

# 1. protection of circuits supplied by an alternator

a major difficulty encountered when an installation may be supplied from alternative sources (e.g. a HV/LV transformer or a LV generator) is the provision of electrical protection which operates satisfactorily on either source. The crux of the problem is the great difference in the source impedances; that of the generator being much higher than that of the transformer, resulting in a corresponding difference in the magnitudes of fault currents.

Most industrial and large commercial electrical installations include certain important loads for which a power supply must be maintained, in the event that the public electricity supply fails:

- either, because safety systems are involved (emergency lighting, automatic fire-protection equipment, smoke dispersal fans, alarms and signalization, and so on...); or
- because it concerns priority circuits, such

as certain equipment, the stoppage of which would entail a loss of production, or the destruction of a machine tool, etc.

One of the current means of maintaining a supply to the so-called "essential" loads, in the event that other sources fail, is to install a diesel-generator set connected, via a changeover switch, to an emergency-power standby switchboard, from which the essential services are fed (figure J1-1).

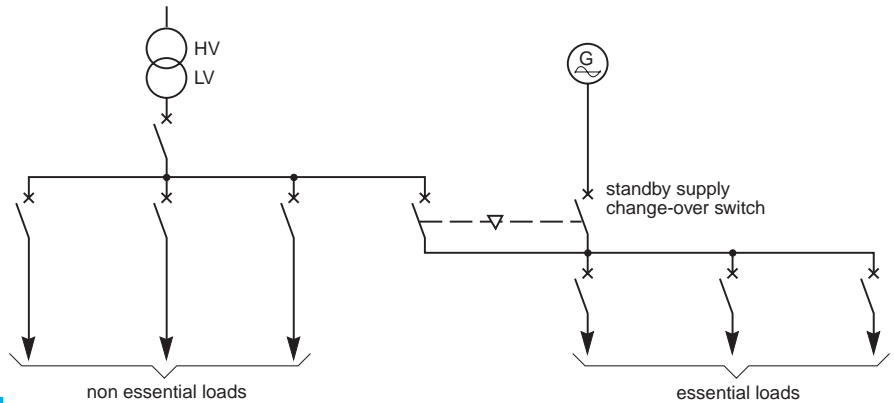


fig. J1-1: example of circuits supplied from a transformer or from an alternator.

## 1.1 an alternator on short-circuit

### the establishment of short-circuit current (fig. J1-2)

Apart from the limited magnitude of fault current from a standby alternator, a further difficulty (from the electrical-protection point of view) is that during the period in which LV circuit breakers are normally intended to operate, the value of short-circuit current changes drastically.

For example, on the occurrence of a short-circuit at the three phase terminals of an alternator, the r.m.s. value of current will immediately rise to a value of  $3 I_n$  to  $5 I_n^*$ . An interval of 10 ms to 20 ms following the instant of short-circuit is referred to as the "sub-transient" period, in which the current decreases rapidly from its initial value. The current continues to decrease during the ensuing "transient" interval which may last for 80 ms to 280 ms depending on the machine type, size, etc. The overall phenomenon is referred to as the "a.c. decrement". The current will finally stabilize in about

0.5 seconds, or more, at a value which depends mainly on the type of excitation system, viz:

- manual;
- automatic (see figure J1-2).

Almost all modern generator sets have automatic voltage regulators, compounded to maintain the terminal voltage sensibly constant, by overcoming the synchronous impedance of the machine as reactive current demand changes.

This results in an increase in the level of fault current during the transient period to give a steady fault current in the order of  $2.5 I_n$  to  $4 I_n^*$  (figure J1-2).

In the (rare) case of manual control of the excitation, the synchronous impedance of the machine will reduce the short-circuit current to a value which can be as low as  $0.3 I_n$ , but is often close to  $I_n^*$ .

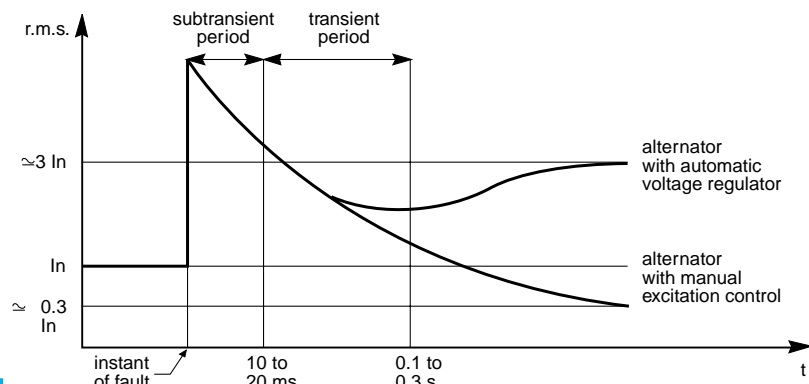


fig. J1-2: establishment of short-circuit current for a three-phase short circuit at the terminals of an alternator.

\* depending on the characteristics of the particular machine.

# 1. protection of circuits supplied by an alternator (continued)

## J

### 1.1 an alternator on short-circuit (continued)

Figure J1-2 shows the r.m.s. values of current, on the assumption that no d.c. transient components exist. In practice, d.c. components of current are always present to some degree in at least two phases, being maximum when the short-circuit occurs at the alternator terminals.

This feature would appear to complicate still further the matter of electrical protection, but, in fact, the d.c. component in each phase simply increases the r.m.s. values already mentioned, so that calculations and tripping-current settings for protective devices based only on the a.c. components, as indicated below, will be conservative, i.e. the actual currents will always be either equal to or higher than those calculated.

The further the point of short-circuit from the generator the lower the fault current, and the more rapidly the transient d.c. components disappear. Furthermore, the a.c. decrement also becomes negligible when the network impedance to the fault position attains ohmic values which are high compared with the reactance values of the alternator (since the overall change in impedance is then relatively small).

#### alternator impedance data

Manufacturers furnish values of the several impedances mentioned below. Resistances are negligibly small compared to the reactances.

It can be seen from the constantly-changing value of r.m.s. current that the effective reactance\* changes constantly from a low value (sub-transient reactance) to a high value (synchronous reactance) in a smooth progression.

The values discussed below are derived from test curves and correspond with current values measured at the instant of short-circuit.

\* An explanation of the significance of the fixed reactance values and how they relate to a smooth variation of current is briefly described in Appendix J1.

■ the sub-transient reactance  $x''d$  is expressed in % by the manufacturer (analogous to the short-circuit impedance voltage of a transformer). The ohmic value  $X''d$  is therefore calculated as follows:

$$X''d \text{ (ohms)} = \frac{x''d U_n^2 10^{-5}}{P_n}$$

where:

$x''d$  is in %

$U_n$  is in volts (phase/phase)

$P_n$  is in kVA

■ the % transient reactance  $x'd$  is given in ohms by:

$$X'd \text{ (ohms)} = \frac{x'd U_n^2 10^{-5}}{P_n}$$

■ the % zero-phase-sequence reactance  $x'o$  is given in ohms by:

$$X'o \text{ (ohms)} = \frac{x'o U_n^2 10^{-5}}{P_n}$$

In the absence of more precise information, the following representative values may be used:

$x''d = 20\%$  ;  $x'd = 30\%$  ;  $x'o = 6\%$

$P_n$  and  $U_n$  being, respectively, the rated 3-phase power (kVA) and the rated phase/phase voltage of the alternator (volts).

The sub-transient reactance is used when calculating the short-circuit current-breaking rating for LV circuit breakers which have opening times of 20 ms or less, and also for the electrodynamic stresses to be withstood by CBs and other components (such as busbars, cleated single-core cables, etc.). The transient reactance is used when considering the breaking capacity of LV circuit breakers with an opening time that exceeds 20 ms, and also for the thermal withstand capabilities of switchgear and other system components.

**Remark:** from the instant at which the short-circuit is established, the alternator reactance will rapidly increase. This means that the currents calculated from the defined fixed values  $x''d$  and  $x'd$  (for breaking capacity) will always exceed those that will actually occur at the instant of circuit breaker contact separation, i.e. there is an inherent safety factor incorporated in the current-level calculation.

These calculations for the circuit breaker short-circuit **breaking** capacity are based on the symmetrical a.c. components of current only, i.e. no account is taken of the d.c. unidirectional components.

For the circuit breaker short-circuit **making** capacity, the d.c. components are crucial, as discussed in Chapter C, Sub-clause 1.1 (figure C-5).

### short-circuit current magnitude at the terminals of an alternator

■ the transient 3-phase short-circuit current at the terminals of an alternator is given by:

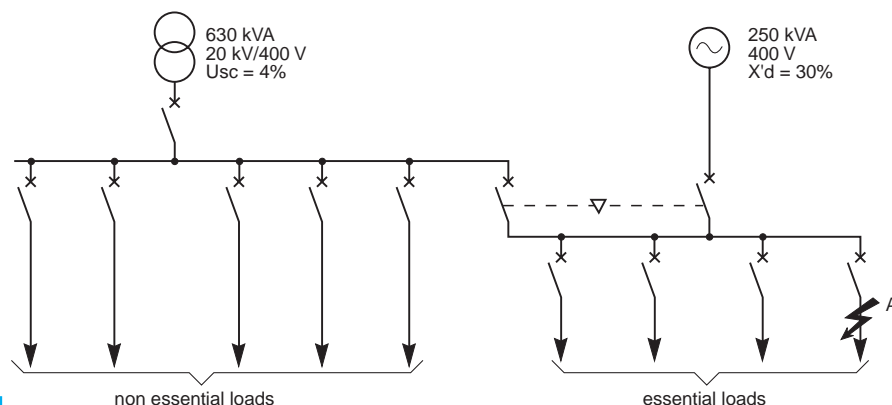
$$I_{sc} = \frac{I_g}{x'd} \times 100^* \quad \text{where:}$$

$I_g$ : rated full-load current of the alternator  
 $x'd$  = transient reactance per phase of the alternator in %;

■ when these values are compared with those for a short-circuit at the LV terminals of

a transformer of equal kVA rating, the current from the alternator will be found to be of the order of 5 or 6 times less than that from the transformer. The difference will be even greater where (as is generally the case) the alternator rating is lower than that of the transformer.

\* for CBs with opening time exceeding 20 ms.



**fig. J1-3: example of an essential services switchboard supplied (in an emergency) from a standby alternator.**

#### Example (figure J1 - 3)

What is the value of 3-phase short-circuit current at point A according to the origin of supply?

Circuit impedances are negligible compared with those of the sources.

■ transformer supply

3-phase  $I_{sc} = 21.5 \text{ kA}$   
 (see table C20 in Chapter C)

■ alternator supply

$$3\text{-phase } I_{sc} = \frac{I_g}{x'd} \times 100 = \frac{P_n}{\sqrt{3} U_n} \times \frac{100}{x'd}$$

where:  $P_n$  is expressed in kVA

$U_n$  is expressed in volts

$x'd$  is expressed in %

$I_{sc}$  is expressed in kA

$$3\text{-phase } I_{sc} = \frac{250 \times 100}{\sqrt{3} \times 400 \times 30} = 1.2 \text{ kA}$$

# 1. protection of circuits supplied by an alternator (continued)

## J

### 1.2 protection of essential services circuits supplied in emergencies from an alternator

the difficulty is due to the small margin between the rated current and the short-circuit current of the alternator.

The characteristics (s.c. breaking capacity and range of adjustable magnetic tripping unit) of the CBs protecting the circuits of essential loads must be defined as described below:

#### Choice of s.c. breaking capacity

This parameter must always be calculated for the condition of supply from the transformer, or other "normal" source.

#### Adjustment of magnetic tripping units

In practice, the only circuit breakers concerned are those protecting the essential services circuits at the main general distribution board.

The protection of circuits from local distribution or sub-distribution boards is always calibrated at a much lower level than those at the main general distribution board, so that, except in unusual cases, adequate fault currents are available from an alternator to ensure satisfactory protective-gear operation at these lower levels.

Two difficulties have to be overcome:

- the first is the need for discrimination of circuit protection with the protection scheme for the alternator.

For the basic protection requirements of an alternator, viz: overload protection, the curve shown in figure J1-4 is representative (see Note 1).

- the second concerns protection of persons against electric shock from indirect contact, when the protection depends on the operation of overcurrent relays (for example, in IT\* or TN systems). The operation of these relays must be assured, whether the supply is from the alternator or from the transformer (see Note 2).

Instantaneous or short-time delay magnetic-relay trip settings of the circuit breakers concerned must therefore be set to operate at minimum fault levels occurring at the extremity of the circuits they protect, when being supplied from the alternator.

**Note 1.** Sensitive high-speed protection of an alternator against internal faults (i.e. upstream of its CB) is always possible by using a pilot-wire and current-transformers differential scheme of protection, with the advantage that discrimination with circuit protection schemes is absolute. The problem of discriminative overload protection (as noted above) remains, however.

A widely-used solution to this problem is provided by a voltage-controlled overcurrent relay, which depends on the following principle: short-circuit currents cause much lower system voltages than overload currents. An inverse-time/current overload relay is used having two operating curves, one of which corresponds to that of fig. J1-4, and is effective when system voltage levels are normal.

If the system voltage falls below a pre-set value, the relay is automatically switched to operate much faster and at lower current levels than those shown in fig. J1-4.

Modern low-setting magnetic tripping units, however, often provide a simpler solution as noted in 1.3 below.

**Note 2.** Where the level of earth-fault current is not sufficient, in IT\* and TN systems, to trip CBs on overcurrent, the protection against indirect-contact hazards can be provided by an appropriate use of RCDs, as indicated in Chapter G Sub-clause 6.5 Suggestion 2 (for IT circuits) and Sub-clause 5.5. Suggestion 2 (for TN circuits).

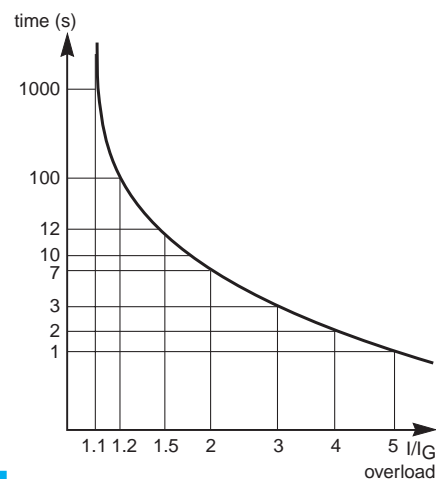


fig. J1-4: overload protection of an alternator.

\* Two concurrent earth faults on different phases or on one phase and on a neutral conductor, are necessary on IT systems, to create an indirect-contact hazard.

### 1.3 choice of tripping units

the calculation of the minimum fault current (in IT or TN schemes) is complex. Software packages for this purpose are available.

#### calculation of the fault-current loop impedance (Zs) for IT and TN systems

The determination of the minimum level of short-circuit current, from the calculation of the fault-loop impedance Zs (by the sum of impedances method) is difficult, mainly because of the uncertainty, in a practical installation, of the accuracy of the zero-phase-sequence impedances. When conductor routes are known in sufficient detail, impedances can then be determined by the use of software, currently available commercially. Approximate methods for 3-phase and 1-phase short circuits are presented in Sub-clause 1.4.

#### types of suitable tripping units

The choice of low-setting magnetic tripping units will generally be necessary, such as Compact NS\* with STR (magnetic-trip short time delay is adjustable from 1.5 to 10 Ir) or circuit breakers Multi 9\* curve B (tripping between 3 and 5 In).

In practice, these CBs (or their equivalents) will always be necessary when the current rating of the CB is greater than one third of the alternator current rating and will, in most cases, obviate the need for voltage-controlled overload relays.

Switchgear manufacturers often furnish tables showing recommended combinations of circuit breakers for commonly-used standby-generator schemes.

\* Merlin Gerin products.

