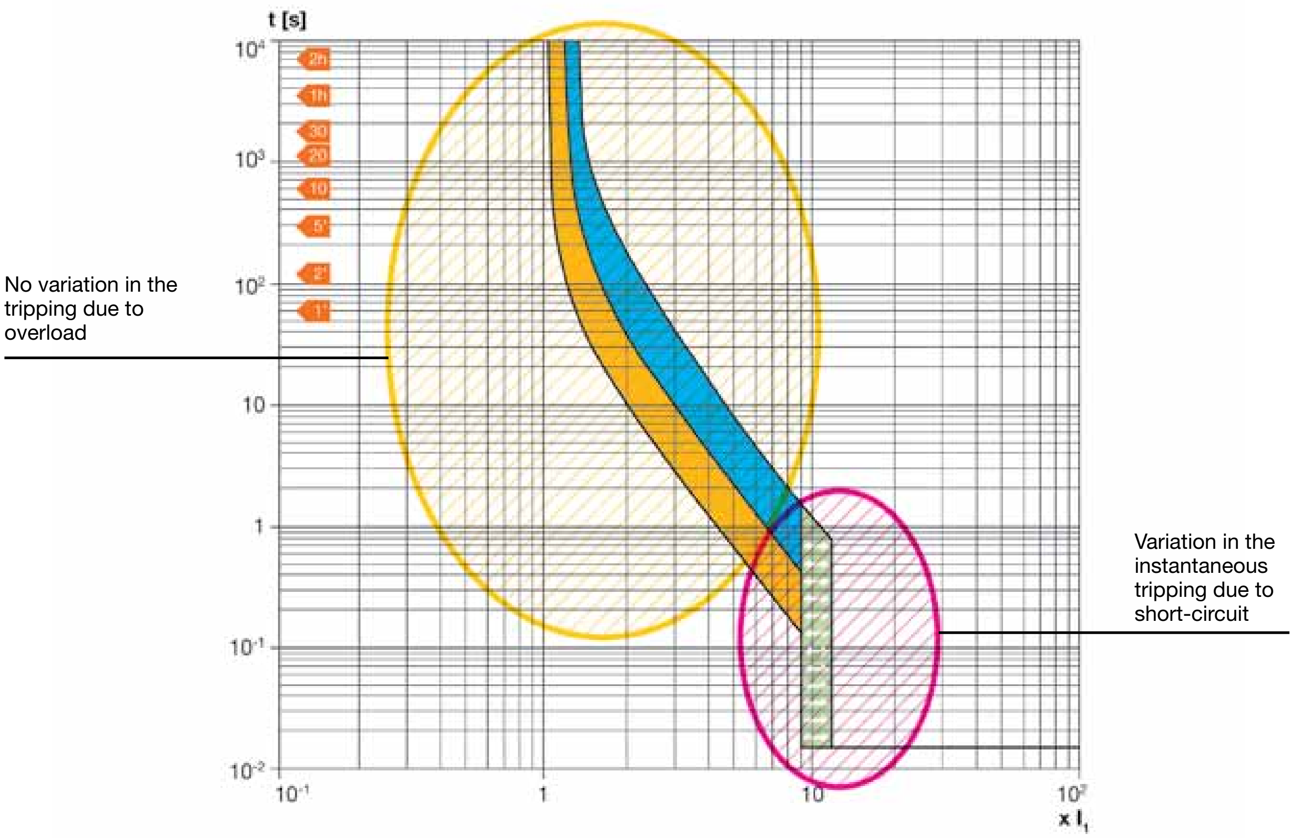
8. Use of alternating current equipment in direct current

8.1 Variation of the magnetic tripping

The thermal magnetic trip units fitted to AC circuit breakers are also suitable for use with direct current.

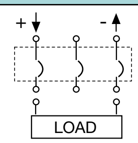
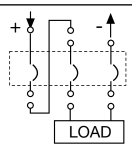
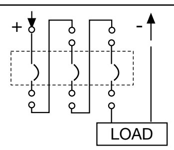
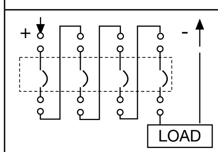
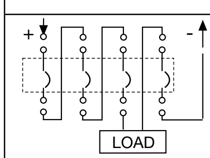
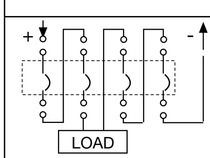
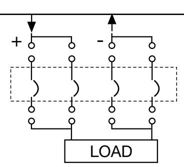
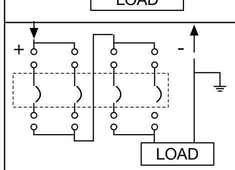
The tripping characteristics of the thermal protection do not change since the bimetal strips of the trip units are influenced by the heating caused by current flow. It does not matter whether alternating or direct. The bimetal strips are sensitive to the r.m.s. value.

Due to ferromagnetic phenomena, the instantaneous tripping occurs at a different value than in alternating current. The green area in the figure shows the shifting of the magnetic tripping. A coefficient called km, a function of the circuit breaker and of the connection type of its poles, allows the DC instantaneous trip threshold to be derived starting from the relevant value in alternating current. Therefore this coefficient is to be applied to the threshold I3.



There is no derating for IEC Emax equipped with the DC PR122-PR123/DC electronic trip units because the trip times comply with the curve set on the electronic trip unit.

Table 14 Coefficient km according to the connection modality of the circuit breaker poles

Connection modality	Circuit breaker					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
	1.3	1.3	1.3	1.3	1.1	1.1
	1	1.15	1.15	1.15	1	1
	1	1.15	1.15	1.15	1	1
	-	-	-	1	0.9	0.9
	-	-	-	1	0.9	0.9
	-	-	-	1	0.9	0.9
	-	-	-	-	-	1
	-	-	-	-	-	0.9

The following table reports the coefficient km according to the circuit breaker type and to the pole connection. The given diagrams are valid for all types of networks because the coefficient km depends exclusively on the circuit breaker characteristics.

Example

With a T2N 100 TMD In=100 circuit breaker (having the AC magnetic tripping I3=10xIn) and choosing a pole connection corresponding to the first figure of Table 14, it is possible to visualize the coefficient km equal to 1.3; the DC magnetic tripping shall be equal to:

$$I3 = 10 \times In \times km = 10 \times 100 \times 1.3 = 1300 \text{ A}$$

(±20% tolerance)

8.2 Connection of the circuit breaker poles in parallel

Tmax molded case circuit breakers equipped with thermal magnetic trip units can be used both for alternating current and for direct current. When used for DC applications, they are available for rated current from 15 A (T1) up to 800 A (T6).

For applications where higher currents are required, it is possible to connect the circuit breaker poles in parallel so that the required current carrying capacity can be obtained.

When choosing a circuit breaker, it is necessary to consider that the connection of the poles in parallel involves a variation of the magnetic tripping and also a derating to be applied to the rated current of the trip unit. This derating varies based on the number of poles connected in parallel.