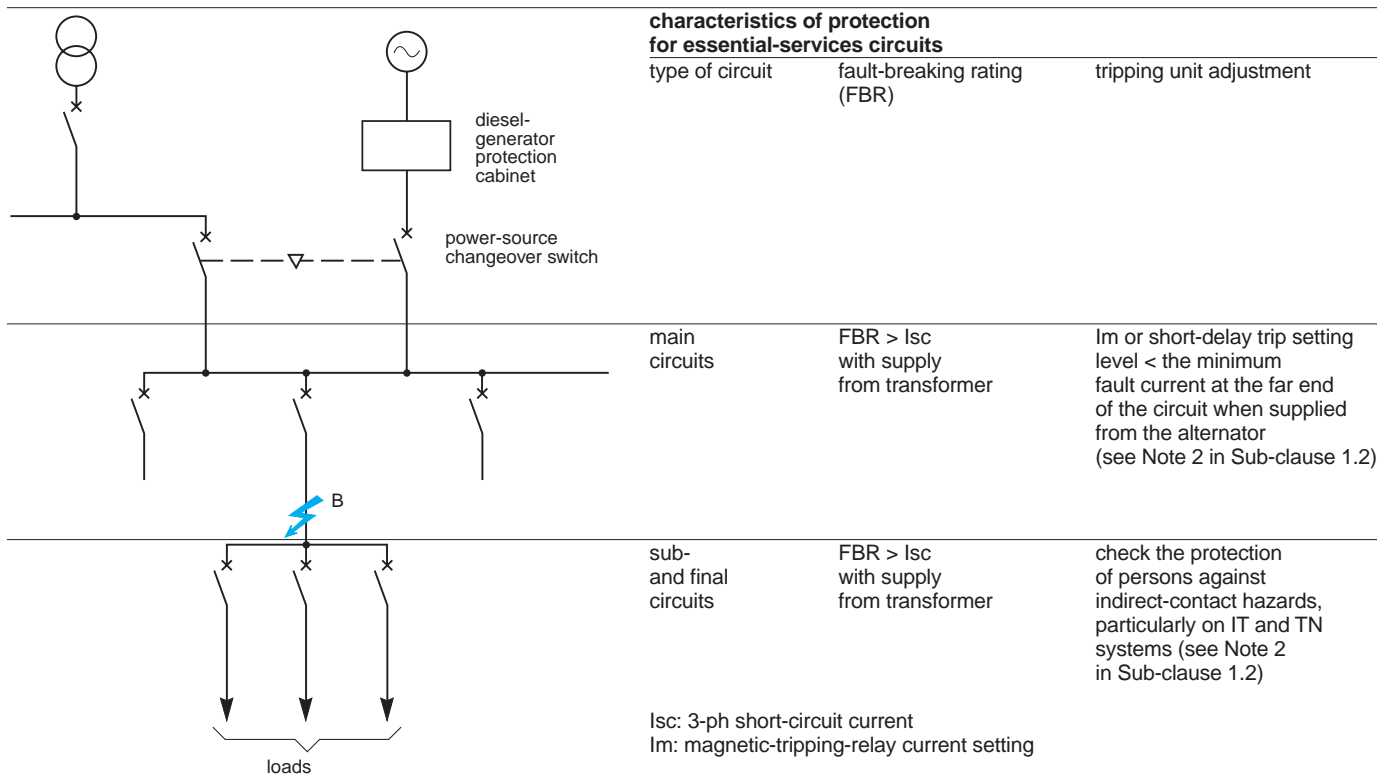


fig. J1-5: the protection of essential services circuits.

# 1. protection of circuits supplied by an alternator (continued)

J

## 1.4 methods of approximate calculation

An installation on (normal) 630 kVA transformer supply (figure J1-6) includes an essential-services distribution board which can also be supplied from a standby 400 kVA diesel-alternator set.

What circuit breakers should be installed on the out-going ways from the essential-services board:

- if the installation is TN-earthed?
- if the installation is IT-earthed?

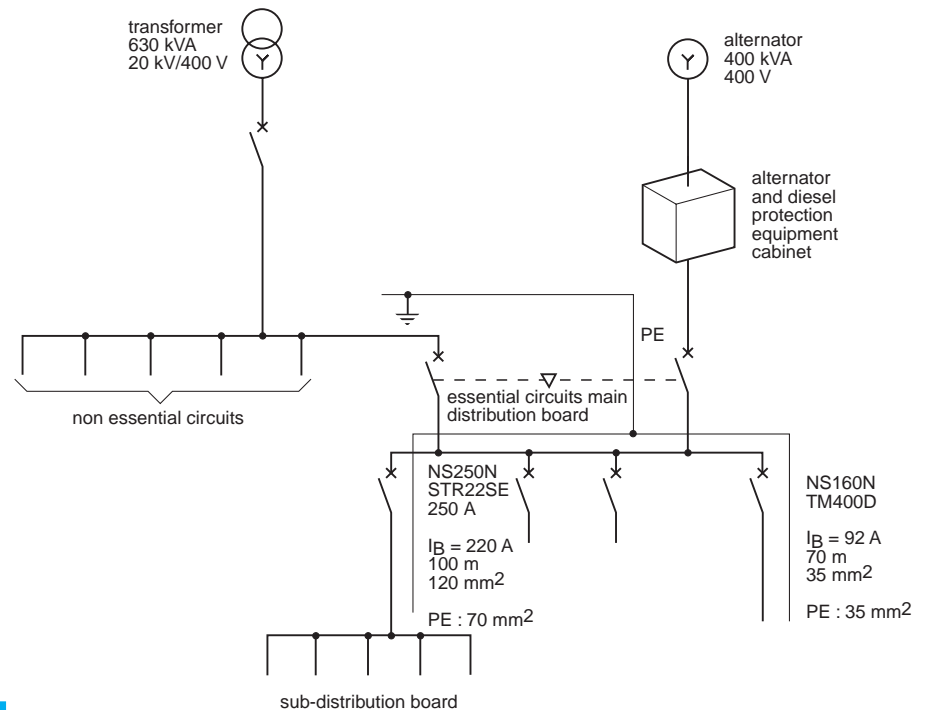


fig. J1-6: example.

### calculation of the minimum level of 3-phase short-circuit current

Table J1-7 shows the procedure for an alternator together with one or several circuits.

item of plant	R mΩ	X mΩ	Z mΩ	I <sub>sc</sub> kA
alternator	R <sub>a</sub>	X' <sub>d</sub>		
circuit	$\frac{22.5 L}{S}$	0.08 x L		
total	R	X	$\sqrt{R^2 + X^2}$	$\frac{1.05xV_n}{\sqrt{R^2 + X^2}}$

table J1-7: procedure for the calculation of 3-phase short-circuit current.

S = c.s.a. in mm<sup>2</sup>

L = length in metres

For the calculation of cable impedance, refer to Chapter H1, Sub-clause 4.2.

**Consider the 220 A circuit in figure J1-6**

■ alternator

$R_a = 0$

$X'd = \frac{Un^2 \times 0.30}{P_n} = \frac{400^2 \times 0.30}{400} = 120 \text{ m}\Omega$

■ circuit

$R_c = \frac{22.5 \times 100}{120} = 18.75 \text{ m}\Omega$

$X_c = 0.08 \times 100 = 8 \text{ m}\Omega$

■ application of the method of impedances as indicated in table J1-7;

$R = R_a + R_c = 0 + 18.75 = 18.75 \text{ m}\Omega$

$X = X'd + X_c = 120 + 8 = 128 \text{ m}\Omega$

total impedance per phase:

$Z = \sqrt{R^2 + X^2} = \sqrt{(18.75)^2 + (128)^2} = 129.4 \text{ m}\Omega$

$I_{sc} = \frac{1.05 V_n}{Z} = \frac{1.05 \times 230}{0.129} = 1.87 \text{ kA (r.m.s.)}$

**Note:** In practice there will always be some measure of d.c. transient current in at least two phases, so that the above value will normally be exceeded during the period required to trip the CB.

**calculation of the minimum level of 1-phase to earth short-circuit fault current**

Table J1-8 shows the procedure for an alternator together with one or several circuits.

item of plant	R mΩ	X mΩ	Z mΩ	Isc kA
alternator	R <sub>a</sub>	$\frac{2 X'd + X_o}{3}$		
circuit	$\frac{22.5 L (1 + m)}{S_{ph}}$	0.08 x L x 2		
total	R	X	$\sqrt{R^2 + X^2}$	$\frac{1.05xV_n}{\sqrt{R^2 + X^2}}$

**table J1-8: procedure for the calculation of 1-phase to neutral short-circuit current.**

For the calculation of cable impedance, refer to Chapter H1, Sub-clause 4.2.

**Consider the 220 A circuit in figure J1-6**

■ alternator

$R_a = 0$

$X_a = (2 \times 120 + \frac{400^2}{400} \times 0.06) \times \frac{1}{3} = 88 \text{ m}\Omega$

■ circuit

$R_c = 22.5 \times \frac{100 \times (1 + 120 / 70)}{120} = 50.89 \text{ m}\Omega$

$X_c = 0.08 \times 100 \times 2 = 16 \text{ m}\Omega$

■ application of the method of impedances, as for the previous example:

$R = R_a + R_c = 0 + 50.89 = 50.89 \text{ m}\Omega$

$X = X_a + X_c = 88 + 16 = 104 \text{ m}\Omega$

The total impedance:

$Z = \sqrt{R^2 + X^2} = \sqrt{50.89^2 + 104^2} = 115.8 \text{ m}\Omega$

and  $I_{sc, (phase/neutral)} = \frac{1.05 \times 230}{115.8} = 2.09 \text{ kA.}$

# 1. protection of circuits supplied by an alternator (continued)

J

## 1.4 methods of approximate calculation (continued)

### maximum permissible setting of instantaneous or short-time delay tripping units

#### ■ TN scheme

Of the two fault conditions considered (3-phase and 1-phase/neutral) the 3-phase fault was found to give the lower short-circuit current. The setting of the protective relay must therefore be selected to a current level below that calculated.

For the 220 A outgoing circuit the trip unit would be rated at 250 A and adjusted (in principle) to  $I_{sc}/250$ , i.e.  $1,870/250 = 7.4 I_n$ . Owing to a  $\pm 20\%$  manufacturing tolerance however, the maximum permissible setting would be  $\frac{7.4}{1.2} = 6.2 I_n$

A tripping unit type TM250D\* set at  $6 I_n$  on a NS250N\* circuit breaker (breaking capacity = 36 kA i.e.  $> 21.5$  kA) would be appropriate;

#### ■ IT scheme

In this case the protection must operate for a second earth fault occurring before the first earth fault is cleared. This condition (only) produces indirect-contact hazards on an IT system.

If the neutral conductor is not distributed, then the minimum short-circuit current for the system will be the phase-to-phase value (i.e. concurrent earth faults on two different phases) which is equal to  $0.866 I_{sc}$  ( $I_{sc}$  = the 3-phase s.c. current).

If the neutral is distributed, the minimum s.c. current occurs when a phase-to-earth fault and a neutral-to-earth fault occur concurrently, and a protective relay setting equal to  $0.5 I_{sc}$  (phase to neutral) i.e. half the value of a phase-to-neutral short-circuit current, is conventionally used to ensure positive relay operation,

□ for the case of a non-distributed neutral, the minimum s.c. current =

$$0.5 \times 0.866 \times 1.87 = 0.81 \text{ kA}$$

The tripping unit rated at 250 A will be set at

$$\frac{810}{250} \times \frac{1}{1.2} = 2.7 I_n$$

(the factor 1.2 accounting for the  $\pm 20\%$  manufacturing tolerance for tripping units).

A TM250D or a STR22SE tripping unit set at  $2.5 I_n$  would be appropriate,

□ when the neutral is distributed, the minimum s.c. current relay setting =

$$0.5 \times 2.08 = 1.04 \text{ kA}$$

The 250 A tripping unit will be set at

$$\frac{1.040}{250} \times \frac{1}{1.2}$$

=  $3.5 I_n$  (the 1.2 factor covering manufacturing tolerance, as before)

A STR22SE tripping unit, set at  $3.0 I_n$  would be satisfactory.

**Note:** The foregoing method is based on a simplified application of the following formulae:

①

$$I_{sc} \text{ (3-phase)} = \frac{V_{ph}}{Z_1}$$

②

$$I_{sc} \text{ (phase/phase)} = \frac{\sqrt{3} V_{ph}}{Z_1 + Z_2}$$

③

$$I_{sc} \text{ (phase/earth)} = \frac{3 V_{ph}}{Z_1 + Z_2 + Z_0}$$

Where

$Z_1$  = positive phase-sequence impedance

$Z_2$  = negative phase-sequence impedance

$Z_0$  = zero phase-sequence impedance

Simplifications:

■  $Z_1$  is assumed to be equal to  $Z_2$  so that formula ② becomes

$$\frac{\sqrt{3} V_{ph}}{2 Z_1} = 0.866 \frac{V_{ph}}{Z_1} \text{ or } 0.866 I_{sc} \text{ (3-phase)}$$

■ In table J1-8 the calculated cable reactance assumes that  $X_1 = X_2 = X_0$  for the cable, so that in formula ③ the total reactance =  $(X_1 + X_2 + X_0) 1/3 = (3 X_1) 1/3 = X_1$

\* Merlin Gerin product.

## 1.5 the protection of standby and mobile a.c. generating sets

Practical guides in certain national standards classify generator sets according to three categories, viz:

- permanent installations (as discussed in Sub-clauses 1.1 to 1.4);
- mobile sets (figure J1-9);
- portable power packs (figure J1-10).

### mobile sets

These are used mainly to provide temporary supplies (on construction sites for example) where protection of persons against electric shock must be ensured by the use of RCDs with an operating threshold not exceeding 30 mA.

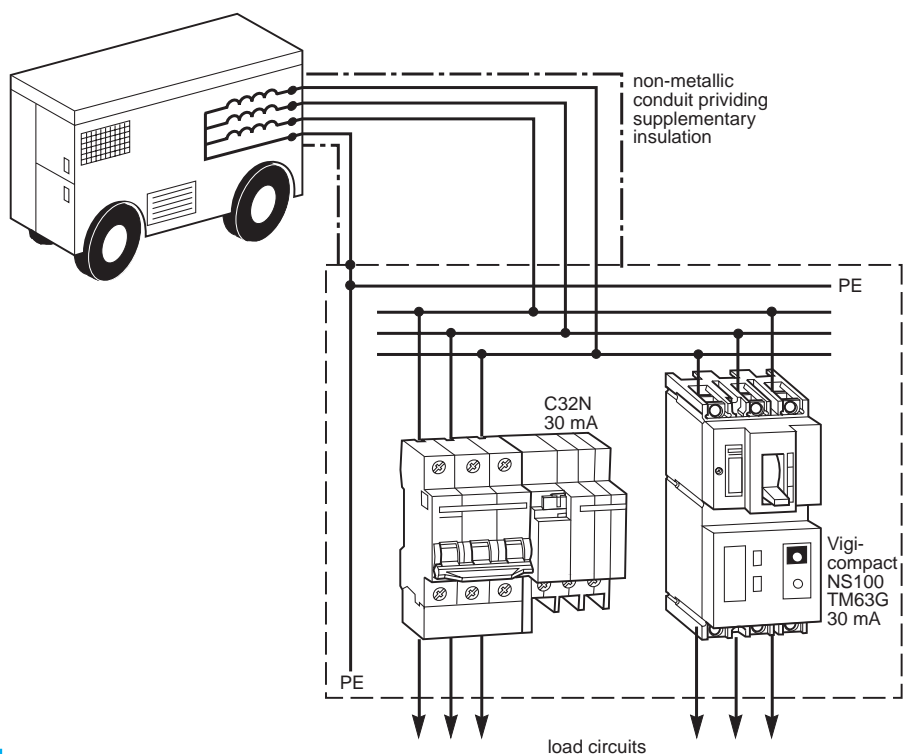


fig. J1-9: mobile generating set.

### portable power packs

The use of hand-carried power packs by the general public is becoming more and more popular. When the pack and associated appliances are not of Class II (i.e. double insulation), 30 mA RCDs are required by most national standards.

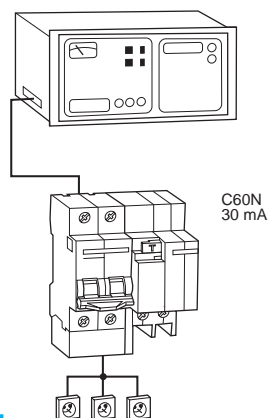


fig. J1-10: portable power pack with RCD protection.

## 2. inverters and UPS (Uninterruptible Power Supply units)

J

### 2.1 what is an inverter?

An inverter produces an a.c. supply of high quality (i.e. an undistorted sine-wave, free from interference) from a d.c. source; its function is the inverse of that of a rectifier (figure J2-1).

Its main purpose (when associated with a rectifier which provides its input) is to afford a high-quality power supply to equipment for which the interference and disturbances of a normal power-supply system cannot be tolerated (e.g. to computer systems). Power systems are subjected to many kinds of perturbation which adversely affect the quality of supply: atmospheric phenomena (lightning, freezing), accidental faults (short-circuits), industrial parasites, the switching of large electric motors (lifts, fluorescent lighting) are among the many causes of poor quality of supplies.

Apart from occasional loss of supply, the disturbances take the form of more-or-less severe voltage dips, high- and low-frequency parasites, continuous "noise" from

fluorescent-lamp circuits and (normally undetectable, but totally unacceptable to sensitive electronic systems) of mini-interruptions of several milli-seconds. By the addition of a storage battery at the input terminals of the inverter (and therefore across the output terminals of the associated rectifier), an elementary UPS system is formed.

In normal circumstances, the rectifier supplies the load through the inverter, while, at the same time, a trickle charge from the rectifier maintains the battery fully charged.

A loss of a.c. power supply from the distribution network would simply result in the battery automatically maintaining the output from the inverter with no discernable interruption.

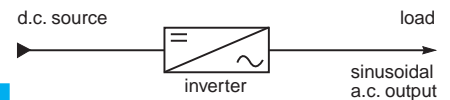


fig. J2-1: inverter function.

### 2.2 types of UPS system

there are two main types of UPS system:

- off-line,
- on-line.

Several types of UPS system exist according to the degree of protection against power-network "pollution" required, and whether supply autonomy (automatic standby-supply on the loss of normal power supply) is specified, or not. The two most commonly-used types are described below.

**An off-line type of UPS system** (figure J2-2) is connected in parallel with a supply direct from the public distribution network, as shown in figure J2-2, and is autonomous, within the capacity of its battery, on loss of the a.c. power supply. In normal operation the filter improves the quality of the current while the voltage is maintained sensibly constant at its declared value by appropriate and automatic regulation within the filter unit.

When the tolerance limits are exceeded, including a total loss of supply, a contactor, which carries the normal load, changes over rapidly to the UPS unit (in less than 10 ms) the power then being supplied from the battery. On the return of normal power supply, the contactor changes back to its original condition; the battery then recharges to its full capacity.

These units are normally of low rating ( $\leq 3$  kVA) but are capable of passing large

transient currents such as those for motor-starting and switching on of (cold) resistive loads. The most common use for such units is the supply to multi-workstation ITE (information technology equipment) installations, such as cash registers.

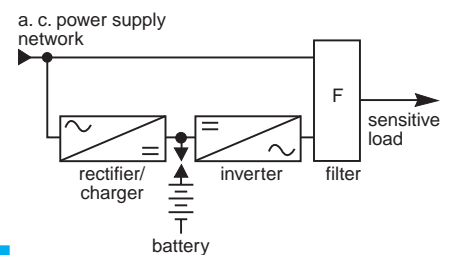


fig. J2-2: off-line UPS system.

**An on-line type of UPS system** (figure J2-3) is connected directly between the public a.c. supply network and the load, and has an autonomous capability, the period of which depends on the battery capacity and load magnitude.

The total load passes through the system, which affords a supply of electrical energy within strict tolerance limits, regardless of the state of the a.c. power supply network. On loss of the latter, the battery automatically, and without interruption, maintains the pollution-free a.c. supply to the load.

This system is equally suitable for small loads ( $\leq 3$  kVA) or large loads (up to several MVA).

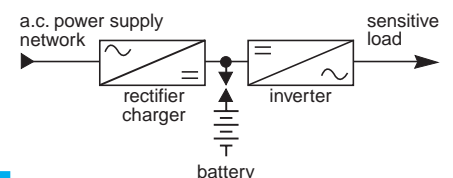


fig. J2-3: on-line UPS system.

Other apparatus, not assuring a no-break performance, but which protect sensitive loads from certain disturbances commonly occurring on power distribution network, include the following:

- the filter-plug which is simply an a.c. plug for connecting or interconnecting loads, which has built-in HF (high-frequency) filters, in order to reduce HF parasitic interference to acceptable levels. Its principal use is on micro-informatic stand-alone PCs rated at 250 to 1,000 VA, for general office purposes;

- the network (or mains) -supply conditioner is a complete system for providing an uncontaminated a.c. power supply, but without autonomy, i.e. no provision against loss of supply from the a.c. distribution network.

Its principal functions are to:

- filter out HF parasites,
- maintain a sensibly-constant voltage level,
- isolate (galvanically) the load from the a.c. power network.

It is equally applicable to office or industrial systems which do not require a no-break standby supply, up to ratings of 5,000 VA;

- the slim-line UPS has integral protection with autonomy for each micro-informatic stand-alone PC and its peripherals, and is installed immediately under the micro-processor. Two outputs, each with back-up from the UPS unit, supply the central processor and screen. Two further outputs, which are filtered, supply other less-sensitive units (e.g. the printer). The slim-line UPS belongs to the class of off-line UPS schemes.

types of UPS units, conditioners and filters	filter plug	mains-supply conditioner	slim-line UPS	off-line UPS	on-line UPS
diagrams of principle					
<b>disturbances considered</b>					
type of network disturbance					
corrective measures					
HF parasites	■	■	■	■	■
variations of voltage		■	■	■	■
regulation					
<b>autonomy</b>					
10 to 30 mn (according to battery capacity)			■	■	■
<b>rated power</b>					
≤ 250 VA	■	■	■	■	■
300 - 1,000 VA		■	■	■	■
1,000 - 2,500 VA		■		■	■
> 2,500 VA		■			■
<b>applications</b>					
	minimal protection	all sensitive loads	micro-informatic stand-alone PC	micro-informatic terminals	highly disturbed a.c. power systems and/or heavy loads

table J2-4: examples of different possibilities and applications of inverters, in decontamination of supplies and in UPS schemes.

### 2.3 standards

The international standard presently covering semi-conductor converters is IEC 146-4.

### 2.4 choice of a UPS system

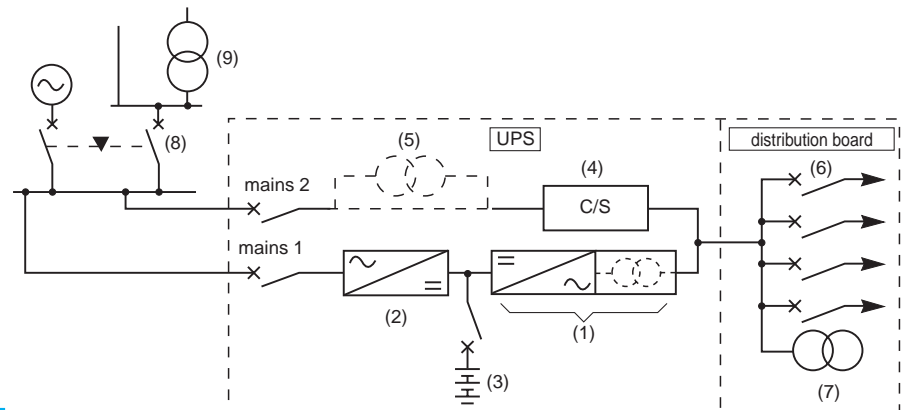
The choice of a UPS system is determined mainly by the following parameters:

- rated power, based on:
  - maximum value of actual estimated kVA demand,
  - transitory current peaks (motor starting, energization of resistive loads, transformers...).

**Note:** in order to obtain satisfactory discrimination of protective devices for all

types of load, it may be necessary to adjust the power rating of the UPS system.

- voltage levels upstream (input) and downstream (output) of the UPS unit;
- duration of autonomy required (i.e. supply from the battery);
- frequencies upstream (input) and downstream (output) of the UPS unit;
- level of availability required.



**fig. J2-5: classical arrangement of a UPS on-line installation, using an inverter.**

- UPS
1. inverter
  2. rectifier/charger
  3. batteries (usual periods of autonomy 10 - 15 - 30 mn - several hours)
  4. static contactor (see "availability" below)
  5. isolating transformer, if galvanic isolation from upstream circuits is necessary.
  6. outgoing ways
  7. transformer for specific downstream-circuits voltage
  8. changeover switch
  9. transformer to match the upstream voltage to that of the consumer.

**Note:** At first sight, the circuit arrangement in figure J2-5 closely resembles that of the off-line UPS system (of figure J2-2). In fact, however, it is an on-line system, in which the load is normally passing through circuit 1. The static contactor is open in this situation, but closes automatically if the UPS system becomes overloaded, or fails for any reason. In such a case, the load will then be supplied from the (reserve) circuit 2. This action is the converse of that of the off-line scheme.

Conditions will automatically return to normal if the overload, etc. is corrected.

In this arrangement, the voltage output of the inverter is always maintained in synchronism with the voltage of the power-supply network (i.e. within close tolerance limits of magnitude and phase difference) thereby minimizing the disturbance in the event of "instantaneous" changeover from circuit 1 to circuit 2 operation.

the power rating of a UPS unit must take account of the peak motor-starting currents, of the possibility of future extensions to the installation, and of the overload capability of the inverter and other UPS-unit components.

#### power (VA)

The rated power of the UPS unit must be sufficient to satisfy the steady load demand as well as loads of a transitory nature. The demand will be the sum of the apparent (VA) loads of individual items, for example, the CPU (central processing unit) and will amount to  $P_a$ , generally corrected by a factor (1.2 to 2) to allow for future extensions.

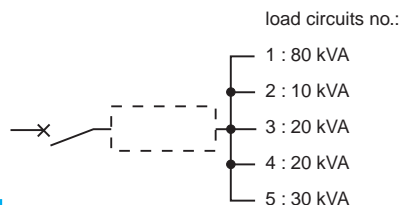
However, in order to avoid oversizing of the installation, account should be taken of the overload capacity of the UPS components. For example, inverters manufactured by Merlin Gerin can safely withstand the following overloaded condition:

- 1.5  $I_n$  for 1 minute;
- 1.25  $I_n$  for 10 minutes.

Instantaneous variations of load: these variations occur at times of energizing and de-energizing of one or more items of load. For an instantaneous change of load up to 100 % of the nominal rating of the UPS unit, the output voltage generally remains between + 10 % and - 8 % of its rated value.

**Example of a power calculation**

Choice of a UPS unit suitable for the loads shown in figure J2-6.



**fig. J2-6: example.**

Assumed operating constraints:  
 circuit no. 4 will take a transitory current equal to 4 In for a period of 200 ms when initially energized. This operation will be carried out at least once a day. The peak kVA demand, therefore, represents a supplement (over the steady-state 20 kVA demand) of  $3 \times 20 \text{ kVA} = 60 \text{ kVA}$ .

The remaining circuits require no such transitory peak currents. In all cases the kVA values cited have taken the load power factors into account. Possible future extensions to the installation are estimated to amount to 20% of the existing load.

The maximum steady-state power demand presently considered is therefore:

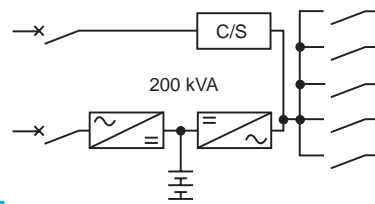
$$P = 80 + 10 + 20 + 20 + 30 = 160 \text{ kVA.}$$

$$\text{With allowance for extensions (of 20\%)} \\ = 160 \times 1.2 = 192 \text{ kVA.}$$

$$\text{With an additional 200 ms peak of (3 x 20)} \\ \text{kVA the total amounts to } 192 + 60 = 252 \text{ kVA.}$$

The total of 252 kVA however, includes the 60 kVA peak current which is easily absorbed by the 1.5 In overload capability of (a M.G) UPS system, so that the rating of a suitable UPS unit would be  $252 \times 1/1.5 = 168 \text{ kVA}$  for the nearest standard rating available above the calculated value, e.g. 200 kVA.

For the choice of suitable protective devices, see Sub-clause 2.9.



**fig. J2-7: solution to the example.**

**availability**

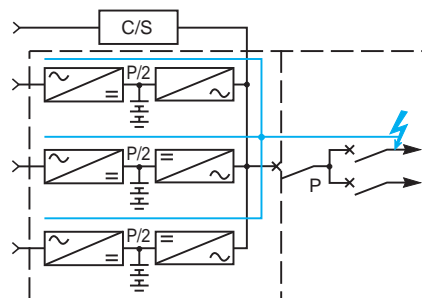
A UPS system is generally provided with an alternative (unconditioned) emergency source, a situation which affords a relatively high level of availability.

By way of example, a UPS alone has a MTBF (mean time between failures) of 50,000 hours.

In the usual case, where the supply is doubled as noted above (mains 1 and mains 2 in figure J2-5) the MTBF obtained is in the range 70,000 to 200,000 hours, depending on the availability of the second source.

Switching from one source to the other is achieved automatically by a static (solid state) contactor.

Configurations having a higher redundancy, e.g. three UPS units each rated at P/2 to supply a load of P (figure J2-8) are also sometimes installed. The calculation of their level of availability can be carried out by specialists, and the manufacturers are able to quote availability levels, relative to their own products and recommended layouts.



**fig. J2-8: 3 UPS P/2 units providing a high level of availability of a power rated P.**

### 2.5 UPS systems and their environment

UPS system components include the means to communicate with other equipments.

UPS units can communicate with other equipments, notably with IT (information technology) systems, passing data concerning the state of the UPS components (static contactor open or closed, and so on...) and receiving orders controlling its function, in order to:

- optimize the protection scheme: the UPS, for example, transmits data (such as: condition normal, supply being maintained by the battery, alarm for period of autonomy almost reached) to the computer it is supplying. The computer deduces the appropriate corrective action, and indicates accordingly;

- permit remote control: the UPS transmits data concerning the state of UPS components, together with measured quantities, to the console of an operator, who is then able to carry out operational manoeuvres through remote-control channels;

- supervise (manage) the installation: the consumer (i.e. the "user") has a centralized management technique facility which allows him to acquire data from the UPS unit(s) which are then stored and analysed, with anomalies indicated, and the state of the UPS is presented on a mimic board or displayed on a screen, and finally to exercise remote control of UPS functions (figures J2-9 to J2-11).

This evolution towards a general compatibility between diverse systems and related hardware requires the incorporation of new functions in the UPS systems. These functions can be designed to ensure mechanical and electrical compatibility with other equipments: standard versions are now provided with dry contacts and current loops. Interconnection facilities according to the standards RS 232, RS 422 or RS 485 can be incorporated on request.

In fact, certain advanced modules include modern cards with integral protocols (JBUS for example).

Furthermore, they can make use of specialized software for automatic checking and fault diagnosis (e.g. Soft-Monitor on PC) which may be integrated into other systems of overall supervision (figure J2-10).



fig. J2-9: UPS units can communicate with centralized system management terminals.

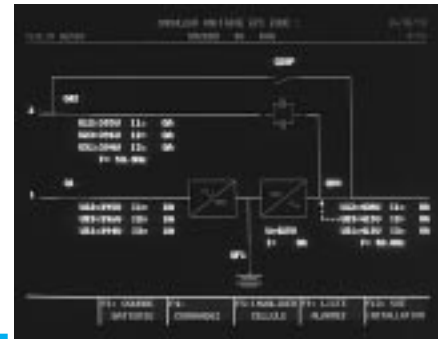


fig. J2-10: software (e.g. Soft-Monitor) allows remote checking and automatic fault diagnosis of the UPS system.



fig. J2-11: UPS units are readily integrated into centralized management systems.

## 2.6 putting into service and technology of UPS systems

UPS unit for individual stand-alone PCs.

### location of UPS units



fig. J2-12: a UPS (slim-line) is easily accommodated under the computer of a stand-alone PC.

UPS system installed in a computer room.



fig. J2-13: for large computer installations, the UPS cabinets are generally located in the computer room.

UPS cabinets installed in an electrical services room.



fig. J2-14: large UPS systems are frequently located in an electrical services room.

### 2.6 putting into service and technology of UPS systems (continued)

#### types of battery

Two types of battery are associated with UPS systems.

#### Maintenance-free sealed units

These batteries are used for systems rated at 250 kVA or less, and provide an autonomy of up to 30 minutes. For certain installations, the natural ventilation of its location is considered to be adequate, provided that the particular conditions of charging and regulation, together with the characteristics of the battery, respect the necessary constraints. These constraints are defined in the national standards of some countries (e.g. NF C 15-100, Sub-clause 554 for France). To date, there is no IEC equivalent recommendation, so that consultation with the battery manufacturer may be advisable.

#### Non-sealed batteries

These batteries are generally lead-acid units and are used for all large installations. The batteries must be installed in dedicated battery rooms, which usually require forced-air ventilation. For certain applications, open-type (i.e. non-sealed) cadmium-nickel batteries are preferred.

#### battery location

For any closed location housing batteries, most national standards impose a system of ventilation, forced or natural, which relates the renewal rate of air to the size and charging rate of the battery (or batteries). A recommended air-change rate in cubic metres per hour can be calculated from the formula  $0.05 NI$  where:

$N$  = number of cells in the battery

$I$  = maximum charging-current capability of the battery charger (in amperes).

In the case of forced ventilation, the battery charger must be automatically switched off if the fan(s) of the system fail, or if the air-flow is stopped or reduced, for any other reason. For UPS systems of large rating, the batteries are generally located in specially designed battery rooms, complying with the relevant local standards and regulations.



fig. J2-15: a typical battery room.

## 2.7 earthing schemes

### general

In the general case the UPS system is fed from two circuits (as shown typically in figure J2-16) each of which is protected separately; they are referred to as mains 1 and mains 2. Mains 1 is a 3-phase 3-wire circuit connected to the UPS rectifier/charger input terminals, while mains 2 is a 3-phase 4-wire circuit connected to the upstream terminals of the static contactor. The downstream distribution board is supplied at 230/400 V. Where other values of voltage are required, adaptor transformers may be employed.

### galvanic separation of the upstream and downstream circuits of the UPS system

The measures taken to provide protection against electric shock depend on the earthing scheme, and therefore on the existence, or not, of galvanic separation of the downstream circuits from the upstream circuits. Manufacturers should be ready to provide all the necessary information.

■ if there is no separation, then the earthing scheme is evidently identical on both sides of the UPS system;

■ if there is complete separation between the upstream and downstream sides of the UPS system, the earthing schemes upstream and downstream may be different (or identical). The Technical Notes CT 129 of Merlin Gerin explain this subject in more detail.

### TT/TT scheme

The neutral of the inverter cannot be permanently connected to earth, as described above, but only temporarily, i.e. when D2 is open in figure J2-16. D2 is a 4-pole circuit breaker which breaks the neutral conductor when it is open. The neutral conductor is earthed at the HV/LV transformer, and so, when D2 opens, contactor C closes automatically to reconnect the neutral busbar of the LV distribution board to earth.

#### General protection

A RCD is installed at each outgoing way of the MGDB feeding the UPS system (D1 and D2 in figure J2-16) and discrimination between these RCDs and those on the outgoing ways of the DB downstream of the UPS system, is arranged to ensure the maximum possible continuity of supply. The sensitivity of the RCDs is selected according to the value of earthing resistance (electrode plus earth-wires).

**Note:** Certain versions of RCD are designed to avoid malfunctioning under abnormal conditions (d.c. components of current...) that are sometimes generated by UPS systems. It is recommended that the manufacturers of the UPS system be consulted concerning this aspect of their product.