The following table reports the correction factors for the poles connected in parallel. When using a 4-pole circuit breaker, the neutral conductor shall be always at 100%:

	Number of poles in parallel		
	2	3	4 (neutral at 100%)
Derating coefficient	0.9	0.8	0.7

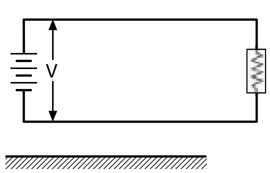
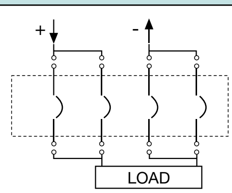
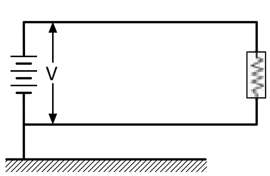
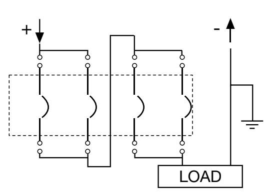
For example, by using a T6N 800 circuit breaker and connecting two poles in parallel for each terminal, the rated uninterrupted current shall be equal to:

$$In = In \times n°_{\text{no.of poles in parallel}} \times K = 800 \times 2 \times 0.9 = 1440 \text{ A}$$

However, it is necessary to take into consideration the likely fault types in relation to the grounding arrangement of the plant.

ABB advises against the connection in parallel because it is quite difficult to realize a connection which can guarantee that the currents flowing in the circuit breaker poles are perfectly balanced. Therefore, for rated operational currents exceeding 800 A, the use of air circuit breakers of IEC Emax series equipped with PR122 - PR123/DC electronic trip units is suggested when possible.

Table 15. Connections of poles in parallel with the relevant derating and performances under short-circuit conditions referred to the adopted network type:

Type of network	Connection of the poles in parallel	Electrical characteristics
ungrounded network 		To obtain this connection it is necessary to use a four-pole circuit breaker with the neutral conductor at 100%. With a T6 800 circuit breaker, the available settings are: -maximum line current = 1440 A -instantaneous tripping = 14400 A (±20% tolerance) This application can be obtained with an installation voltage not exceeding 500 VDC The breaking capacities are (IEC/UL): N= 36/35 kA with Vn< 250 VDC - 20/20 kA with Vn< 500 VDC S= 50/50 kA with Vn< 250 VDC - 35/25 kA with Vn< 500 VDC H= 70/65 kA with Vn< 250 VDC - 50/35 kA with Vn< 500 VDC L= 100/100 kA with Vn< 250 VDC - 65/42 kA with Vn< 500 VDC
network with one terminal grounded 	protection function without insulation function 	To obtain this connection it is necessary to use a four-pole circuit breaker with the neutral conductor at 100%. With a T6 800 circuit breaker, the available settings are: -maximum line current = 1440 A -instantaneous tripping = 12960 A (±20% tolerance) This application can be obtained with an installation voltage not exceeding 500VDC The breaking capacities are (according to the different versions): N= 36/35 kA with Vn< 250 VDC - 20/20 kA with Vn< 500 VDC S= 50/50 kA with Vn< 250 VDC - 35/25 kA with Vn< 500 VDC H= 70/65 kA with Vn< 250 VDC - 50/35 kA with Vn< 500 VDC L= 100/100 kA with Vn< 250 VDC - 65/42 kA with Vn< 500 VDC

9. ABB offering

9.1 Circuit breakers

ABB offers the following range of products for the protection and disconnection of DC networks.

Circuit breakers

Circuit breakers, devices carrying out the protection function against overcurrents, are divided into three families including miniature circuit breakers, molded case circuit breakers and air circuit breakers.

Miniature circuit breakers

Miniature circuit breakers available for use in direct current are series S280UC, S800S UC and S800 PV.

Miniature circuit breakers series S280 UC comply with IEC 60947-2 and differ from the standard versions in that they are equipped with permanent magnetic elements on the internal arcing chambers. Such elements allow the electric arc to be broken, up to voltages equal to 440 VDC.

The presence of these permanent magnetic elements establishes the circuit breaker terminal (positive or negative). As a consequence, their connection shall be carried out in compliance with the terminal indicated on the circuit breakers.

Incorrect connection of the terminals could damage the circuit breaker.

S280 UC circuit breakers with a special version for DC applications are available with characteristics B, C, K and Z.

See the tables of Chapter 7: "Choice of the protective device" for information on pole connection.

Table 16. Electrical characteristics of the MCBs type S280 UC:

			S280 UC	
Reference Standard			IEC 60947-2	
Rated current In		[A]	0.5 ≤ In ≤ 40	50 ≤ In ≤ 63
Poles			1P, 2P	
Rated voltage Ve	1P	[V]	220 VDC	
	2P, 3P, 4P	[V]	440 VDC	
Insulation voltage Vi		[V]	500	
Max. operating voltage Vb max	DC 1P	[V]	220 VDC	
	DC 2P	[V]	440 VDC	
"Rated breaking capacity IEC 60947-2	Icu	[kA]	6	4.5
1P - 220 VDC, 2P - 440 VDC"	Ics	[kA]	6	4.5
Rated impulse voltage (1.2/50) Vimp		[kA]	5	
Dielectric test voltage at industrial frequency for 1 min.		[kA]	3	
Characteristics of the thermomagnetic release	B: 3In< Im < 5 In		■	
	C: 5In< Im < 10 In		■	
	K: 8In< Im < 14 In		■	
	Z: 2In< Im < 3 In		■	
Number of electrical operations			10000	
Number of mechanical operations			20000	

Molded case circuit breakers

The following tables show the DC electrical performances of Tmax MCCBs

Table 17. Tmax IEC 60947-2

		T1 1P	T1			T2				T3		T4					T5					T6			
Rated uninterrupted current, Iu	(A)	160	160			160				250		250/320					400/630					630/800			
Poles	(Nr)	1	3/4			3/4				3/4		3/4					3/4					3/4			
Rated service voltage, Ve	V	125	500			500				500		750					750					750			
Rated impulse withstand voltage, Uimp	kV	8	8			8				8		8					8					8			
Rated insulation voltage, Vi	V	500	800			800				800		1000					1000					1000			
Test voltage at industrial frequency for 1 min.	V	3000	3000			3000				3000		3500					3500					3500			
Rated ultimate short-circuit current, Icu			B	C	N	N	S	H	L	N	S	N	S	H	L	V	N	S	H	L	V	N	S	H	L
250 VDC - 2 poles in series	(kA)	25 (to 125V)	16	25	36	36	50	70	85	36	50	36	50	70	100	150	36	50	70	100	150	36	50	70	100
250 VDC - 3 poles in series	(kA)	-	20	30	40	40	55	85	100	40	55	-	-	-	-	-	-	-	-	-	-	-	-	-	-
500 VDC - 2 poles in series	(kA)	-	-	-	-	-	-	-	-	-	-	25	36	50	70	100	25	36	50	70	100	20	35	50	65
500 VDC - 3 poles in series	(kA)	-	16	25	36	36	50	70	85	36	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
750 VDC - 3 poles in series	(kA)	-	-	-	-	-	-	-	-	-	-	16	25	36	50	70	16	25	36	50	70	16	20	36	50
Utilization category (IEC 60947-2)		A	A			A				A		A					B (400 A) ① - A (630 A)					B ②			
Insulation behavior		■	■			■				■		■					■					■			
Thermomagnetic releases																									
T fixed, M fixed	TMF	■	-			-				-		-					-					-			
T adjustable, M fixed	TMD	-	■			■				■		■ (up to 50 A)					-					-			
T adjustable, M adjustable (5…10 x In)	TMA	-	-			-				-		■ (up to 250 A)					■					■			
T adjustable, M fixed (3 x In)	TMG	-	-			■				■		-					-					-			
T adjustable, M fixed (2,5...5 x I)	TMG	-	-			-				-		-					■					-			
Interchangeability		-	-			-				-		■					■					■			
Versions		F	F-P			F-P				F-P		F-P-W					F-P-W					F-W			