### Protection of the d.c. circuits of the UPS system

■ battery protection:

most national standards and codes of practice, covering battery installations are based on stringent regulations, which, if properly observed, reduces the probability of a short-circuit fault or an accidental indirect contact occurring, sufficiently, to consider that the circuit from the battery terminals to the controlling circuit breaker adequately assures the safety of persons. Such will be the case, if:

□ the battery and all d.c. circuits are in the same cabinet as the other components of the UPS system, i.e. an equipotential location is created,

□ in the case of a battery location remote from the UPS system, class II insulation standards are respected;

■ for the remainder of the installation: in particular, the section from the downstream side of the battery circuit breaker and the junction of the rectifier output with the inverter input, where an insulation fault on the d.c. circuits presents a risk, an insulation monitoring scheme is strongly recommended. A suitable system of permanent surveillance injects a low-frequency test current (a XM 200\* monitor, as mentioned in Merlin Gerin Technical Notes CT 129, for example).

### Protection of pollution-free output circuits

Circuits supplying socket-outlets will be protected by RCDs of 30 mA (or less) sensitivity (for example, differential circuit breakers Multi 9 curve B 30 mA)\*. Other outgoing ways should be protected by RCDs of suitable sensitivity (in general 300 mA) which must discriminate with the protection afforded by D1 and 2 (figure J2-16).

\* Merlin Gerin product.

### 2.7 earthing schemes (continued)

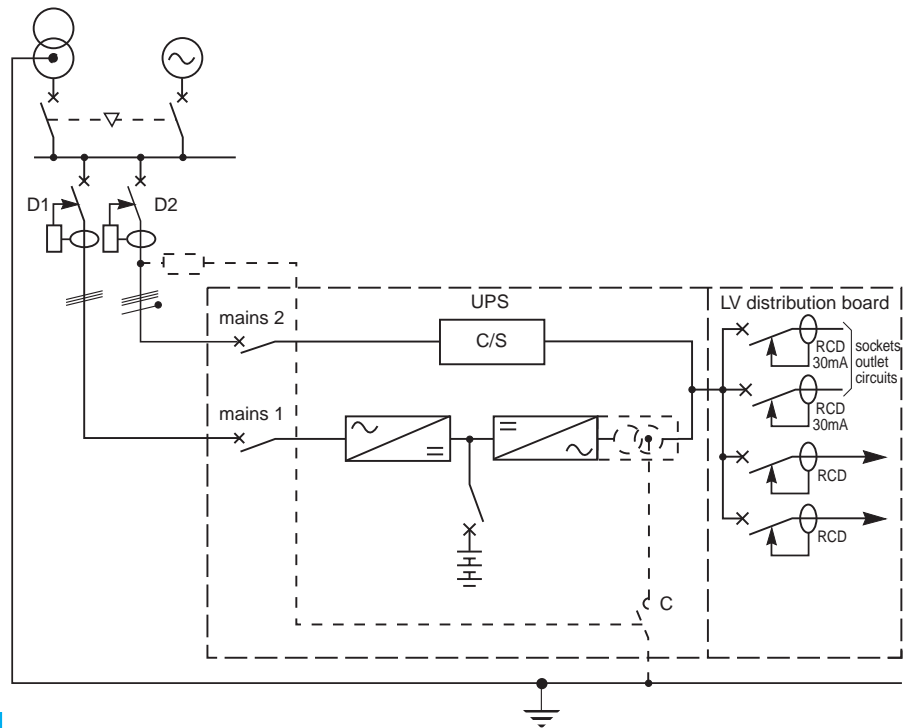


fig. J2-16: TT/TT scheme.

### TN-C / TN-S scheme

■ the automatic cut-off of supply by indirect-contact hazard protection is achieved in this scheme by overcurrent relays. The calculation of the impedance loop  $Z_s$  however, is not possible in this case. The basic rule to be observed, is that the short-circuit current from the inverter (which is the maximum it can pass before its internal protection operates) exceeds that of the tripping threshold of downstream overcurrent protection.

Circuit breakers with magnetic trip units of low-setting ranges are suitable for both TN-C and TN-S schemes. For TN-S installations (only) RCDs of medium sensitivity may also be used;

- the d.c. section of the UPS system is protected as previously described for the TT scheme;
- protection for the pollution-free output circuits will be by 30 mA RCDs for circuits supplying socket outlets, and by circuit breakers of low short-circuit tripping settings, previously mentioned.

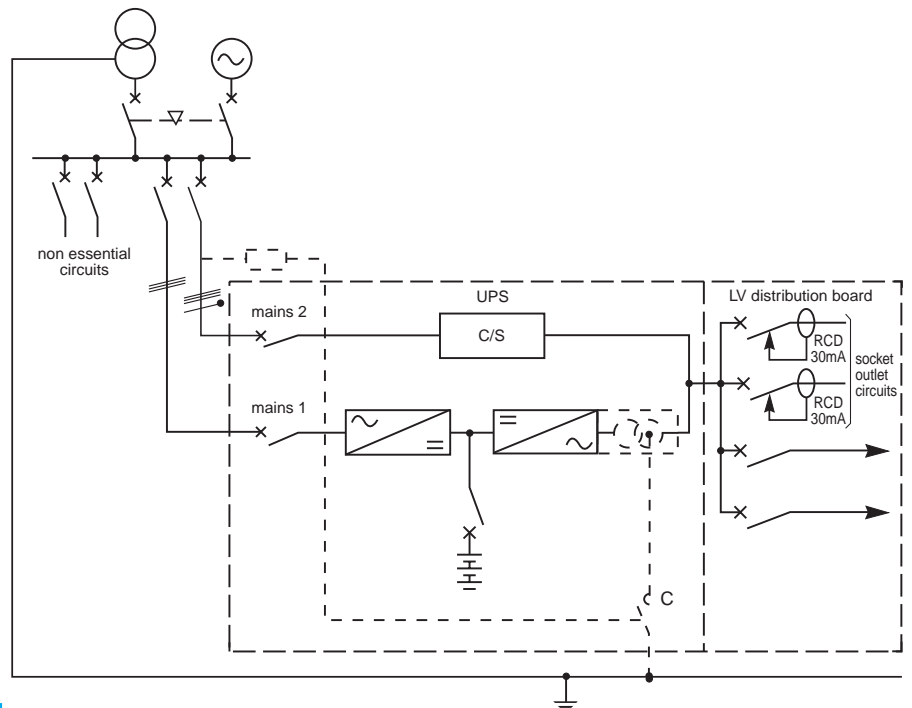


fig. J2-17: TN-C/TN-S scheme.

## IT/IT scheme

### ■ insulation monitoring

The CIC<sub>1</sub> continuous insulation check relay at the origin of the installation (between the isolated neutral point of the HV/LV transformer and earth) is automatically replaced by the CIC<sub>2</sub> at the output of the inverter, when mains 2 is out of service;

### ■ the choice of CIC

□ on the d.c. section of the system, CIC<sub>3</sub> uses a very low frequency a.c. current injection relay, type Vigilohm XM 200\*;

□ on the a.c. sections, the CIC<sub>1</sub>, and CIC<sub>2</sub> relays are d.c. current-injection relays of type TR 22A\*. In fact, a fault on the d.c. part of the system will be detected by CIC<sub>1</sub> and CIC<sub>2</sub> but these relays will not operate because the impedance measurement made by them is not correct.

CIC current-injection relays operating at very low frequency (type XM 200\* for example) allow correct measurement of the impedance;

### ■ reminder of IT system constraints

The design and operation of an IT system requires careful study and exploitation.

The advantages of IT operation can only be realized if an in-depth study is completed by clear and concise operating instructions. In particular, the capacitances present in the network (cables and filters on appliances) must be taken into account, and all items of load must be insulated to withstand phase-to-phase voltage.

\* a Merlin Gerin product.

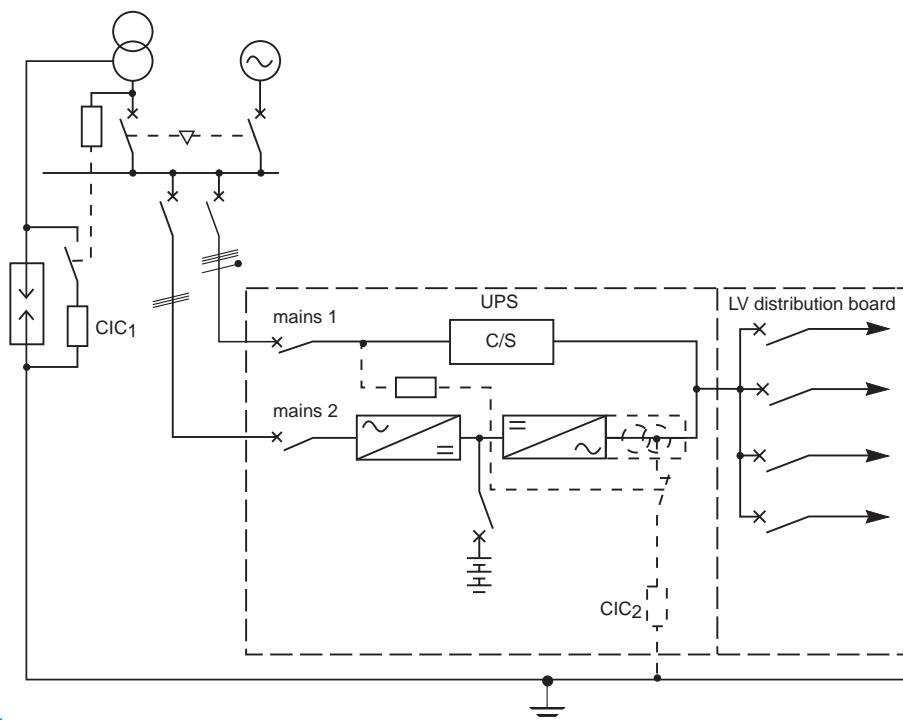


fig. J2-18: IT/IT scheme.

### complete galvanic separation of the circuits upstream of the UPS system from those downstream

Galvanic separation of the upstream and downstream circuits of the UPS system is sometimes required, and is effected by installing a 2-winding transformer upstream of the static contactor. In this case, the earthing schemes upstream and downstream of the separation can be different, so that the type of earthing required for the downstream circuits can be created at the output transformer of the inverter.

### Protection of the d.c. circuits of the UPS system

The d.c. circuits of the UPS system are protected as already described, and the insulation monitoring relays, if required, are selected as indicated in Sub-clause 2.7 for the IT/IT scheme.

### 2.8 choice of main-supply and circuit cables, and cables for the battery connection

self-contained UPS units of small power ratings are supplied for direct connection, by plugging into their input and output sockets.

#### ready-to-use UPS units

The UPS units for low-power applications such as individual PCs and micro-informatic installations are marketed as complete units in a metal enclosure, as shown typically in figure J2-19. All internal wiring is factory-installed and adapted to the characteristics of the components.



fig. J2-19: ready-to-use UPS unit.

in other cases, wiring and cables, for interconnection of the several elements of the UPS system, must be installed by the consumer's contractor.

#### UPS systems requiring interconnection of constituent elements.

For larger UPS installations the battery is generally located at some distance from the inverter, and in the case of an off-line arrangement the static contactor and filters (if installed) require interconnection. The cable sizes selected depend on the current level at each interconnection, as indicated in figure J2-20, and described below.

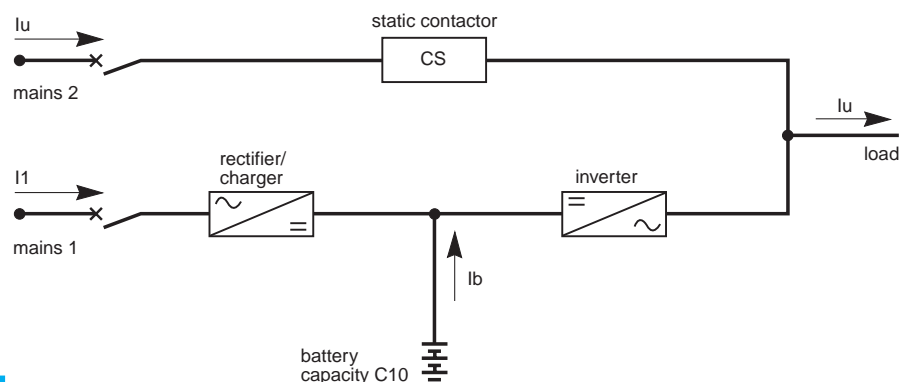


fig. J2-20: currents to be considered for cable selection.

#### Calculation of the currents $I_1$ and $I_u$

- current  $I_u$  is the maximum estimated utilization current of the load;
- current  $I_1$  input to the rectifier/charger of the UPS system depends on:
  - the capacity of the battery (C10) and its charging rate,
  - the characteristics of the charger,
  - the output from the inverter;
- the current  $I_b$  is the current in the battery cable. These current magnitudes are obtained from the manufacturers of the UPS equipment.

#### Choice of cables

In this application the basis of cable selection is the maximum voltage drop allowable for satisfactory performance of the load.

Preferable values are for this application:

- 3% for a.c. circuits;
- 1% for d.c. circuits.

Each of these parameters imposes a minimum c.s.a. of conductor. Calculation of the c.s.a. of conductors may be carried out as shown in Chapter H1 Clause 2.

Merlin Gerin recommends cable sizes to be used with Maxipac and EPS 2000 systems (tables J2-22 to J2-24) in normal conditions, for cable lengths of less than 100 m (voltage drop < 3 %).

Table J2-21 shows the voltage drop for d.c. circuit lengths of less than 100 m of copper cable. That for a.c. cables can be calculated as described in Chapter H1 Clause 3.

The voltage-drop values in % given in table J2-21 correspond to a nominal d.c. voltage of 324 V. For other voltage levels multiply the table values by a factor equal to the actual battery voltage divided by 324.

c.s.a.	mm <sup>2</sup>	25	35	50	70	95	120	150	185	240	300
In (A)	100	5.1	3.6	2.6	1.9	1.3	1	0.8	0.7	0.5	0.4
	125		4.5	3.2	2.3	1.6	1.3	1	0.8	0.6	0.5
	160			4.0	2.9	2.2	1.6	1.2	1.1	0.8	0.7
	200				3.6	2.7	2.2	1.6	1.3	1	0.8
	250					3.3	2.7	2.2	1.7	1.3	1
	320						3.4	2.7	2.1	1.6	1.3
	400							3.4	2.8	2.1	1.6
	500								3.4	2.6	2.1
	600								4.3	3.3	2.7
	800									4.2	3.4
	1000									5.3	4.2
	1250										5.3

table J2-21: voltage drop in % of 324 V d.c. for a copper-cored cable.

nominal rated power	current (A)					c.s.a. (mm <sup>2</sup> ) of copper-cored cables of length < 100 m		
	circuit 1 with battery (1)				circuit 2 or load	circuit 1		circuit 2 or load
	I1	I1	I1	I1		3-phase 400 V	1-phase 230 V	
		I1 battery floating	I1 battery on charge	I1 battery floating	I1 battery on charge	Iu		
3.5 kVA				18	20	16		10
5 kVA	8.5		10.5	26	28	23	6	16
7.5 kVA	15		19			34	10	16
10 kVA	20		24			45.5	10	16
15 kVA	30		38			68	10	16
20 kVA	40		48			91	10	16

table J2-22: currents and c.s.a. of copper-cored cables feeding the rectifier, and supplying the load for UPS system Maxipac (cable lengths < 100 m).

nominal rated power	current (A)						c.s.a. (mm <sup>2</sup> ) of copper-cored cables of length < 100 m		
	circuit 1 with battery 3-phase 400 V				circuit 2 or load 400 V Iu	battery Ib	circuit 1 3-phase 400 V	circuit 2 or load 3-phase 400 V	battery
	I1	recharging for standby period of:							
		floating	10 mn	15 mn	30 mn				
10 kVA	19	23	25	25	15.2	27	10	10	10
15 kVA	29	36	37	39	22.8	40.5	10	10	10
20 kVA	37	49	50	52	30.4	54	16	10	16
30 kVA	58	73	76	78	45	81	25	16	25
40 kVA	75	97	100	104	60.8	108	35	25	35
60 kVA	116	146	151	157	91.2	162	50	35	70
80 kVA	151	194	201	209	121.6	216	70	50	95

table J2-23: currents and c.s.a. of copper-cored cables feeding the rectifier, and supplying the load for UPS system EPS 2000 (cable lengths < 100 m). Battery cable data are also included.

## 2. inverters and UPS (Uninterruptible Power Supply units) (continued)

### J

### 2.8 choice of main-supply and circuit cables, and cables for the battery connection (continued)

nominal rated power	current (A)				
	circuit 1 with battery 3-phase 400 V - I <sub>1</sub>			circuit 2 or load 3-phase 400 V I <sub>u</sub>	battery I <sub>b</sub>
	floating	recharging for standby period of:			
		10 mn	15-30 mn		
40 kVA	70	86	87.6	60.5	109
60 kVA	100	123	127	91	160
80 kVA	133	158	164	121	212
100 kVA	164	198	200	151	255
120 kVA	197	240	244	182	317
160 kVA	261	317	322	243	422
200 kVA	325	395	402	304	527
250 kVA	405	493	500	360	658
300 kVA	485	590	599	456	790
400 kVA	646	793	806	608	1050
500 kVA	814	990	1005	760	1300
600 kVA	967	1180	1200	912	1561
800 kVA	1290	1648	1548	1215	2082

table J2-24: input, output and battery currents for UPS system EPS 5000 (Merlin Gerin).

For a given power rating of a UPS system, these tables indicate the value of input current I<sub>1</sub> to the rectifier/charger when the battery is on trickle charge (i.e. "floating") as well as the load current I<sub>u</sub>, together with the c.s.a. of corresponding input and output cables.

The value of I<sub>1</sub> when the battery is recharging (following a period in which the load has been temporarily supplied entirely from the battery) has no influence on the sizing of the cable, due to the short duration of the recharging cycle. The recharging current has to be taken into account however, to correctly determine the upstream protection requirements of circuit 1.

#### Example:

For a Maxipac UPS system rated at 7.5 kVA 3-phase 400 V, I<sub>1</sub> = 15 A with the battery floating and I<sub>u</sub> = 34 A (see table J2-22). The c.s.a. of the corresponding cables are: 10 mm<sup>2</sup> for the (3-phase) input cable to the rectifier/charger, 16 mm<sup>2</sup> for the (1-phase) output cable to the load.



fig. J2-25: examples of interconnections.

## 2.9 choice of protection schemes

in the choice of protection schemes, it is necessary to take account of the characteristics particular to UPS systems.

In the choice of protection schemes, it is necessary to take account of the characteristics particular to UPS systems: the short-circuit current from a UPS system is always very limited, sometimes less than

twice its rated current. Manufacturers carry out tests to ensure a satisfactory co-ordination between the characteristics of the UPS system and the protection afforded by associated CBs.

### choice of circuit breaker ratings

The current ratings ( $I_n$ ) of CBs D1, D2, D3 and Ddc (figure J2-26) must be chosen such, that:

$I_n \geq I_1$  for D1 ( $I_1$  including the battery re-charging current)

$I_n \geq I_u$  for D2

$I_n \geq I_{de}$  for Ddc

The current rating ( $I_n$ ) for each outgoing CB D3 depends on the current rating of the particular circuit.

The currents  $I_1$  and  $I_u$  for UPS systems of Merlin Gerin manufacture, are given in tables J2-22 to J2-24. The currents  $I_b$  are given in the Merlin Gerin low-voltage distribution catalogue.

### fault-current breaking capacity of the circuit breakers

#### Circuit breakers D1 and D2

These CBs must have a fault-current breaking rating equal to or exceeding the value calculated for its location in the network. The calculation is made conventionally, as previously indicated in Chapter H1, Sub-clauses 4.1 and 4.2, for example.

#### Circuit breaker Ddc

The short-circuit current breaking level for this CB is always low. In fact, the maximum short-circuit current from a battery is always less than 20 times its ampere-hour capacity (battery capacities are indicated in the Merlin Gerin low-voltage distribution catalogue).

#### Circuit breakers D3

The very low level of short-circuit current available from the UPS system, gives rise to particularities concerning the organization of discriminative tripping on the one hand, and protection against indirect-contact hazards in TN systems, on the other.

■ case 1: circuit configuration in which the static contactor is closed, but without any particular requirement concerning autonomy: the short-circuit current is supplied from the power network, so that the choice of CBs to ensure correct discrimination is determined by classical methods, previously covered in Chapter H2, Sub-clause 4.5;

■ case 2: circuit configuration without the static contactor or with delayed transfer to it, so that discrimination must be achieved by instantaneous or short time-delay overcurrent protection, operated by the limited short-circuit current available from the UPS unit, before its internal overcurrent protection operates. For Merlin Gerin UPS units EPS 5000 or 2000\* and Merlin Gerin circuit breakers, the following conditions must be complied with:

$I_n$  of a type B circuit breaker  
 $\leq \frac{I_n \text{ of UPS unit}}{2}$

\* In the case of a Maxipac  $I_n$  of a type B circuit breaker  $\leq \frac{I_n \text{ of UPS unit}}{3}$

### example

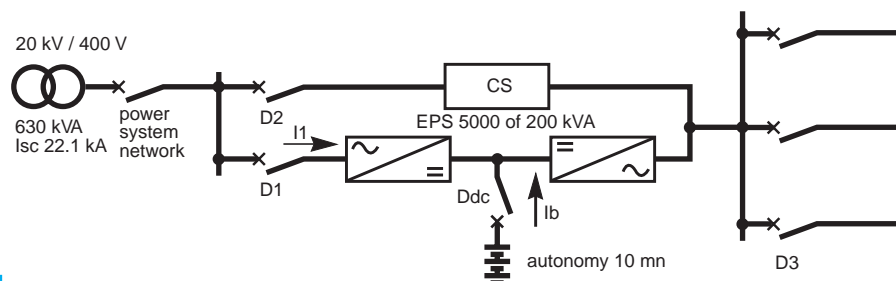


fig. J2-26: example.

#### Selection of circuit breakers D1 and D2

Table J2-24 shows the values of normal-load currents through D1 and D2 respectively, viz: 395 A for  $I_1$  and 304 A for  $I_u$ . The short-circuit current-breaking rating of D1 and D2 at their points of installation must be, for such transformers  $\geq 22$  kA.

Circuit breakers type NS400N\* (400 A at 40 °C - 36 kA) would be satisfactory; regulated for overload protection (by thermal tripping device) at  $I_{rth} \geq 395$ A for D1 and  $\geq 304$  A for D2.

\* Merlin Gerin product.

### 2.10 complementary equipments

#### transformers

A two-winding transformer included on the upstream side of the static contactor of circuit 2 (see figure J2-5) allows:

- a change of voltage level when the power network voltage is different to that of the load;
- a different arrangement for the neutral on the load-side winding, from that of the power network.

Moreover, such a transformer:

- reduces the short-circuit current level on the secondary, (i.e. load) side compared with that on the power network side,

- prevents third harmonic currents (and multiples of them) which may be present on the secondary side from passing into the power-system network, providing that the primary winding is connected in delta.

#### anti-harmonic filter

The UPS system includes a battery charger which is controlled by commutated thyristors or transistors. The resulting regularly-chopped current cycles “generate” harmonic components in the power-supply network. These undesirable components are filtered at the input of the rectifier and for most cases this reduces the harmonic current level sufficiently for all practical purposes. In certain specific cases however, notably in very large installations, an additional filter circuit may be necessary.

For example, when:

- the power rating of the UPS system is large relative to the HV/LV transformer supplying it;
  - the LV busbars supply loads which are particularly sensitive to harmonics;
  - a diesel (or gas-turbine, etc.) driven alternator is provided as a standby power supply.
- In such cases, the manufacturers of the UPS system should be consulted.

#### communications equipment

Communication with equipment associated with informatic systems (see Sub-clause 2.5) may entail the need for suitable facilities within the UPS systems.

Such facilities may be incorporated in an original design, or added to existing systems on request.



fig. J2-27: a UPS installation with incorporated communication systems.

### 3. protection of LV/LV transformers

These transformers are generally in the range of several hundreds of VA to some hundreds of kVA and are frequently used for:

- changing the (LV) voltage level for:
    - auxiliary supplies to control and indication circuits,
    - lighting circuits (230 V created when the primary system is 400 V 3-phase 3-wires),
  - changing the method of earthing for certain loads having a relatively high capacitive current to earth (informatic equipment) or resistive leakage current (electric ovens, industrial-heating processes, mass-cooking installations, etc.).
- LV/LV transformers are generally supplied

with protective systems incorporated, and the manufacturers must be consulted for details. Overcurrent protection must, in any case, be provided on the primary side. The exploitation of these transformers requires a knowledge of their particular function, together with a number of points described below.

**Note:** In the particular cases of LV/LV safety isolating transformers at extra-low voltage, an earthed metal screen between the primary and secondary windings is frequently required, according to circumstances, as recommended in European Standard EN 60742, and as discussed in detail in Sub-clause 3.5 of Chapter G.

#### 3.1 transformer-energizing in-rush current

At the moment of energizing a transformer, high values of transient current (which includes a significant d.c. component) occur, and must be taken into account when considering protection schemes. The magnitude of the current peak depends on:

- the value of voltage at the instant of energization,
- the magnitude and polarity of magnetic flux (if any) existing in the core of the transformer,
- characteristics of the load on the transformer.

In distribution-type transformers, the first current peak can attain a value equal to 10 to 15 times the full-load r.m.s. current, but for small transformers (< 50 kVA) may reach values of 20 to 25 times the nominal full-load current. This transient current decreases rapidly, with a time constant  $\theta$  (see figure J3-1) of the order of several milli-seconds to several tens of milli-seconds.

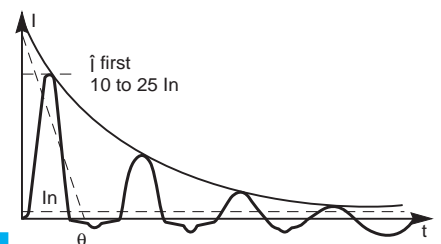


fig. J3-1: transformer-energizing in-rush current.

#### 3.2 protection for the supply circuit of a LV/LV transformer

The protective device on the supply circuit for a LV/LV transformer must avoid the possibility of incorrect operation due to the magnetizing in-rush current surge, noted above in 3.1. It is necessary to use therefore:

- selective (i.e. slightly time-delayed) circuit breakers of the type Compact NS STR\* (figure J3-2) or
- circuit breakers having a very high magnetic-trip setting, of the types Compact NS or Multi 9\* curve D (figure J3-3).

\* Merlin Gerin.

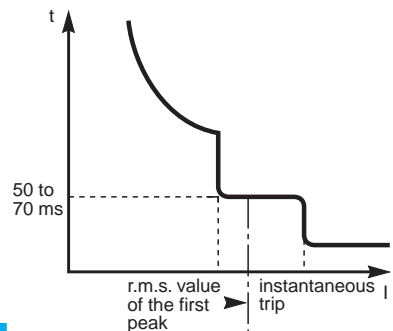


fig. J3-2: tripping characteristic of a Compact NS STR circuit breaker.

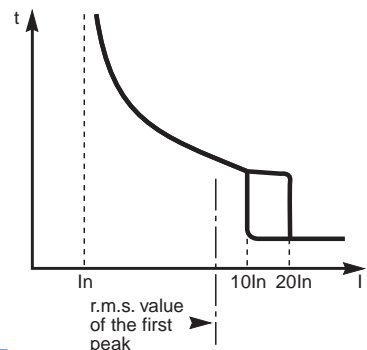


fig. J3-3: tripping characteristic of a circuit breaker according to standardized type D curve (for Merlin Gerin 10 to 14 In).

### 3. protection of LV/LV transformers (continued)

J

#### 3.2 protection for the supply circuit of a LV/LV transformer (continued)

##### Example (figure J3-4)

A 400 V 3-phase circuit is supplying a 125 kVA 400/230 V transformer ( $I_n = 180$  A) for which the first in-rush current peak can reach  $17 I_n$ , i.e.  $17 \times 180$  A = 3,067 A. A Compact NS250 circuit breaker with  $I_r$  setting of 200 A would therefore be a suitable protective device.

##### A particular case: overload protection installed at the secondary side of the transformer

An advantage of overload protection located on the secondary side, is that the short-circuit protection on the primary side can be set at a high value, or alternatively a circuit breaker type MA\* may be used. The primary-side short-circuit protection setting must, however, be sufficiently sensitive to ensure its operation in the event of a short-circuit occurring on the secondary side of the transformer (upstream of secondary protective devices).

\* Motor-control circuit breaker, the short-circuit protective relay of which is immune to high transient-current peaks, as shown in figure J5-3.

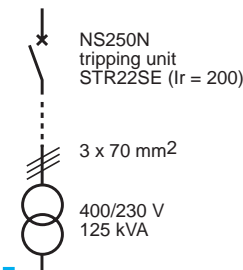


fig. J3-4: example.

**Note:** The primary protection is sometimes provided by fuses, type a M. This practice has two disadvantages:

- the fuses must be largely oversized (at least 4 times the nominal full-load rated current of the transformer);
- in order to provide isolating facilities on the primary side, either a load-break switch or a contactor must be associated with the fuses.

#### 3.3 typical electrical characteristics of LV/LV 50 Hz transformers

3-phase																							
kVA rating	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800
no-load losses (W)	100	110	130	150	160	170	270	310	350	350	410	460	520	570	680	680	790	950	1160	1240	1485	1855	2160
full-load losses (W)	250	320	390	500	600	840	800	1180	1240	1530	1650	2150	2540	3700	3700	5900	5900	6500	7400	9300	9400	11400	11400
s.c. voltage (%)	4.5	4.5	4.5	5.5	5.5	5.5	5.5	5.5	5	5	4.5	5	5	5.5	4.5	5.5	5	5	4.5	6	6	5.5	5.5
1-phase																							
kVA rating	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160									
no-load losses (W)	105	115	120	140	150	175	200	215	265	305	450	450	525	635									
full-load losses (W)	400	530	635	730	865	1065	1200	1400	1900	2000	2450	3950	3950	4335									
s.c. voltage (%)	5	5	5	4.5	4.5	4	4	5	5	4.5	5.5	5											

table J3-5: typical electrical characteristics of LV/LV 50 Hz transformers.

#### 3.4 protection of transformers with characteristics as tabled in J3-5 above, using Merlin Gerin circuit breakers

3-phase transformers (400 V primary)			circuit breakers	
P (kVA)	$I_n$ (A)	$U_{sc}$ %	type	trip-unit current rating (A)/type no.
5	7	4.5	C60 / NC100 D or K	20
10	14	5.5	C60 / NC100 D or K	32
16	23	5.5	C60 / NC100 D or K	63
20	28	5.5	C60 / NC100 D or K	63
25	35	5.5	NC100 D	80
31.5	44	5	NC100 D	80
40	56	5	NC100 D	80
50	70	4.5	NC100 D	100
63	89	5	NS100H/L NS160H/L	MA100 STR22SE
80	113	5	NS160H/L	STR22SE
100	141	5.5	NS250N/H/L	STR22SE
125	176	4.5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
160	225	5.5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
250	352	5	C801N/H/L	STR35SE
315	444	4.5	C801N/H/L	STR35SE
400	563	6	C801N/H/L	STR35SE
500	704	6	C801NH/L C1001N/H/L	STR35SE STR35SE
630	887	5.5	C1001N/H/L C1251N/H	STR35SE STR35SE

table J3-6: protection of 3-phase LV/LV transformers with 400 V primary windings.

3-phase transformers (230 V primary)			circuit breakers	
P (kVA)	I <sub>n</sub> (A)	U <sub>sc</sub> %	type	trip-unit current rating (A)/type no.
5	12	4.5	C60 / NC100 D or K	40
10	24	5.5	C60 / NC100 D or K	63
16	39	5.5	NC100 D	80
20	49	5.5	NC100 D	100
25	61	5.5	NS100H/L	STR22SE
31.5	77	5	NS100H/L	STR22SE
40	97	5	NS100H/L	STR22SE
50	122	4.5	NS100H/L	STR22SE
63	153	5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
80	195	5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
100	244	5.5	NS630N/H/L	STR23SE
125	305	4.5	C801N/H/L	STR35SE
160	390	5.5	C801N/H/L	STR35SE
250	609	5	C801N/H/L C1001N/H/L	STR35SE STR35SE
315	767	4.5	C1001N/H/L C1251N/H	STR35SE STR35SE
400	974	6	C1251N/H	STR35SE

table J3-7: protection of 3-phase LV/LV transformers with 230 V primary windings.

1-phase transformers (400 V primary)			circuit breakers	
P (kVA)	I <sub>n</sub> (A)	U <sub>sc</sub> %	type	trip-unit current rating (A)/type no.
0.1	0.24	13	C60 D or K	1
0.16	0.39	10.5	C60 D or K	1
0.25	0.61	9.5	C60 D or K	1
0.4	0.98	7.5	C60 D or K	2
0.63	1.54	7	C60 D or K	3
1	2.44	5.2	C60 D or K	6
1.6	3.9	4	C60 / NC100 D or K	10
2	4.88	2.9	C60 / NC100 D or K	10
2.5	6.1	3	C60 / NC100 D or K	16
4	9.8	2.1	C60 / NC100 D or K	20
5	12.2	1.9	C60 / NC100 D or K	32
6.3	15.4	1.6	C60 / NC100 D or K	40
8	19.5	5	C60 / NC100 D or K	50
10	24	5	C60 / NC100 D or K	63
12.5	30	5	C60 / NC100 D or K	63
16	39	4.5	NC100 D	80
20	49	4.5	NC100 D	100
25	61	4.5	NS160H/L	STR22SE
31.5	77	4	NS160H/L	STR22SE
40	98	4	NS160H/L	STR22SE
50	122	4	NS160H/L	STR22SE
63	154	5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
80	195	4.5	NS250N/H/L NS400	STR22SE STR23SE
100	244	5.5	NS630	STR23SE
125	305	5	C801N/H/L	STR35SE
160	390	5	C801N/H/L	STR35SE

table J3-8: protection of 1-phase LV/LV transformers with 400 V primary windings.