Table 18. Tmax PV IEC 60947-3 MCSs

	T1D PV	T3D PV	T4D PV	T5D PV	T6D PV	T7D PV
Poles	4	4	4	4	4	4
Conventional thermal current, Ith [A]	160	250	250	630	800	1600
Rated service current in category DC22 B, Ie [A]	160	200	250	500	800	1600
Rated service voltage, Ve [V]	1100 VDC	1100 VDC	1100 VDC	1100 VDC	1100 VDC	1100 VDC
Rated impulse withstand voltage, Uimp [kV]	8	8	8	8	8	8
Rated insulation voltage, Vi [V]	1150 VDC	1150 VDC	1150 VDC	1150 VDC	1150 VDC	1150 VDC
Test voltage at industrial frequency for 1 minute [V]	3500	3500	3500	3500	3500	3500
Rated short-circuit making capacity, MCS only, Icm [kA]	1.5	2.4	3	6	9.6	19.2
Rated short-time withstand current for 1s, Icw [kA]	1.5	2.4	3	6	9.6	19.2
Versions	F	F	F	F	F	F
Terminals	FC Cu	FC Cu	FC Cu	FC Cu	FC CuAl	FC CuAl
Mechanical life [no. operations]	25000	25000	20000	20000	20000	10000
Mechanical life [no. hourly operations]	120	120	120	120	120	60

① Icw=5 kA
② Icw=7.6 kA (630 A) - 10 kA (800 A)

Table 19. Tmax UL 489

			Tmax T1	Tmax T2		Tmax T3		Tmax Ts3			Tmax Ts3		
Frame size		[A]	100	100		225		150			225		
Number of poles		[Nr]	3-4	3-4		3-4		2-3-4			2-3-4		
Rated voltage	DC	[V]	500			500		600			500		
Interrupting ratings			N	S	H	N	S	N	H	L	N	H	L
	250V DC (2 poles in series)	[kA rms]	25			25	35						
	500V DC (3 poles in series)	[kA rms]	25			25	35						
	500V DC (2 poles in series)	[kA rms]						35	50	65	20	35	50
	600V DC (3 poles in series)	[kA rms]						20	35	50			
Trip units	TMF		■	■		■		■			■		
	TMD/TMA												
	ELT			■									
	MA			■		■		■			■		
	Electronic			■									
Dimensions	H	[in/mm]	5.12/130	5.12/130		5.9/150		6.7/170			6.7/170		
	W 3p	[in/mm]	3/76	3.54/90		4.13/105		4.13/105			4.13/105		
	D	[in/mm]	2.76/70	2.76/70		2.76/70		4.07/103.5			4.07/103.5		
Mechanical life		[No. operations]	25000	25000		25000		25000			25000		

Table 20. Tmax UL 489

			Tmax T4					Tmax T5					Tmax T6			
Frame size		[A]	250					400-600 ①					800			
Number of poles		[Nr]	2-3-4 ②					2-3-4 ②					3-4			
Rated voltage	DC	[V]	600					600					600			
Interrupting ratings			N	S	H	L	V	N	S	H	L	V	N	S	H	L
	250V DC (2 poles in series)	[kA rms]														
	500V DC (3 poles in series)	[kA rms]														
	500V DC (2 poles in series)	[kA rms]	25	35	50	65	100	25	35	50	65	100	35	35	50	65
	600V DC (3 poles in series)	[kA rms]	16	25	35	50	65	16	25	35	50	65	20	20	35	50
Trip units	TMF		■													
	TMD/TMA		■					■					■			
	ELT															
	MA															
	Electronic		■					■					■			
Dimensions	H	[in/mm]	8.07/205					8.07/205					10.55/268			
	W 3p	[in/mm]	4.13/105					5.51/140					8.26/210			
	D	[in/mm]	4.07/103.5					4.07/103.5					4.07/103.5			
Mechanical life		[No. operations]	20,000					20,000					20,000			

Table 21. DC rated currents available for the UL 489 Tmax circuit breakers with the different types of trip units

In	T1 100	T3 225	Ts3 150/225	T4 250			T5 400	T6 600/800
	TMF	TMF	TMF	TMD	TMA	TMF	TMA	TMA
15	■		■	■	■	■		
20	■		■	■	■	■		
25	■		■	■	■	■		
30	■		■	■	■	■		
35			■	■	■	■		
40	■		■	■	■	■		
50	■		■	■	■	■		
60	■	■	■	■	■	■		
70	■	■	■	■	■	■		
80	■	■	■	■	■	■		
90	■	■	■	■	■	■		
100	■	■	■	■	■	■		
125		■	■	■	■	■		
150		■	■	■	■	■		
175		■	■	■	■	■		
200		■	■	■	■	■		
225		■	■	■	■	■		
250				■	■	■		
300							■	
400							■	
600								■
800								■

In	T2 100	Ts3 150/225
	MA	MA
3		■
5		■
10		■
20	■	■
25		■
50	■	■
100	■	■
125		■
150		■
175		■
200		■

Caption
TMF = thermomagnetic trip unit with fixed thermal and magnetic threshold
TMD = thermomagnetic trip unit with adjustable thermal and fixed magnetic threshold
TMA = thermomagnetic trip unit with adjustable thermal and magnetic threshold
MA = adjustable magnetic only trip unit

Air circuit breakers

IEC Emax air circuit breakers equipped with DC PR122/DC-PR123/DC electronic trip units are divided into four basic sizes. They have an application field from 800 A (E2) to 5000 A (E6) and current breaking capacities ranging from 35 kA to 100 kA (at 500 VDC).

By using the dedicated voltage module PR120/LV, the minimum rated operational voltage is 24 VDC.

Please refer to Chapter 7: "Choice of the protective device" for information on pole connection and supply voltage.

Thanks to their exclusive technology, the DC PR122DC-PR123/DC electronic trip units cover any possible installation requirement and perform the same protection functions that were previously available for AC applications only.

The DC Emax circuit breakers keep the same overall dimensions and the electrical and mechanical accessories as the Emax range for AC applications.

Table 22. Electrical characteristics of DC Emax ACBs

			E2		E3		E4		E6
Rated uninterrupted current, Iu		(A)	B	N	N	H	S	H	H
		(A)	800	1600	800	1600	1600	3200	3200
		(A)	1000		1000	2000	2000		4000
		(A)	1250		1250	2500	2500		5000
		(A)	1600		1600		3200		
		(A)			2000				
		(A)			2500				
Poles		(Nr)	3/4		3/4		3/4		3/4
Rated operational voltage, Ue		V	< 1000		< 1000		< 1000		< 1000
Rated impulse withstand voltage, Uimp		kV	12		12		12		12
Rated insulation voltage, Ui		V	1000		1000		1000		1000
Rated ultimate breaking capacity under short-circuit, Icu	500 VDC	(kA)	35	50	60	85	75	100	100
	750 VDC	(kA)	25	35	50	65	65	85	85
	1000 VDC	(kA)	25	35	35	65	50	65	65
Rated service breaking capacity under short-circuit, Ics	500 VDC	(kA)	35	50	60	85	75	100	100
	750 VDC	(kA)	25	35	50	65	65	85	85
	1000 VDC	(kA)	25	35	35	65	50	65	65
Rated short-time withstand current, Icw (0.5 s)	500 VDC	(kA)	35	50	35	65	75	100	100
	750 VDC	(kA)	25	35	35	65	65	85	85
	1000 VDC	(kA)	25	35	35	65	50	65	65
Utilization category (IEC 60947-2)			B		B		B		B
Insulation behavior			■		■		■		■
Overcurrent protection	PR122/DC		■		■		■		■
	PR123/DC		■		■		■		■

In addition to the standard protection functions (i.e. protection against overload and short-circuit), the PR122-PR123DC trip units offer some advanced protection functions summed up in the following table:

Table 23. PR122-PR123 Trip unit characteristics

Protection functions		PR122	PR123
L	Protection against overload with inverse long time-delay trip	■	■
S	Selective protection against short-circuit inverse or definite short time-delay trip	■	■
S	Second selective protection against short-circuit inverse or definite short time-delay trip		■
I	Protection against instantaneous short-circuit with adjustable trip current threshold	■	■
G	Protection against ground fault		■
U	Protection against phase unbalance		■
OT	Protection against overtemperature (check)	■	■
UV	Protection against undervoltage		■
OV	Protection against overvoltage		■
RP	Protection against reverse active power		■
M	Thermal memory for functions L and S	■	■

Thanks to a new human-machine interface, the electronic trip units allow complete control over the system. More precisely, such releases provide the following measuring and control functions:

Table 24.

Measurements	PR122/DC-PR123/DC
Currents	■
Voltage	■ (1)
Power	■ (1)
Energy	■ (1)
Event marking and maintenance data	
Event marking with the instant it occurred	■
Chronological event storage	■
Counting the number of operations and contact wear	■
Communication with supervision system and centralised control	
Remote parameter setting of the protection functions, unit configuration, communication	opt. (2)
Transmission of measurements, states and alarms from circuit breaker to system	opt. (2)
Transmission of the events and maintenance data from circuit breaker to system	opt. (2)
Watchdog	
Alarm and trip for release overtemperature	■
Check of release status	■
Interface with the user	
Presetting parameters by means of keys and LCD viewer	■
Alarm signals for functions L, S, I and G	■
Alarm signal of one of the following protections: undervoltage, overvoltage, residual voltage, active reverse of power, phase unbalance, overtemperature	■
Complete management of pre-alarms and alarms for all the self-control protection functions	■
Enabling password for use with consultation in "READ" mode or consultation and setting in "EDIT" mode	■
Load control	
Load connection and disconnection according to the current passing through the circuit breaker	■
Zone selectivity	
Can be activated for protection functions S, G (1)	■

(1) for PR 123/DC only
(2) with communication module PR120/D-M

9.2 Molded case switches

To carry out the isolating function and to cut off the power supply from all or from a discrete section of the DC installation, the product range offered by ABB is:

Tmax molded case switches

Tmax molded case switches keep the same overall dimensions, versions, terminals and accessories as Tmax molded case circuit breakers. This version only differs from the circuit breakers in the absence of the trip unit.

These molded case switches can be used up to 750 VDC (with T4D-T5D-T6D-T7D). The new Tmax PV line of molded case switches can be applied up to 1100 VDC.

See the tables of Chapter 7: "Choice of the protective device" for information on pole connection.

The following tables show the electrical characteristics of the Tmax molded case switches:

Table 25.

			Tmax T1N-D	Tmax T3S-D	Tmax T3S-D	Tmax Ts3H-D 150	Tmax Ts3H-D 225	Tmax T4N-S-H-L-V-D	Tmax T5N-S-H-L-V-D	Tmax T6H-D	Tmax T7H-D
Rating		[A]	100	150	225	150	225	250	400-600	800	1200
Poles		[Nr]	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4
Magnetic override		[A]	1000	1500	2250	1500	2250	3000	5000	10000	20000
Rated voltage	AC (50-60 Hz)	[V]	600Y/347	600Y/347	600Y/347	600	480	600	600	600	600
	DC	[V]	500	500	500	600	500	600	600	600	—
Reference standard			UL489	UL489	UL489	UL489	UL489	UL489	UL489	UL489	UL489

Table 26.

			Tmax T1B-C-N-D	Tmax T3N-S-D	Tmax T4N-S-H-L-V-D	Tmax T5N-S-H-L-V-D	Tmax T6N-S-H-L-D	Tmax T7S-H-L-V-D
Rating		[A]	160	250	250-320	400-630	630-800-1000	1000-1250-1600
Poles		[Nr]	3, 4	3, 4	3, 4	3, 4	3, 4	3, 4
Rated voltage	AC (50-60 Hz)	[V]	690	690	690	690	690	690
	DC	[V]	500	500	750	750	750	750
Reference standard			IEC 60947-2	IEC 60947-2	IEC 60947-2	IEC 60947-2	IEC 60947-2	IEC 60947-2

Table 27.

			Tmax PV T1-D	Tmax PV T3-D	Tmax PV T4-D	Tmax PV T5-D	Tmax PV T6-D	Tmax PV T7-D	Tmax PV T7M-D
Rating		[A]	160	250	250	630	800	1600	1600
Poles		[Nr]	4	4	4	4	4	4	4
Service current (category DC22B)			160	200	250	500	800	1600	1600
Rated voltage	DC	[V]	1100	1100	1100	1100	1100	1100	1100
Reference standard			IEC 60947-3	IEC 60947-3	IEC 60947-3	IEC 60947-3	IEC 60947-3	IEC 60947-3	IEC 60947-3

Emax switch disconnectors

Emax switch disconnectors maintain the same overall dimensions and the same accessories as the Emax air circuit breakers. This version differs from the circuit breakers only in the absence of trip units. These switch disconnectors are available both in fixed and withdrawable versions, three or four poles and can be used according to utilization category DC 23A (switching of motors or other highly inductive loads, e.g. motors in series).

Table 28. Electrical characteristics of the Emax switch disconnectors:

			E1B/E MS		E2N/E MS		E3H/E MS		E4H/E MS		E6H/E MS	
Rated current (at 40° C) Iu		[A]	800		1250		1250		3200		5000	
		[A]	1250		1600		1600		4000		6300	
		[A]			2000		2000					
		[A]					2500					
		[A]					3200					
Poles			3	4	3	4	3	4	3	4	3	4
Rated service voltage Ve		[V]	750	1000	750	1000	750	1000	750	1000	750	1000
Rated insulation voltage Vi		[V]	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Rated impulse withstand voltage Vimp		[kA]	12	12	12	12	12	12	12	12	12	12
Rated short-time withstand current Icw (1s)		[kA]	20	20	25	25	40	40	65	65	65	65
Rated making capacity Icm	750 VDC	[kA]	20	20	25	25	40	40	65	65	65	65
	1000 VDC	[kA]	—	20	—	25	—	40	—	65	—	65

Reference standard IEC 60947-3

NOTE: The breaking capacity Icu, by means of external protection relay, with 500 ms maximum timing, is equal to the value of Icw (1s).

Annex A

Direct current distribution systems

The Standard IEC 60364-1 defines the direct current and alternating current distribution systems analogously:

TT system

a terminal of the system and the exposed conductive-parts are connected to two electrically independent grounding arrangements. If necessary, the middle point of the supply can be connected to ground.