### 3. protection of LV/LV transformers (continued)

J

#### 3.4 protection of transformers with characteristics as tabled in J3-5 above, using Merlin Gerin circuit breakers (continued)

1-phase transformers (230 V primary)			circuit breakers	
P (kVA)	I <sub>n</sub> (A)	U <sub>sc</sub> %	type	trip-unit current rating (A)/type no.
0.1	0.4	13	C60 D or K	1
0.16	0.7	10.5	C60 D or K	2
0.25	1.1	9.5	C60 D or K	3
0.4	1.7	7.5	C60 D or K	4
0.63	2.7	7	C60 D or K	6
1	4.2	5.2	C60 / NC100 D or K	10
1.6	6.8	4	C60 / NC100 D or K	16
2	8.4	2.9	C60 / NC100 D or K	16
2.5	10.5	3	C60 / NC100 D or K	20
4	16.9	2.1	C60 / NC100 D or K	40
5	21.1	1.9	C60 / NC100 D or K	50
6.3	27	1.6	C60 / NC100 D or K	63
8	34	5	NC100 D	80
10	42	5	NC100 D	100
12.5	53	5	NC100 D	100
16	68	4.5	NS160H/L	STR22SE
20	84	4.5	NS160H/L	STR22SE
25	105	4.5	NS250N/H/L NS250N/H/L	STR22SE STR22SE
31.5	133	4	NS250N/H/L	STR22SE
40	169	4	NS250N/H/L NS400N/H/L	STR22SE STR23SE
50	211	5	NS250N/H/L NS400N/H/L	STR22SE STR23SE
63	266	5	NS630N/H/L	STR23SE
80	338	4.5	C801N/H/L	STR35SE
100	422	5.5	C801N/H/L	STR35SE
125	528	5	C801N/H/L	STR35SE
160	675	5	C801N/H/L C1001N/H/L	STR35SE STR35SE

table J3-9: protection of 1-phase LV/LV transformers with 230 V primary windings.

## 4. lighting circuits

J

the presence of adequate lighting contributes to the safety of persons.

The planning and realization of a lighting installation requires a sound understanding of the materials installed, together with familiarity with the rules for safety against fire hazards in establishments receiving the public.

In fact, the provision of adequate illumination in the event of fire or other catastrophic circumstances is of great importance in reducing the likelihood of panic, and in permitting the necessary safety manoeuvres to be carried out.

emergency lighting is intended to facilitate the evacuation of persons in case of fire or other panic-causing situations, when normal lighting systems may have failed.

### definitions

**Normal lighting** refers to the installation designed for everyday use.

**Emergency lighting** must ensure easy evacuation of persons from the premises concerned, in the event that the normal lighting system fails. Furthermore, emergency lighting must be adequate to allow any particular safety manoeuvres provided in the premises to be carried out.

**Standby lighting** is intended to substitute normal lighting, where the latter fails. Standby lighting permits everyday activities to continue more or less normally, depending on the original design specification, and on the extent of the normal lighting failure. Failure of the standby lighting system must automatically switch on the emergency lighting system.

### 4.1 service continuity

continuity of normal lighting service must be sufficient, independent of other supplementary systems.

#### normal lighting

Regulations governing the minimum requirements for ERP (Establishments Receiving the Public) in most European countries, are as follows:

- installations which illuminate areas accessible to the public must be controlled and protected independently from installations providing illumination to other areas;
- loss of supply on a final lighting circuit (i.e. fuse blown or CB tripped) must not result in total loss of illumination in an area which is capable of accommodating more than 50 persons;
- protection by RCDs (residual current differential devices) must be divided amongst several devices (i.e. more than one device must be used).

in emergency lighting circuits, absolute discrimination between protective devices on the different circuits must be provided.

#### emergency lighting

These schemes include illuminated emergency exit signs and direction indications, as well as general lighting.

##### ■ emergency exit indications

In areas accommodating more than 50 persons, luminous directional indications to the nearest emergency exits must be provided;

##### ■ general emergency lighting

General lighting is obligatory when an area can accommodate 100 persons or more (50 persons or more in areas below ground level).

A fault on a lighting distribution circuit must not affect any other circuit:

- the discrimination of overcurrent-protection relays and of RCDs must be absolute, so that only the faulty circuit will be cut off,
- the installation must be an IT scheme, or must be entirely class II, i.e. doubly-insulated.

Sub-clause 4.7 describes different kinds of suitable power supplies.

## 4. lighting circuits (continued)

J

### 4.2 lamps and accessories (luminaires)

#### fluorescent tubes

For normal operation a fluorescent tube requires a ballast and a starter (device for initiating the luminous discharge).

- the ballast is an iron-cored inductor, permanently connected in series with the tube; its function is threefold, viz:
  - to limit the preheating current during the (brief) starting period,
  - to provide a pulse of high voltage at the end of the starting period to strike the initial arc,
  - to stabilize the current through the luminous column (hence the term "ballast").

The presence of the ballast means that the power-factor ( $\cos \phi$ ) of the circuit is low (of the order 0.6) with the corresponding consumption of reactive energy, which is generally metered. For this reason each fluorescent lamp is normally provided with its own power-factor-correction capacitor.

- the starter is a switch, which, by breaking the (electrode-preheating) current passing through the ballast, causes a high-voltage transient pulse to appear across the tube. This causes an arc (in the form of a gaseous discharge) to be established through the tube. The discharge is then self-sustaining at normal voltage.
- The ballast, capacitor and the tube, engender disturbances during the periods of starting, steady operation and extinction. These disturbances are analysed in table J4-1 below.

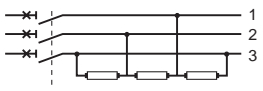
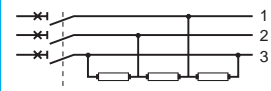
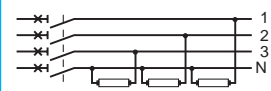
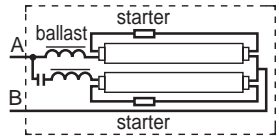
	switching-on disturbances	switching-off disturbances	steady-operating disturbances
<p>single-phase fluorescent lamp with its individual p.f. correction capacitor</p> 	<ul style="list-style-type: none"> <li>■ high current peak to charge capacitor; order of magnitude <math>10 I_n</math> for 1 sec.</li> <li>A number of lamps on one circuit can result in peaks of 300-400 A for 0.5 ms.</li> <li>This can cause a CB to trip, or the welding of contacts in a contactor. In practice, limit each circuit to 8 tubes per contactor;</li> <li>■ moderate overload at the beginning of steady operating condition (<math>1.1-1.5 I_n</math> for 1 sec) according to type of starter.</li> </ul>	no particular problems	<p>circulation of harmonic currents (sinusoidal currents at frequencies equal to whole-number multiples of 50 (or 60) Hz:</p> <ul style="list-style-type: none"> <li>■ delta-connected lamps (see Appendix J2) (3-ph 3-wire 230 V system)</li> </ul>  <p>presence of 5th and 7th harmonics at very low level</p> <ul style="list-style-type: none"> <li>■ star-connected lamps (3-ph 4-wire 400/230 V system)</li> </ul>  <p>presence of 3rd harmonic currents in the neutral, which can reach 70 to 80% of the nominal phase current. In this case, therefore, the c.s.a. of the neutral conductor must equal that of the phase conductors.</p>
<p>single-phase twin-tube fluorescent lamp with each tube having its own starter and series ballast. One of the tubes has a capacitor connected in series with its ballast. The two sets of equipment are connected in parallel. The arrangement is known internationally as a "duo"-circuit luminaire. The capacitor displaces the phase of the current through its tube, to nullify the flicker effect, as well as correcting the overall p.f.</p> 	<ul style="list-style-type: none"> <li>■ no high current peak as noted above;</li> <li>■ same order of moderate overload at beginning of steady operating condition as for the single tube noted above.</li> <li>This arrangement is recommended for difficult cases.</li> </ul>	no particular problems	
<p>fluorescent lamp with HF ballast</p> <p>Advantages: Energy savings of the order of 25%. Rapid one-shot start. No flicker or stroboscopic effects.</p>	<ul style="list-style-type: none"> <li>■ can generate a current peak at start;</li> <li>■ can cause leakage to earth of HF current (at 30 kHz) via the phase conductor capacitances to earth.</li> </ul>	no particular problems	

table J4-1: analysis of disturbances in fluorescent-lighting circuits.

## 4.3 the circuit and its protection

### dimensions and protection of the conductors

The maximum currents in the circuits can be estimated using the methods discussed in Chapter B.

Accordingly, account must be taken of:

- the nominal power rating of the lamp and the ballast;
- the power factor.

The temperature within the distribution panel also influences the choice of the protective device (see Chapter H2 Sub-clause 4.4).

In general tables are available from manufacturers to assist in making a choice.

**Note:** for circuits in which large peak currents occur (at times of switching on) and their magnitude is such that CB tripping is a possibility, the cable size is chosen after the protective CB (with an instantaneous trip setting sufficient to remain closed during the current peaks) has been selected. See the Note following table J4-2.

### factor of simultaneity $k_s$ (diversity)

A particular feature of large (e.g. factory) lighting circuits is that the whole load is "on" or "off", i.e. there is no diversity. Furthermore, even among a number of lighting circuits from a given distribution panel, the factor  $k_s$  is generally near unity.

Consequently, the interior of distribution panels supplying lighting schemes are frequently at an elevated temperature, an important consideration to be taken into account when selecting protective devices.

## 4.4 determination of the rated current of the circuit breaker

The rated current of a circuit breaker is generally chosen according to the rating of the circuit conductors it is protecting (in the particular circumstances in the Note of 4.3 above, however, the reverse procedure was found to be necessary). The circuit conductor ratings are defined by the maximum steady load current of the circuit.

The following tables allow direct selection of circuit breaker ratings for certain particular cases.

power (kW)	230 V 1-phase current rating $I_n$ (A)	230 V 3-phase current rating $I_n$ (A)	400 V 3-phase current rating $I_n$ (A)
1	6	3	2
1.5	10	4	3
2	10	6	4
2.5	16	10	4
3	16	10	6
3.5	20	10	10
4	20	16	10
4.5	25	16	10
5	25	16	10
6	32	20	10
7	32	20	16
8	40	25	16
9	50	25	16
10	50	32	20

**table J4-2: protective circuit breaker ratings for incandescent lamps and resistive-type heating circuits (see Note below).**

**Note:** at room temperature the filament resistance of a 100 W 230 V incandescent lamp is approximately 34 ohms. Some milli-seconds after switching on, the filament resistance rises to  $230^2/100 = 529$  ohms.

The initial current peak at the instant of switch closure is therefore practically 15 times its normal operating current.

A similar (but generally less severe) transient current peak occurs when energizing any resistive-type heating appliance.

## 4. lighting circuits (continued)

J

### 4.4 determination of the rated current of the circuit breaker (continued)

The following table (J4-3) is valid for 230 V and 400 V installations, with or without individual power-factor correcting capacitors.

mercury vapour fluorescent lamps	
P ≤ 700 W	6 A
P ≤ 1000 W	10 A
P ≤ 2000 W	16 A
metal-halogen mercury-vapour lamps	
P 275 W	6 A
P 1000 W	10 A
P 2000 W	16 A
high-pressure sodium discharge lamps	
P 400 W	6 A
P 1000 W	10 A

**table J4-3: maximum limit of rated current per outgoing lighting circuit, for high-pressure discharge lamps.**

single-phase distribution 230 V		three-phase distribution + N : 400 V phase/phase													
types de luminaires	tube rating (W)	number of luminaires per phase													
single-phase	18	7	14	21	42	70	112	140	175	225	281	351	443	562	703
with capacitor	36	3	7	10	21	35	56	70	87	112	140	175	221	281	351
	58	2	4	6	13	21	34	43	54	69	87	109	137	174	218
duo circuit	2x18= 36	3	7	10	21	35	56	70	87	112	140	175	221	281	351
with capacitor	2x36= 72	1	3	5	10	17	28	35	43	56	70	87	110	140	175
	2x58= 116	1	2	3	6	10	17	21	27	34	43	54	68	87	109
<b>current rating of 1-,2-,3 -or 4- pole CBs</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>6</b>	<b>10</b>	<b>16</b>	<b>20</b>	<b>25</b>	<b>32</b>	<b>40</b>	<b>50</b>	<b>63</b>	<b>80</b>	<b>100</b>

**Calculation for tubes with p.f. capacitor; connected in star**

$$\text{number of tubes per phase} = \frac{0.8 C \times 0.86 V}{P_u \times 1.25}$$

where: C = current rating of C B, V = phase/neutral voltage, 0.86 = cos  $\phi$  of circuit, 0.8 = derating factor for high temperature in CB housing, 1.25 = factor for watts consumed by ballast, P<sub>u</sub> = nominal power rating of tube (W).

three-phase 3 wire system(230 V) phase/phase		number of luminaires per phase													
types de luminaires	tube rating (W)	number of luminaires per phase													
single-phase	18	4	8	12	24	40	64	81	101	127	162	203	255	324	406
with capacitor	36	2	4	6	12	20	32	40	50	64	81	101	127	162	203
	58	1	2	3	7	12	20	25	31	40	50	63	79	100	126
duo circuit	2x18= 36	2	4	6	12	20	32	40	50	64	81	101	127	162	203
with capacitor	2x36= 72	1	2	3	6	10	16	20	25	32	40	50	63	81	101
	2x58= 116	0	1	1	3	6	10	12	15	20	25	31	39	50	63
<b>current rating of 2- or 3- pole CBs</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>6</b>	<b>10</b>	<b>16</b>	<b>20</b>	<b>25</b>	<b>32</b>	<b>40</b>	<b>50</b>	<b>63</b>	<b>80</b>	<b>100</b>

**Calculation for tubes with p.f. capacitor; connected in delta**

$$\text{number of tubes per phase} = \frac{0.8 C \times 0.86 U}{P_u \times 1.25 \times \sqrt{3}}$$

where: U = phase/phase voltage

**tables J4-4: current ratings of circuit breakers related to the number of fluorescent luminaires to be protected.**

## 4.5 choice of control-switching devices

The advent of switching devices which combine the functions of remote control and protection, of which the remotely-controllable residual-current circuit breaker is the prototype, simplifies lighting-control circuits considerably, thereby enlarging the scope and diversity of control schemes.

Certain switching devices include control circuitry for operation at ELV (extra-low-voltage, i.e. < 50 V or < 25 V according to requirements); these control circuits being insulated for 4,000 V with respect to the power circuits.

The situation at the time of writing is summarized below in table J4-5.

remote-control mode	function of corresponding switchgear and controlled equipment				
	remote control	remote control + overcurrent protection	remote control + overcurrent protection + insulation monitoring and protection	local control devices	centralized control devices
point-to-point remote control	bistable switch	circuit breaker controlled by hard-wire system	residual current circuit breaker controlled by hard-wire system	push-button	stairway time-switch with automatic switch-off
centralized remote control	contactor			switch	automatic photo-electric lighting-control switches
point-to-point and centralized remote control	"pilot" bistable switch remote controlled switch			push button	movement detectors; central clock relaying
control signals over communications bus	remotely controlled switch	remotely controlled circuit breaker over communications bus	residual current circuit breaker controlled over communications bus	according to type	
control signals over time-multiplexing channels	remotely controlled static contactor/circuit breaker combination				

table J4-5: types of remote control.

## 4. lighting circuits (continued)

J

### 4.6 protection of ELV lighting circuits

A LV/ELV transformer is often located in an inaccessible position, so that protection installed on the secondary side would be equally difficult to reach.

For this reason the protection is commonly provided on the primary circuit.

The protective device is therefore chosen:

- to provide switching control (Multi 9 type C CB, or type aM fuses);
  - to ensure protection against short-circuits.
- It must therefore be verified that:

□ in the case of a CB, the minimum value of short-circuit current exceeds by a suitable margin the short-circuit magnetic relay setting  $I_m$  of the CB concerned,

□ in the case of fuses it is also necessary to ensure that the  $I^2t$  energy let-through of the fuse(s) at minimum short-circuit current is well below the level of the thermal withstand capacity of the circuit conductors,

■ if necessary, overload protection must be provided. If the number of lamps on the circuit has been correctly chosen, however, overload protection is not necessary.

#### Example:

The s.c. current  $I_{sc2}$  at the secondary terminals of a single-phase LV/ELV transformer is equal to

$$\frac{U_s}{Z_s} \text{ where } Z_s = \frac{U_s^2}{P_n} \times \frac{U_{sc}\%}{100}$$

$$\text{so that } I_{sc2} = \frac{P_n \times 100}{U_s \times U_{sc}\%} = \frac{400 \times 100}{12 \times 6} = 555 \text{ A which gives } I_{sc1} = 29 \text{ A in the primary circuit.}$$

Circuit breaker type C trips if the primary current  $\geq I_{m1} = 10 I_n = 20 \text{ A}$ , which corresponds to a secondary current of

$$20 \times \frac{230}{12} = 383 \text{ A}$$

The maximum resistance of the ELV (i.e. secondary) circuit\* may be deduced from these two secondary s.c. currents, viz: 555 A and 383 A as follows:

$$R_c = \frac{U_2}{I_{m2}} - \frac{V_2}{I_{sc2}} = \frac{12}{383} - \frac{12}{555} = 0.0313 - 0.0216 = 9.7 \text{ m}\Omega$$

\* from the transformer terminals to the ELV distribution board.

**Note:** The true value of  $R_c$  permitted is, in principle, greater than 9.7 milli-ohms, because the source impedance (i.e.  $U_2/555$ ), will be mainly reactive, not resistive, as (implied) in the example. However, for simplicity, and to automatically provide a safety margin under all circumstances, an arithmetic subtraction, as shown, is recommended.

The maximum length of the 12 V circuit based on 9.7 m $\Omega$  will therefore be:

$$\frac{R_c \text{ (m}\Omega\text{)} \times S \text{ (mm}^2\text{)}}{2 \times 22.5 \text{ (}\mu\Omega\text{.mm)}} \text{ in metres} = \frac{9.7 \times 6}{2 \times 22.5} \text{ for a 6 mm}^2 \text{ copper cable} = 1.3 \text{ m}$$

It is then necessary to check that this length is sufficient to reach the 12 V distribution board, where the outgoing ways are protected with other devices. If the length is insufficient, then an increase in the c.s.a. of the conductors, proportional to the increased length required, will satisfy the constraint for maximum  $R_c$ ; for example, a conductor of 10 mm<sup>2</sup> would allow  $1.3 \times 10/6 = 2.2 \text{ m}$  of circuit length in the above case.

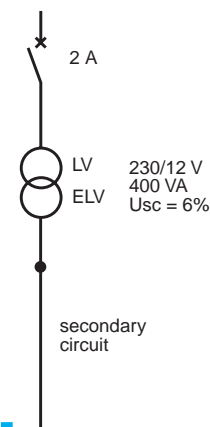


fig. J4-6: example.

## 4.7 supply sources for emergency lighting

Supply sources for emergency-lighting systems must be capable of maintaining the supply to all lamps in the most unfavourable circumstances likely to occur, and for a period judged necessary to ensure the total evacuation of the premises concerned, with (in any case) a minimum of one hour.

### compatibility between emergency lighting sources and other parts of the installation

Emergency-lighting sources must supply exclusively the circuits installed only for operation in emergency situations. Standby lighting systems operate to maintain illumination, on failure of normal lighting circuits (generally in non-emergency circumstances). However, failure of standby lighting must automatically bring the emergency lighting system into operation.

Central sources for emergency supplies may also be used to provide standby supplies, provided that the following conditions are simultaneously fulfilled:

- where there are several sources, the failure of one source must leave sufficient capacity in service to maintain supply to all safety systems, with automatic load shedding of non-essential loads (if necessary);
- the failure of one source, or one equipment concerned with safety, must leave all other sources and safety equipments unaffected;
- any safety equipment must be arranged to receive supply from any source.

### classification of emergency-lighting schemes

Many countries have statutory regulations concerning safety in buildings and areas intended for public gatherings. Classification of such locations leads to the determination of suitable types of solutions, authorized for use in emergency-lighting schemes in the different areas. The following four classifications are typical.

#### Type A

The lamps are supplied permanently and totally during the presence of the public by a single central source (battery of storage cells, or a heat-engine-driven generator). These circuits must be independent of any other circuits (1).

#### Type B

The lamps are permanently supplied during the presence of the public, either:

- by a battery to which the lamps are permanently connected, and which is on permanent trickle charge from a normal lighting source, or,
- by a heat-engine-driven generator, the characteristics of which also assure supplies to essential loads within one second (since the set is already running and supplying the emergency lighting) in the event of failure of the normal power supply, or,
- by autonomous units which are normally supplied and permanently alight from the normal lighting supply, and which remain alight (for at least one hour), on the loss of normal supply, by virtue of a self-contained battery. The battery is trickle-charged in normal circumstances.

These units have fluorescent lamps for general emergency lighting, and fluorescent or incandescent lamps for exit and direction-indicating signs.

The circuits for all emergency lamps must be independent of any other circuits (1).

#### Type C

The lamps may, or may not, be supplied in normal conditions and, if supplied, may be fed from the normal lighting system, or from the emergency-lighting supply.

- the emergency-lighting batteries must be maintained on charge from the normal source by automatically regulated systems, that ensure a minimum of capacity equal to the full emergency-lighting load for one hour;
- the heat-engine-driven generator sets must be capable of automatically picking-up the full emergency lighting load from a standby (stationary) condition, in less than 15 seconds, following the failure of normal supply.

The engine start-up power is provided by a battery which is capable of six starting attempts, or by a system of compressed air. Minimum reserves of energy in the two systems of start-up must be maintained automatically.

- failures in the central emergency supply source must be detected at a sufficient number of points and adequately signalled to supervisory/maintenance personnel;
- autonomous units may be of the permanently-lit type or non-permanently-lit type.

The circuits for all emergency lamps must be independent of any other circuits (2).

#### Type D

This type of emergency lighting comprises hand-carried battery-powered (primary or secondary cells) at the disposal of service personnel or the public.

(1) Circuits for types A and B, in the case of a central emergency power source, must also be fire-resistant. Conduit boxes, junction sleeves and so on must satisfy national standard heat tests, or the circuits must be installed in protective cable chases, trunking, etc. capable of assuring satisfactory performance for at least one hour in the event of fire.

(2) Cable circuits of type C are not required to comply with the conditions of (1).

# 5. asynchronous motors

J

the asynchronous (i.e. induction) motor is robust and reliable, and very widely used. 95% of motors installed around the world are asynchronous. The protection of these motors is consequently a matter of great importance in numerous applications.

specific features of motor performance influence the power-supply circuits required for satisfactory operation.

The consequences of an incorrectly protected motor can include the following:

- for persons:
  - asphyxiation due to the blockage of motor ventilation,
  - electrocution due to insulation failure in the motor,
  - accident due to sticking (contact welding) of the controlling contactor;
- for the driven machine and the process:
  - shaft couplings and axles, etc. damaged due to a stalled rotor,
  - loss of production,
  - manufacturing time delayed;
- for the motor:
  - motor windings burnt out due to stalled rotor,
  - cost of dismantling and reinstating or replacement of motor,
  - cost of repairs to the motor.

It is, therefore, the safety of persons and goods, and reliability and availability levels which must influence the choice of protective equipment.

In economic terms, it is the overall cost of failure which must be considered; a penalty which is increasingly severe as the size of the motor, and difficulties of access to it increase. Loss of production is a further, and evidently important factor.

A motor power-supply circuit presents certain constraints not normally encountered in other (common) distribution circuits, owing to the particular characteristics, specific to motors, such as:

- heavy start-up current (see figure J5-1) which is highly reactive, and can therefore be the cause of an important voltage drop;
- number and frequency of start-up operations are generally high;
- the heavy start-up current means that motor overload protective devices must have operating characteristics which avoid tripping during the starting period.

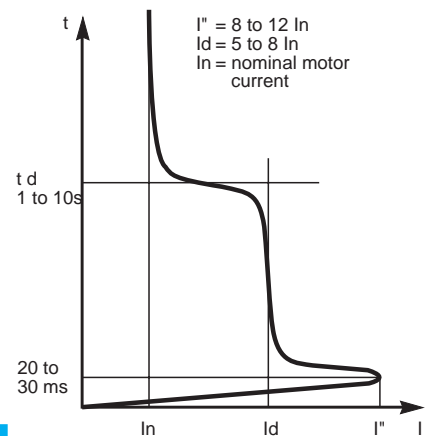


fig. J5-1: direct-on-line starting-current characteristics of an induction motor.

## 5.1 protective and control functions required

functions to be provided generally include:

- basic protective devices,
- electronic control equipment,
- preventive or limitative protection equipment.

Functions generally provided are:

- basic protection, including:
  - isolating facility,
  - manual local and/or remote control,
  - protection against short-circuits,
  - protection against overload;
- electronic controls consisting of:
  - progressive "soft-start" motor starter, or,
  - speed controller;
- preventive or limitative protection by means of:
  - temperature sensors,
  - multi-function relays,
  - permanent insulation-resistance monitor or RCD (residual-current differential device).

Table J5-2 below, shows diverse motor-circuit configurations commonly used in LV distribution boards.

basic protection	fuse-disconnector + disconnector (using thermal relay)	circuit breaker* + disconnector (using thermal relay)	motor circuit breaker* + contactor	contactor circuit breaker* ACPA
<b>standards</b>				
disconnection (or isolation)				
manual control				
remote control				
short-circuit protection				
overload protection				
refer also to Chapter H2, Sub-clause 2-2	<ul style="list-style-type: none"> <li>■ large power range</li> <li>■ allow all types of starting schemes</li> <li>■ a well-proven method</li> <li>■ suitable for systems having high fault levels</li> </ul>	<ul style="list-style-type: none"> <li>■ large power range</li> <li>■ avoids need to stock fuse cartridges</li> <li>■ disconnection is visible in certain cases</li> <li>■ identification of the reason for tripping i.e. short circuit or overload</li> </ul>	<ul style="list-style-type: none"> <li>■ method is simple and compact for low-power motors</li> </ul>	<ul style="list-style-type: none"> <li>■ low installation costs</li> <li>■ no maintenance</li> <li>■ high degree of safety and reliability</li> <li>■ suitable for systems having high fault levels</li> <li>■ long electrical life</li> </ul>
<b>electronic controls</b>		<b>progressive “soft-start” starter device</b> <ul style="list-style-type: none"> <li>■ limitation                             <ul style="list-style-type: none"> <li>□ current peaks I</li> <li>□ voltage drops U</li> <li>□ mechanical constraints during start-up period</li> </ul> </li> <li>■ thermal protection is incorporated</li> </ul>		<b>speed controller</b> <ul style="list-style-type: none"> <li>■ from 2 to 130 % of nominal speed</li> <li>■ thermal protection is incorporated</li> <li>■ possibility of communication facilities</li> </ul>
<b>preventive or limitative protection devices</b>	<b>thermal sensors</b> Protection against abnormal heating of the motor by thermistance-type sensors in the motor windings, connected to associated relays.	<b>multi-function relays</b> Direct and indirect thermal protection against: <ul style="list-style-type: none"> <li>■ the starting period excessively long, or stalled-rotor condition</li> <li>■ imbalance, absence or inversion of phase voltages</li> <li>■ earth fault or excessive earth-leakage current</li> <li>■ motor running on no-load; motor blocked during start-up</li> <li>■ pre-alarm overheating indication</li> </ul>	<b>permanent insulation-to-earth monitor and RCD (residual-current differential relay)</b> Protection against earth-leakage current and short-circuits to earth. Signalled indication of need for motor maintenance or replacement.	

table J5-2: commonly-used types of LV motor-supply circuits.

## 5. asynchronous motors (continued)

J

### 5.2 standards

The international standards covering materials discussed in this Sub-clause are: IEC 947-2, 947-3, 947-4-1, and 947-6-2. These standards are being adopted (often without any changes) by a number of countries, as national standards.

### 5.3 basic protection schemes: circuit breaker / contactor / thermal relay

functions to be implemented are:

- control (start/stop),
- isolation (safety during maintenance),
- protection against short-circuits,
- specific protection as noted in Sub-clause 5.1

Where several different devices are used to provide protection, co-ordination between them is necessary.

The control and protection of a motor can be provided by one, two or three devices, which share the required functions of:

- control (start/stop);
- disconnection (isolation) for safety of personnel during maintenance work;
- short-circuit protection;
- protection specific to the particular motor (but at least thermal relay overcurrent protection).

When these functions are performed by several devices, co-ordination between them is essential. In the case of an electrical fault of any kind, none of the devices involved must be damaged, except items for which minor damage is normal in the particular circumstances, e.g. replaceable arcing contacts in certain contactors, after a given number of service operations, and so on... The kind of co-ordination required depends on the necessary degree of service continuity and on safety levels, etc.

among the many possible methods of protecting a motor, the association of a circuit breaker incorporating an instantaneous magnetic trip for short-circuit protection and a contactor with a thermal overload relay\* provides many advantages.

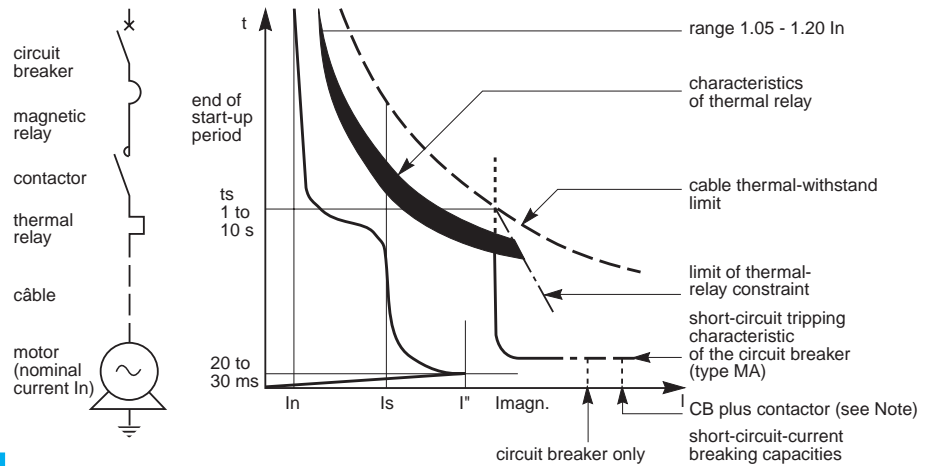


fig. J5-3: tripping characteristics of a circuit breaker (type MA)\*\* and thermal-relay / contactor (1) combination.

#### Advantages

This combination of devices facilitates installation work, as well as operation and maintenance, by:

- the reduction of the maintenance work load: the CB avoids the need to replace blown fuses and the necessity of maintaining a stock (of different sizes);
- better continuity performance: a motor circuit can be re-energized immediately following the elimination of a fault;
- additional complementary devices sometimes required on a motor circuit are easily accommodated;
- tripping of all three phases is assured (thereby avoiding the possibility of "single-phasing");
- full-load current switching possibility (by CB) in the event of contactor failure, e.g. contact welding;

- interlocking;
- diverse remote indications;
- better protection for the starter for short-circuit currents up to about  $30 I_n$  (see figure J5-3).

In the majority of cases short-circuit faults occur at the motor, so that the current is limited by the cable and the wiring of the starter (e.g. the direct-acting trip coil of the CB).

- possibility of adding RCD:
  - an RCD of 500 mA sensitivity practically eliminates fire risk due to leakage current,
  - protection against destruction of the motor (short-circuiting of laminations) by the early detection of earth-fault currents (300 mA to 30 A);
- etc.

\* The association of an overload relay and a contactor is referred to as a "disconnector" in some countries.

\*\* Merlin Gerin.

**Note:** When short-circuit currents are very high, the contacts of some contactors may be momentarily forced open by electro-magnetic repulsion, so that two sets of contacts (i.e. those of the CB and those of the contactor) are acting in series. The combination effectively increases the s.c. current-breaking capacity above that of the CB alone.

**Conclusion**

The association circuit breaker / contactor / thermal relay(1) for the control and protection of motor circuits is eminently appropriate where:

- the maintenance service for an installation is reduced, which is generally the case in tertiary and small-and medium-sized industrial enterprises;
- the job specification calls for complementary functions;
- there is an operational requirement for a load-breaking facility in the event of contact welding of the contactor.

(1) a contactor in association with a thermal relay is commonly referred to as a disconnector.

**standardization of the association of circuit breakers/ disconnectors**

**Categories of contactor**

The standard IEC 947-4 gives utilization categories which considerably facilitate the choice of a suitable contactor for a given service duty.

The utilization categories advise on:

- a range of functions for which the contactor may be adapted;
- its current breaking and making capabilities;
- standard test values for expected life duration on load, according to its utilization.

The following table gives some typical examples of the utilization categories covered.

utilization category	application characteristics
AC-1	Non-inductive (or slightly inductive) loads: $\cos \phi \geq 0.95$ (heating, distribution)
AC-2	Starting and switching off of slip-ring motors
AC-3	Cage motors: starting, and switching off motors during running
AC-4	Cage motors: starting, plugging, inching

**table J5-4: utilization categories for contactors (IEC 947-4).**

**Types of co-ordination**

For each association of devices, a type of co-ordination is given, according to the state of the constituent parts following a circuit breaker trip out on fault, or the opening of a contactor on overload.

IEC 947-4-1 defines two types of co-ordination, type 1 and type 2, which set maximum allowable limits of deterioration of switchgear, which must never present a danger to personnel.

- type 1: deterioration of the contactor and/or of its relay is acceptable under 2 conditions:
  - no risk for the operator,
  - all elements other than the contactor and its relay must remain undamaged;
- type 2: burning, and the risk of welding of the contacts of the contactor are the only risks allowed.

**Which type to choose?**

The type of co-ordination to adopt depends on the parameters of exploitation, and must be chosen to satisfy (optimally) the needs of the user and the cost of installation.

- type 1:
  - qualified maintenance service,
  - volume and cost of switchgear reduced,
  - continuity of service not demanded, or provided by replacement of motor-starter drawer;
- type 2:
  - continuity of service imperative,
  - no maintenance service,
  - specifications stipulating this type of co-ordination.

## 5. asynchronous motors (continued)

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### 5.3 basic protection schemes: circuit breaker / contactor / thermal relay (continued)

#### key points in the successful association of a circuit breaker and a discontactor

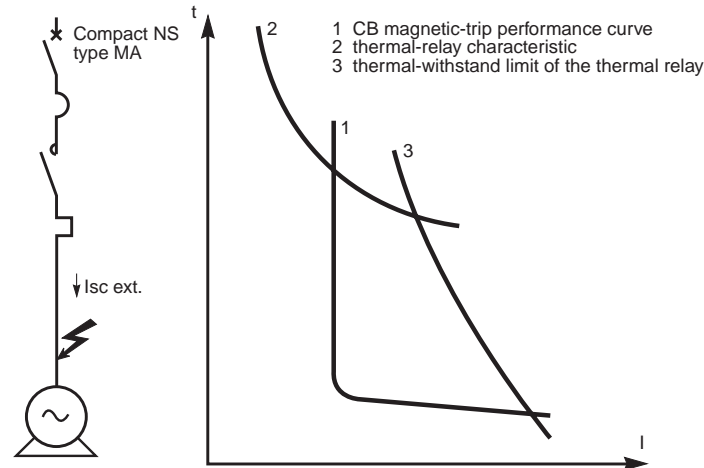


fig. J5-5: the thermal-withstand limit of the thermal relay must be to the right of the CB magnetic-trip characteristic.