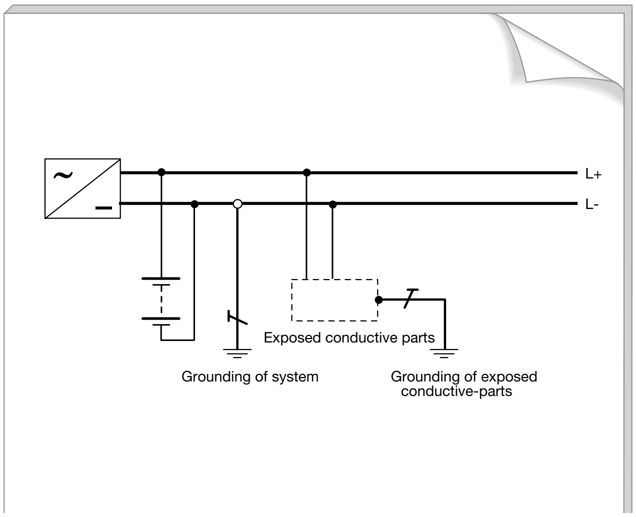


Figure 18
TT DC system

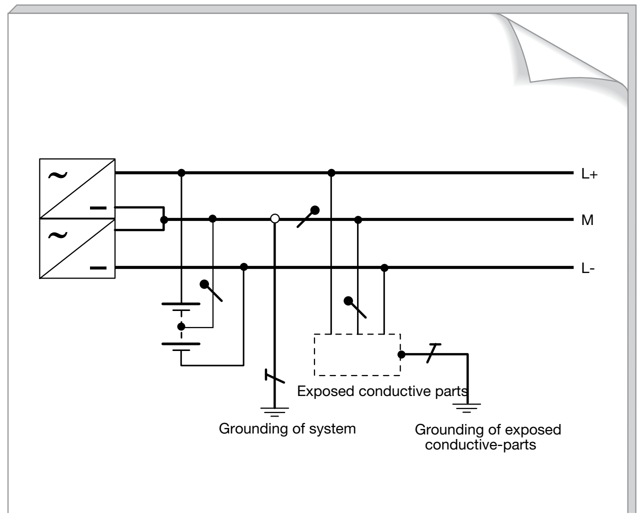


Figure 19
TT DC system with the middle point of the supply connected to ground
The choice of grounding either the positive or the negative terminal is made according to considerations not treated in this Annex.

TT system

A terminal or the middle point of the supply is directly grounded; the exposed-conductive-parts are connected to the same grounded point. Three types of TN system are defined according to whether the grounded terminal and the protective conductor are separated or not:

1.TN-S system – the conductor of the terminal connected to ground and the protective conductor Gnd are separated.

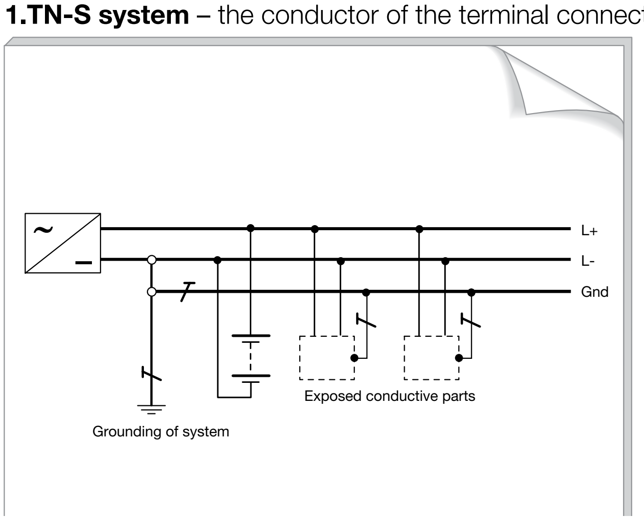


Figure 20 TN-S DC distribution system

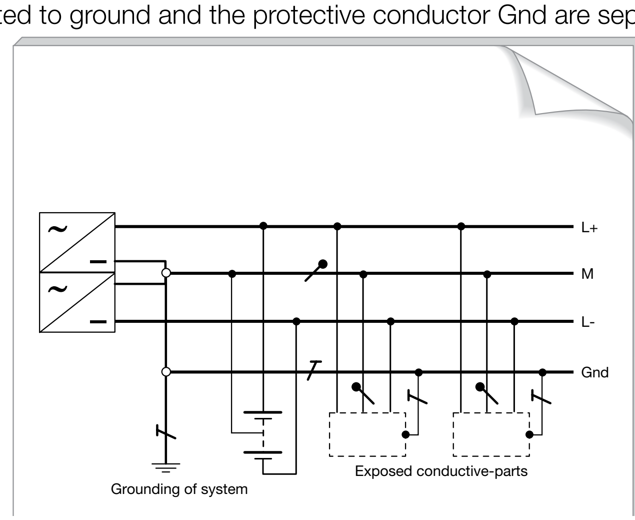


Figure 21 TN-S DC system with the middle point of the supply connected to ground

2.TN-C system – the functions grounded terminal and protective conductor are partially combined in a single conductor called GndN

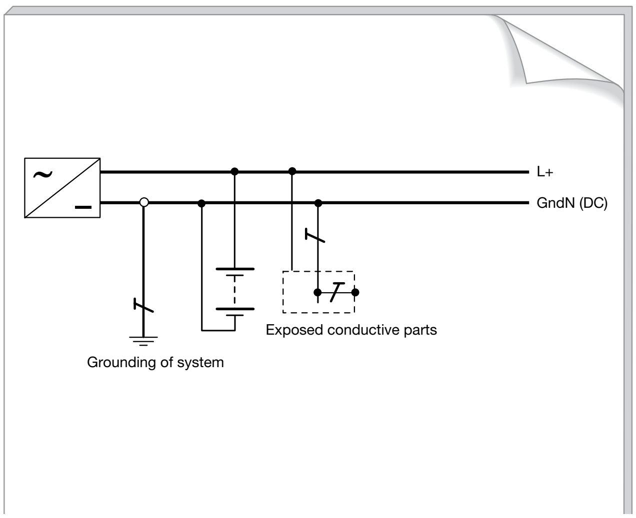


Figure 22
TN-C DC distribution system

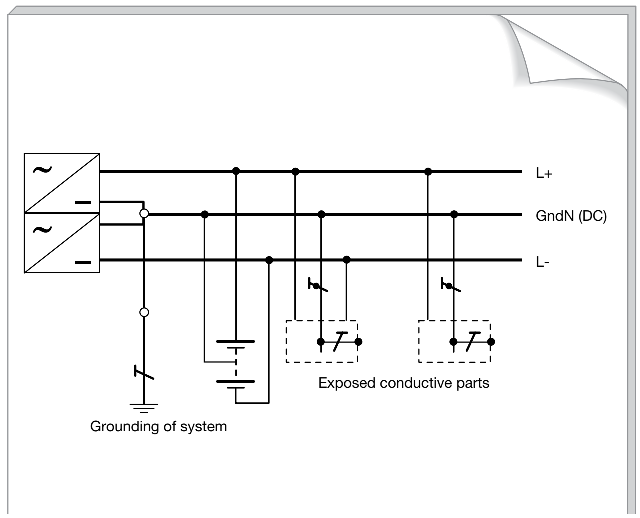


Figure 23
TN-C DC distribution system with the middle point of the supply source connected to ground

3.TN-C-S system – the functions of the grounded terminal and of the protective conductor are partially combined in a single conductor called GndN and partially separated

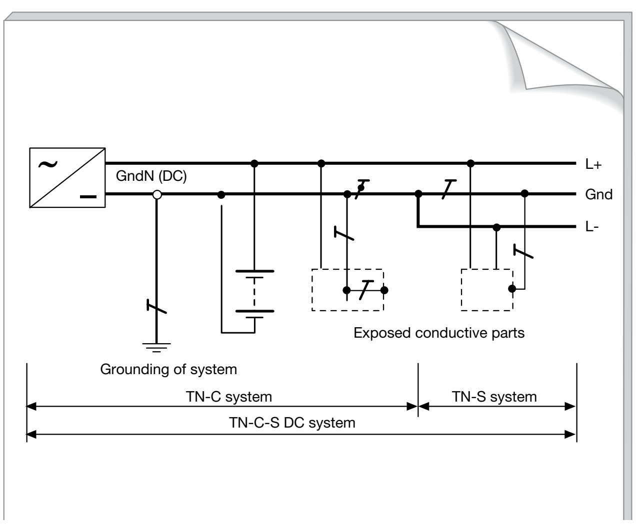


Figure 24 TN-C-S DC distribution system

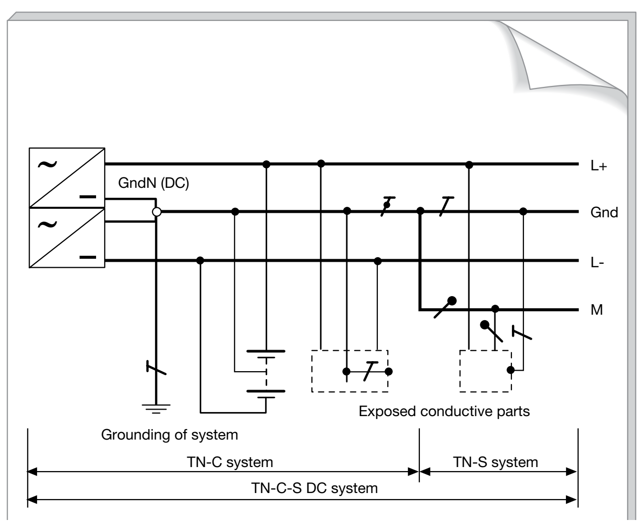


Figure 25 TN-C-S DC distribution system with the middle point of the supply source connected to ground

IT system

The supply source is not grounded; the exposed-conductive-parts are connected to the same grounding point.

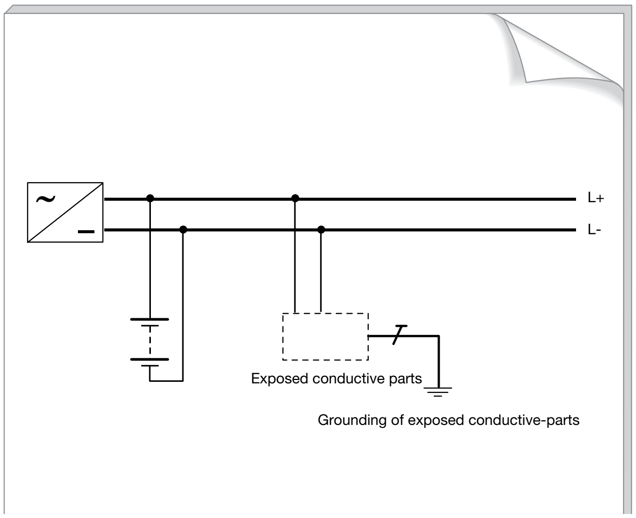


Figure 26 IT DC distribution system

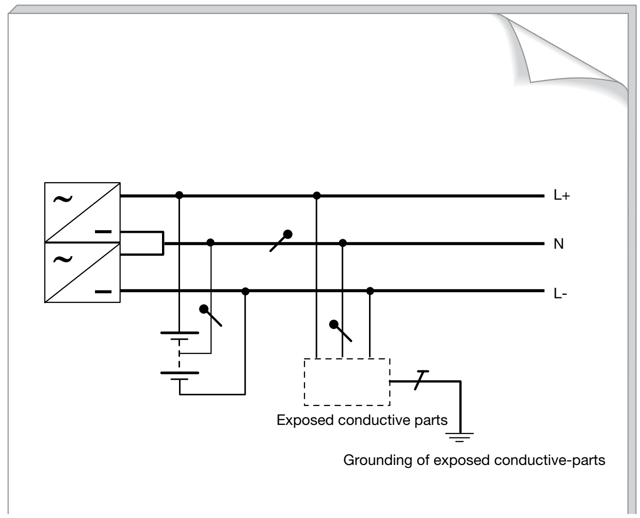


Figure 27 IT DC distribution system with the middle point of the supply isolated form ground

Protection against indirect contact

To protect against direct and indirect contacts, IEC Standard 60364-4 mandates that the protective device shall automatically disconnect the supply so that in the event of a fault between a live part and an exposed-conductive-part or a protective conductor, a voltage exceeding 120 VDC does not persist for a sufficient time to cause harmful physiological effects to a human body ①.

For particular environments, tripping times and voltage values lower than 120 VDC may be required. Further requirements for DC systems are being studied at present.

① For IT systems, the automatic opening of the circuit is not necessarily required in the presence of a first fault.

Annex B

Calculation of short-circuit currents

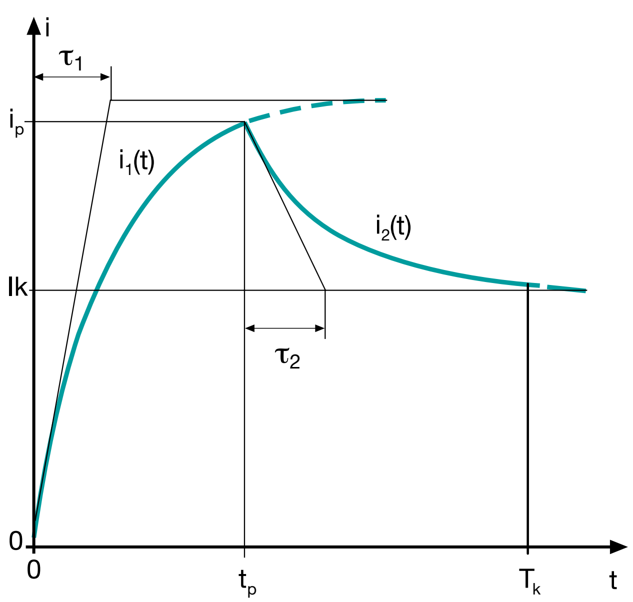
The study of short-circuit currents is fundamental for correct sizing of the components included in the plant.

Here are some brief considerations on how to assess the short-circuit current according to IEEE Std. 1375, "IEEE guide for the protection of stationary battery systems", Annex C.1.1; and IEEE Std. 946, "IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations", Annex C.

This standard provides some calculation methods regarding the variations of the short-circuit currents relevant to electrical components acting as short-circuit current sources.

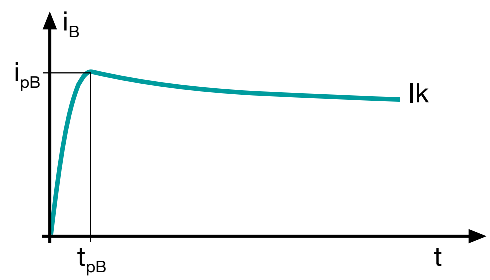
We take into consideration only the information about stationary lead-acid batteries and give the time-current curves of the other sources (rectifiers in three-phase AC bridge connection for 60 Hz, smoothing capacitors and DC motors with independent excitation).

The following figure represents the typical curve of a direct short-circuit current:



Calculation of the short-circuit current provided by a stationary lead-acid battery

The following figure shows the curve of the short-circuit current delivered by a stationary lead-acid battery.



The internal resistance of a cell can be calculated from its discharge characteristic curve. For this example, we will take the following values:

$$R_p = \frac{(V_1 - V_2)}{(I_2 - I_1)} = \frac{(1.7 - 1.52)}{(345 - 215)}$$

$$R_p = 0.001385 \quad \frac{\Omega}{\text{Positive plate}}$$

If we consider 10 positive plates:

$$R_t = \frac{0.001385}{10} = 0.0001385\ \Omega$$

The short circuit current at the cell terminals can be calculated as:

$$I_c = \frac{E_c}{R_t}$$

where E_c is the nominal cell voltage (2.00 V)

$$I_c = \frac{2.0}{0.0001385} = 14{,}440 \text{ Amps}$$

The short circuit current available at the load terminals of the main/battery circuit breaker, considering a battery of 60 cells, would be:

$$I_b = \frac{E_b}{R_t}$$

Where E_b is the nominal battery voltage = (60 cells) (2.00 $\frac{\text{Volts}}{\text{cell}}$) = 120 V

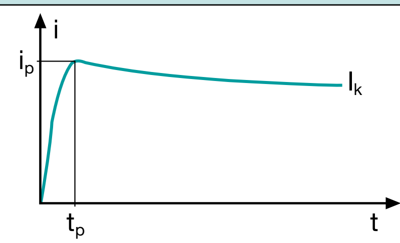
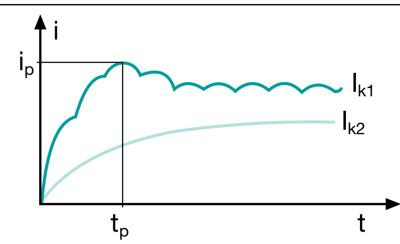
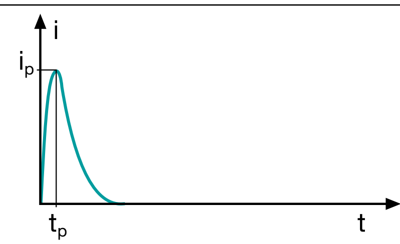
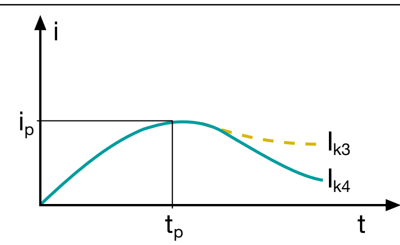
R_b is the total internal resistance of the battery = (0.0001385) (60) = 0.00831 Ω

R_x is the total external circuit resistance = 0.0100 Ω

R_t is the total circuit resistance = R_b + R_x = 0.00831 + 0.0100 = 0.01831 Ω

$$I_b = \frac{120 \text{ V}}{0.01831\ \Omega}) = 6554 \text{ Amps}$$

The following table summarizes all the variations of the short-circuit currents indicated relevant to the different equipment acting as short-circuit sources:

Equipment acting as short-circuit sources	Short-circuit current variations	Description
Stationary lead-acid battery		ip = peak short-circuit current tp = time to peak Ik = quasi steady-state short-circuit current
Rectifiers in three-phase AC bridge connections for 50Hz without (Ik2) and with smoothing reactor (Ik1)		
Smoothing capacitors		
DC motors with independent excitation without additional inertia mass (Ik4) or with additional inertia mass (Ik3)		

Annex C

IEC circuit-breakers and molded case switch disconnectors for applications up to 1000 VDC

The main installations at 1000 VDC are used for traction, mines, road tunnels, railway applications, photovoltaic and industrial applications in general.

This high voltage is used in those plants where it is necessary to have distribution lines longer than normal LV lines or in those applications requiring significant power. In those circumstances, to keep the rated and the short-circuit currents lower, it is necessary to increase the rated voltage of the plant.

Thus it is possible to use conductors with smaller cross sectional areas both in the switchboards as well as in the distribution lines. This causes a consequent reduction in the initial investment costs and in the running costs due to the decrease in the power losses caused by the joule effect.

Another advantage is space savings of the cable runs thanks to the reduction in their cross sectional area. For further applications, such as installation in mines, the narrowness of the available spaces enormously amplifies the problem of the arrangement of the run and of the positioning of the conductors in relation to air/suction ducts and air conditioning.

Moreover, with 1000 V, it is possible to reduce the percentage voltage drop, thus obtaining longer distribution lines. This is one reason why this voltage is used in installations with particular requirements of length.

The increase in voltage also brings better service conditions thanks to the reduction in the short-circuit levels, thus limiting the consequences of possible faults and improving safety.

However, 1000 V affects the choice, the availability and the cost of the switching and protection devices which can be used. These special 1000 V versions have constructional characteristics necessary to meet the most severe requirements.

ABB offering for use up to 1000 VDC

The range of products offered by ABB for applications up to 1000 VDC include products for the protection or the isolation of circuits. When choosing a circuit breaker, it is necessary to take into consideration the grounding of the plant. This helps define the number of poles to be connected in series with the purpose of creating working conditions under which, if a short-circuit occurs, the current breaking is carried out by the series of the four circuit breaker contacts.

In the following pages, both the electrical characteristics of the products as well as the pole connection configurations are reported.

Circuit breakers for use up to 1000 VDC

Tmax circuit breakers equipped with thermal magnetic trip unit

Tmax circuit breakers for use in direct current up to 1000 V have the same dimensions as the standard circuit breakers and are available in the fixed, plug-in and withdrawable version. They can be fed from the top only and can be equipped only with adjustable thermomagnetic trip units. They are compatible with all the accessories provided for the standard version except for the residual current release.

Electrical characteristics of Tmax circuit-breakers for 1000 VDC applications

		Tmax T4	Tmax T5	Tmax T6
Rated uninterrupted current, Iu	[A]	250	400/630	630/800
Poles	[Nr.]	4	4	4
Rated service voltage, Ve	[V]	1000	1000	1000
Rated impulse withstand voltage, Vimp	[kV]	8	8	8
Rated insulation voltage, Vi	[V]	1150	1150	1000
Test voltage at power frequency for 1 min.	[V]	3500	3500	3500
Rated ultimate short-circuit breaking capacity, Icu		V	V	L
(DC) 4 poles in series	[kA]	40	40	40
Rated service short-circuit breaking capacity, Ics				
(DC) 4 poles in series	[kA]	20	20	
Utilization category (IEC 60947-2)		A	B (400 A) ① - A (630 A)	B ②
Insulation behavior		■	■	■
Reference Standard		IEC 60947-2	IEC 60947-2	IEC 60947-2
Thermomagnetic trip units	TMD	■	–	–
	TMA	■	■	■

Emax circuit breakers equipped with electronic trip units

Emax circuit breakers for use in direct current up to 1000 VDC can cover installation requirements up to 5000 A. These circuit breakers have the same dimensions as the standard circuit breakers, and are available in the fixed and withdrawable versions and can be equipped with PR122-PR123DC electronic trip units. They are compatible with all the accessories provided for the standard version.

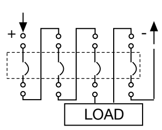
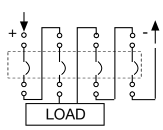
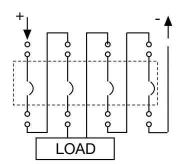
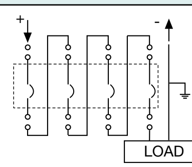
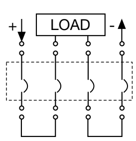
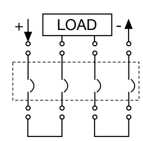
Electrical characteristics at 1000 VDC of Emax circuit breakers equipped with the new PR122-PR123/DC trip unit

			E2		E3		E4		E6
Rated uninterrupted current, Iu		(A)	B	N	N	H	S	H	H
		(A)	800	1600	800	1600	1600	3200	3200
		(A)	1000		1000	2000	2000		4000
		(A)	1250		1250	2500	2500		5000
		(A)	1600		1600		3200		
		(A)			2000				
		(A)			2500				
Poles		(Nr)	3/4		3/4		3/4		3/4
Rated voltage service, Ve		V	< 1000		< 1000		< 1000		< 1000
Rated impulse withstand voltage, Vimp		kV	12		12		12		12
Rated insulation voltage , Vi		V	1000		1000		1000		1000
Rated ultimate breaking capacity under short-circuit, Icu	1000 VDC	(kA)	25	35	35	65	50	65	65
Rated service breaking capacity under short-circuit, Ics	1000 VDC	(kA)	25	35	35	65	50	65	65
Rated short-time withstand current Icw (0.5s)	1000 VDC	(kA)	25	35	35	65	50	65	65
Utilization category (IEC 60947-2)			B		B		B		B
Insulation behavior			■		■		■		■
Electronic releases	PR122/DC		■		■		■		■
	PR123/DC		■		■		■		■

① Icw = 5 kA
② Icw = 7.6 kA (630 A) - 10 kA (800 A)

The table below shows the pole connection configurations with circuit breakers up to 1000 VDC according to the network connection types. This table is valid for both Tmax MCCBs equipped with thermomagnetic trip units (the connections shall be carried out by the customers) as well as for Emax ACBs equipped with the DC PR122-P123/DC electronic trip units (connections carried out in the factory by ABB).

Connection modalities of poles with circuit breakers for applications up to 1000 VDC

	Rated voltage (Vn)	1000 VDC		
	Type of network	INSULATED NETWORK	NETWORK WITH ONE TERMINAL CONNECTED TO GROUND ①	NETWORK WITH THE MIDDLE POINT OF THE SUPPLY SOURCE CONNECTED TO GROUND
	Description	With this network type, a fault is considered to be significant when it occurs between the positive and the negative terminal which makes the series of the four circuit breaker poles open the circuit. The possibility of a double fault to ground (the first fault on the supply side of the poles of one terminal and the second one on the load side of the poles of the other terminal) is not considered. Therefore, it is suggested the use of a device to monitor the insulation to ground capable of signaling the decrease of the insulation to ground as a consequence of a first fault to ground.	With this network type, the poles connected on the terminal insulated from ground are called to break a fault current at 1000 V; therefore it is necessary to provide on this terminal the series of four poles. As a consequence, the grounded terminal cannot be interrupted and often this is not even necessary since it is bound to the ground potential.	With this network type, the two poles connected on one terminal are called to break a fault current at 500 V, whereas in case of a fault between the two terminals, the voltage supporting it returns to be 1000 V and the proposed diagram allows breaking with four poles in series.
Tmax	Protection + isolation function	 		
Tmax	Protection function			
Emax	Protection + isolation function			

① For Emax circuit breakers, please ask ABB.

Switch disconnectors for applications up to 1000 VDC

ABB has developed a range of switch disconnectors (Emax/E MS family) for applications in direct current up to 1000 V in compliance with the international Standard IEC 60947-3.

These switch disconnectors are particularly suitable for use as bus ties or main isolators.
These switch disconnectors are available both in fixed and withdrawable, three-pole and four-pole versions.
The switch disconnectors of the Emax/E MS family maintain the same overall dimensions and can be equipped with the accessories common to the Emax circuit-breakers.

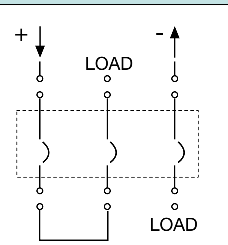
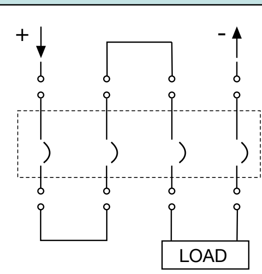
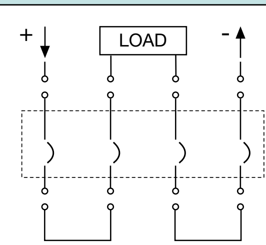
Electrical characteristics of the Emax switch disconnector

		E1B/E MS		E2N/E MS		E3H/E MS		E4H/E MS		E6H/E MS	
Rated current (at 40°C), Iu	[A]	800		1250		1250		3200		5000	
	[A]	1250		1600		1600		4000		6300	
	[A]			2000		2000					
	[A]					2500					
	[A]					3200					
Poles	[Nr.]	3	4	3	4	3	4	3	4	3	4
Rated service voltage, Ve (d.c.)	[V]	750	1000	750	1000	750	1000	750	1000	750	1000
Rated insulation voltage, Vi (d.c.)	[V]	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Rated impulse withstand voltage, Vimp	[kV]	12	12	12	12	12	12	12	12	12	12
Rated short-time withstand current, Icw (1s)	[kA]	20	20	25	25	40	40	65	65	65	65

The performances at 750 V are:
for E1B/E MS Icw=25 kA
for E2N/E MS Icw=40 kA
for E3H/E MS Icw=50 kA

Hereunder are the wiring diagrams suggested by ABB. Also in this case the division of the different connection modalities is carried out according to the installation voltage. As it can be seen from the table below, by connecting three breaking poles in series, it is possible to reach a rated voltage of 750 VDC, while with four poles in series the rated voltage is 1000 VDC.

Connection modalities of poles with Emax/E MS switch disconnectors for applications up to 1000 VDC

Rated voltage	750 VDC	1000 VDC	
Poles connection			
E1…E6/E MS	■	■	■

Glossary

Imax	maximum current
Ip	short-circuit making current
Icn	prospective short-circuit current
Va	maximum arc voltage
Vn	line voltage
T	time constant
In	rated current of the trip unit
Ir.m.s	r.m.s. value of an alternating current
I3	setting of the instantaneous protection against short-circuit
I2	setting of the protection against short-circuit with time delay
I1	setting of the protection against overload
Icu	ultimate short-circuit breaking capacity
Ics	service short-circuit breaking capacity
Icw	rated short time withstand current
Ve	rated operational voltage
TMG	thermomagnetic trip unit with low magnetic threshold
TMF	thermomagnetic trip unit with fixed thermal and magnetic threshold
TMD	thermomagnetic trip unit with adjustable thermal and fixed magnetic threshold
TMA	thermomagnetic trip unit with adjustable thermal and magnetic threshold
MF	magnetic only trip unit, fixed
MA	magnetic only trip unit, adjustable
L	overload protection
S	protection against short-circuit with time-delay trip
I	instantaneous short-circuit protection
Ik	quasi steady-state short-circuit current
ip	peak short-circuit current
Tk	short-circuit duration
tp	time to peak
ipb	peak short-circuit current supplied by a stationary lead-acid battery
tpb	time to peak in a stationary lead-acid battery
Ikb	quasi steady-state short-circuit current of a stationary lead-acid battery

Notes

Notes

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