Standards define precisely all the elements which must be taken into account to realize a correct co-ordination of type 2:

- absolute compatibility between the thermal relay of the discontactor and the magnetic trip of the circuit breaker. In figure J5-5 the thermal relay is protected if its limit boundary for thermal withstand is placed to the right of the CB magnetic trip characteristic curve. In the case of a motor-control circuit breaker incorporating both magnetic and thermal devices, co-ordination is provided in the design;

- the short-circuit current breaking rating of the contactor must be greater than the regulated threshold of the CB magnetic trip relay, since it (the contactor) must be capable of breaking a current which has a value equal to, or slightly less than, the setting of the magnetic relay (as seen from figure J5-5);
- a reliable performance of the contactor and its thermal relay when passing short-circuit current, i.e. no excessive deterioration of either device and no welding of contactor contacts.

it is not possible to predict the s.c. current-breaking capability of a CB + contactor combination. Laboratory tests and calculations by manufacturers are necessary to determine which type of CB to associate with which contactor, and to establish the s.c. breaking capacity of the combination. Tables are published by Merlin Gerin giving this information in their "LV Distribution" catalogue.

#### short-circuit current-breaking capacity of a combination circuit breaker + contactor

In the studies, the s.c. current-breaking capacity which must be compared to the prospective short-circuit current is:

- either, that of the CB + contactor combination, if these devices are physically close together (e.g. in the same drawer or compartment of a MCC\*). A short-circuit downstream of the combination will be limited to some extent by the impedances of the contactor (see previous Note) and the thermal relay. The combination can therefore be used on a circuit for which the prospective short-circuit current level exceeds the rated s.c. current-breaking capacity of the circuit breaker. This feature very often presents a significant economic advantage;
- or, that of the CB only, for the case where the contactor is separated from the CB (so that a short-circuit is possible on the intervening circuit). For such a case, IEC 947-4-1 requires the rating of the circuit breaker to be equal to or greater than the prospective short-circuit current at its point of installation.

\* Motor Control Centre.

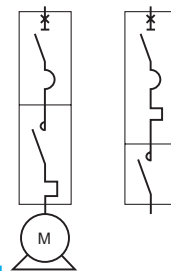


fig. J5-6: circuit breaker and contactor mounted in juxtaposition.

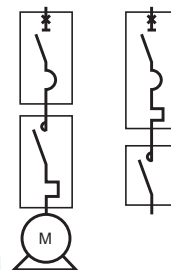


fig. J5-7: circuit breaker and contactor separately mounted, with intervening circuit conductors.

### choice of instantaneous magnetic-trip relay for the circuit breaker

The operating threshold must never be less than  $12 I_n$  for this relay, in order to avoid possible tripping due to the first current peak during start-up. This current peak can vary from  $8 I_n$  to  $11$  or  $12 I_n$ .

## 5.4 preventive or limitative protection

preventive or limitative protection devices detect signs of impending failure, so that action can be taken (automatically or by operator intervention) to avoid or limit the otherwise inevitable consequences.

The main protection devices of this type for motor are:

- thermal sensors in the motor (windings, bearings, cooling-air ducts, etc.);
- multifunction protections;
- insulation-failure detection devices on running, or stationary motor.

### thermal sensors

Thermal sensors are used to detect abnormal temperature rise in the motor by direct measurement.

The thermal sensors are generally embedded in the stator windings (for LV motors), the signal being processed by an associated control device acting to trip the circuit breaker (figure J5-8).

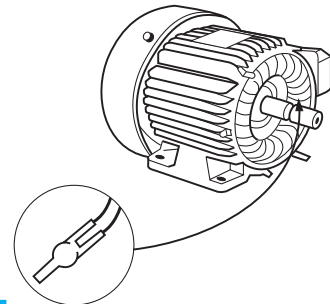


fig. J5-8: overheating protection by thermal sensors.

### multi-function motor-protection relay

The multi-function relay, associated with a number of sensors and indication modules, provides protection for motors, such as:

- thermal overload;
- rotor stalled, or starting-up period too long;
- overheating;
- phase current imbalance, loss of one phase, inverse rotation;
- earth fault (by RCD);
- running on no-load, blocked rotor on start-up.

The advantages of this relay are essentially:

- a comprehensive protection, providing a reliable, high-performance and permanent monitoring/control function;
- efficient surveillance of all motor-operating schedules;
- alarm and control indications;
- possibility of communication via communication buses.

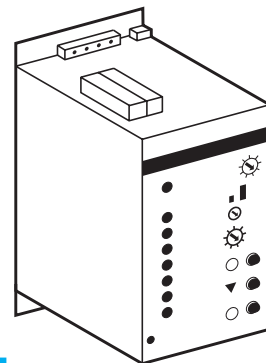


fig. J5-9: multi-function protection, typified by the Telemecanique relay, type LT8 above.

## 5. asynchronous motors (continued)

### J

#### 5.4 preventive or limitative protection (continued)

##### preventive protection of stationary motors

This protection concerns the monitoring of the level of insulation resistance of a stationary motor, thereby avoiding the undesirable consequences of insulation failure during operation, such as:

- for motors used on emergency systems for example: failure to start or to perform correctly;

- in manufacturing: loss of production. This type of protection is indispensable for essential-services and emergency-systems motors, especially when installed in humid and/or dusty locations.

Such protection avoids the destruction of a motor by short-circuit to earth during start-up (one of the most frequently-occurring incidents) by giving a warning in advance that maintenance work is necessary to restore the motor to a satisfactory operational condition.

**Examples of application** (figure J5-10)

Fire-protection system "sprinkler" pumps.

Irrigation pumps for seasonal operation, etc.

Example: a vigilohm SM 20 (Merlin Gerin) relay monitors the insulation of a motor, and signals audibly and visually any abnormal reduction of the insulation resistance level. Furthermore, this relay can prevent any attempt to start the motor, if necessary.

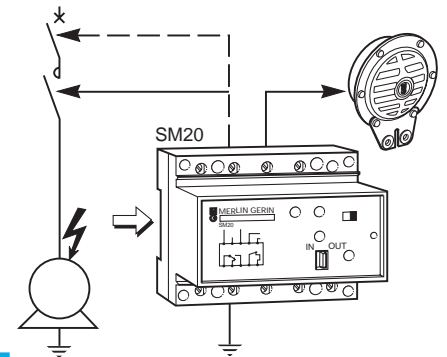


fig. J5-10: preventive protection of stationary motors.

##### limitative protection

Residual current differential protective devices (RCDs) can be very sensitive and detect low values of leakage current which occur when the insulation to earth of an installation deteriorates (by physical damage, contamination, excessive humidity, and so on). Some versions of RCDs, specially designed for such applications, provide the following possibilities:

- to avoid the destruction of a motor (by perforation and short-circuiting of the laminations of the stator) caused by an eventual arcing fault to earth. This protection can detect incipient fault conditions by operating at leakage currents in the range of 300 mA to 30 A, according to the size of the motor (approx. sensitivity: 5 %  $I_n$ ). Instantaneous tripping by the RCD will greatly limit the extent of damage at the fault location;

- to reduce considerably the risk of fire due to earth-leakage currents (sensitivity  $\leq$  500 mA).

A typical RCD for such duties is type RH328A relay (Merlin Gerin) which provides:

- 32 sensitivities (0.03 to 250 A);

- possibility of discriminative tripping or to take account of particular operational requirements, by virtue of 8 possible time-delays (instantaneous to 1 s.);

- automatic operation if the circuit from the current transformer to the relay is broken;

- protected against false operation;

- insulation of d.c. circuit components: class A.

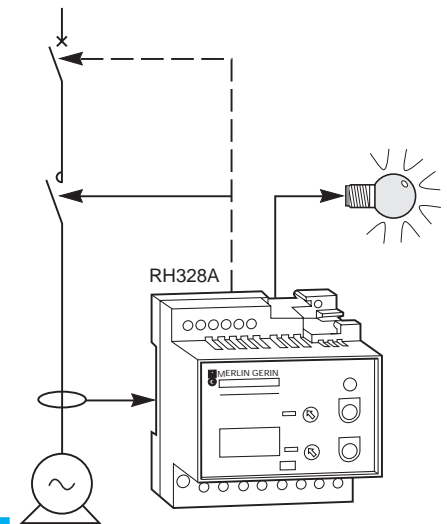


fig. J5-11: example using relay RH328A.

voltage drop at the terminals of a motor during starting must never exceed 10% of rated voltage  $U_n$ .

**The importance of limiting voltage drop at the motor during start-up**

In order that a motor starts and accelerates to its normal speed in the appropriate time, the torque of the motor must exceed the load torque by at least 70%. However, the starting current is much greater than the full-load current of the motor; moreover, it is largely inductive. These two factors are both very unfavourable to the maintenance of voltage at the motor. Failure to provide sufficient voltage will reduce the motor torque significantly (motor torque is proportional to  $U^2$ ) and will result either in an excessively long starting time, or, for extreme cases, in failure to start.

**Example:**

- with 400 V maintained at the terminals of a motor, its torque would be 2.1 times that of the load torque;
- for a voltage drop of 10% during start-up, the motor torque would be  $2.1 \times 0.9^2 = 1.7$  times the load torque, and the motor would accelerate to its rated speed normally;
- for a voltage drop of 15% during start-up, the motor torque would be  $2.1 \times 0.85^2 = 1.5$  times the load torque, so that the motor-starting time would be longer than normal. In general, a maximum allowable voltage drop of 10%  $U_n$  is recommended during the start-up of a motor.

**5.5 maximum rating of motors installed for consumers supplied at LV**

The disturbances caused on LV distribution networks during the start-up of large DOL (direct-on-line) a.c. motors can occasion considerable nuisance to neighbouring consumers, so that most power-supply authorities have strict rules intended to limit such disturbances to tolerable levels. The amount of disturbance created by a given motor depends on the “strength” of the network, i.e. on the short-circuit fault level at the point concerned. The higher the fault level, the “stronger” the system and the lower the disturbance (principally volt-drop) experienced by neighbouring consumers. For distribution networks in many countries, typical values of maximum allowable starting

currents for DOL motors are shown below in table J5-12. Corresponding maximum power ratings of the same motors are shown in table J5-13. Since, even in areas supplied by one power authority only, “weak” areas of the network exist as well as “strong” areas, it is always advisable to secure the agreement of the power supplier before acquiring the motors for a new project. Other (but generally more costly) alternative starting arrangements exist, which reduce the large starting currents of DOL motors to acceptable levels; for example, star-delta starters, slip-ring motors, “soft start” electronic devices, etc.

type of motor single- or three-phase	location	maximum starting current (A)	
		overhead-line network	underground-cable network
single phase	dwellings	45	45
	others	100	200
three phase	dwellings	60	60
	others	125	250

**table J5-12: maximum permitted values of starting current for direct-on-line LV motors (230/400 V).**

type of motor single- or three-phase	location	single-phase 230 V (kW)	three-phase 400 V	
			direct-on-line starting at full load (kW)	other methods of starting (kW)
	dwellings	1.4	5.5	11
	others			
	overhead line network	3	11	22
	underground cable network	5.5	22	45

**table J5-13: maximum permitted power ratings for LV direct-on-line-starting motors.**

**5.6 reactive-energy compensation (power-factor correction)**

The effect of power factor correction on the amount of current supplied to a motor is indicated in table B4 in Chapter B Sub-clause 3-1, and the method of correction in Chapter E Clause 7.

## 6. protection of direct-current installations

J

### differences between a.c. and d.c. installations

Although the basic design principles in each case are similar, there are differences in:

- the calculations for short-circuit currents, and;
- the choice of protective equipment, since the techniques employed for the interruption of direct current differ in practice from those used for alternating current.

### 6.1 short-circuit currents

in order to calculate the maximum short-circuit current from a battery of storage cells, when the internal resistance of the battery is unknown, the following approximate formula may be used:

$I_{sc} = kC$  where  $C$  = the rated ampere-hour capacity of the battery, and  $k$  is a coefficient close to 10 (and in any case is less than 20).

#### battery of storage cells (or accumulators)

For a short-circuit at its output terminals, a battery will pass a current according to Ohm's law equal to  $I_{sc} = V_b / R_i$

where:  $V_b$  = open circuit voltage of the fully-charged battery

$R_i$  = the internal resistance of the battery (this value is normally obtained from the manufacturer of the battery, as a function of its ampere-hour capacity)

When  $R_i$  is not known, an approximate formula may be used, namely:  $I_{sc} = kC$  where  $C$  is the ampere-hour rating of the battery and  $k$  is a coefficient close to 10, and in any case is always less than 20.

#### Example:

What is the short-circuit current level at the terminals of a battery with the following characteristics:

- 500 Ah capacity;
- fully-charged open-circuit voltage 240 V (110 cells at 2.2 V/cell);
- discharge rate 300 A;
- autonomy 1/2 hour;
- internal resistance is 0.5 milli-ohm/cell so that  $R_i = 110 \times 0.5 = 55 \text{ m}\Omega$  for the battery, and  $I_{sc} = \frac{240 \times 10^3}{55} = 4.4 \text{ kA}$

The short-circuit currents are seen to be (relatively) low.



fig. J6-1: battery of storage cells.

#### direct-current generator

If  $V_g$  is the open-circuit voltage of the generator and  $R_i$  its internal resistance, then:  $I_{sc} = V_g / R_i$ .

In the absence of precise data, and for a d.c. system of voltage  $U_n$ ,  $V_g$  may be taken as  $1.1 U_n$ .

#### Example:

A d.c. generator rated at 200 kW, 230 V, and having an internal resistance of 0.032 ohm, will give a terminal short-circuit current of  $\frac{230 \times 1.1}{0.032} = 7.9 \text{ kA}$

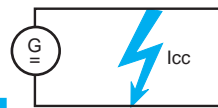


fig. J6-2: direct-current generator.

#### $I_{sc}$ at any point in an installation

In this case  $I_{sc} = \frac{V}{R_i + R_l}$

Where  $R_i$  is as previously defined,  $V$  is either  $V_b$  or  $V_g$  as previously defined,  $R_l$  is the sum of the resistances of the fault-current loop conductors.

Where motors are included in the system, they will each (initially) contribute a current of approximately  $6 I_n$  (i.e. six times the nominal full-load current of the motor) so that:

$I_{sc} = \frac{V}{R_i + R_l} + 6 (I_n \text{ mot})$

where  $I_n \text{ mot}$  is the sum of the full-load currents of all running motors at the instant of short-circuit.

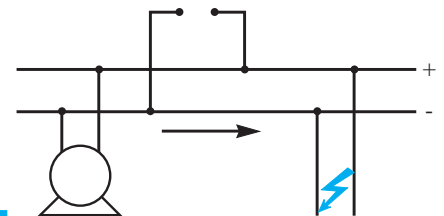


fig. J6-3: short-circuit at any point of an installation.

## 6.2 characteristics of faults due to insulation failure, and of protective switchgear

Devices for circuit interruption are sensitive to the level of d.c. voltage at their terminals when breaking short-circuit currents. The table below provides the means for determining these voltages, which depend on the source voltage and on the method of earthing the source.

**Note:** In the following text the word “pole” has two meanings, viz:

1. Referring to a d.c. source, for example: the positive pole or the negative pole of a battery or generator.
2. Referring to a switch or circuit breaker, for example: a pole of a circuit breaker makes or breaks the current in one conductor. A pole of a circuit breaker may be made up of modules, each of which contains a contact. The pole may therefore consist of one module or (particularly in d.c. circuits) several series-connected modules.

Voltage stresses across opening contacts are reduced by the technique of connecting a number of contacts in series per pole, as mentioned in the table below, and in the following text.

types of network	system earthing	source with mid-point earthing	unearthed system
	one pole earthed at the source		source is not earthed
earthing schemes and various fault conditions			
	case 1	case 2	case 3
analysis of each fault	fault A	pole (a) must break maximum Isc at U volts	there is no short-circuit in this case
	fault B	poles (a) and (b) must break the maximum Isc at U volts	poles (a) and (b) must break the maximum Isc at U volts
	fault C	there is no short-circuit current in this case	as for fault A but concerning pole (b)* * U/2 divided by Ri/2 = Isc (max.)
the most unfavourable case	fault A	A = B = C see Note below the table	fault B (or faults A and C simultaneously)
case of a circuit breaker	all the contacts participating in current interruption are series connected in the positive-conductor (or the negative conductor if the positive pole of the source is earthed). Provide an additional pole for inserting in the earthed polarity conductor, to permit circuit isolation (figure J6-6).	provide in the CB pole for each conductor the number of contacts necessary to break Isc (max.) at the voltage U/2.	provide the number of contacts necessary for breaking the current indicated in the CB pole of each conductor.

table J6-4: characteristics of protective switchgear according to type of d.c. system earthing.

**Note:** each pole is equally stressed for faults at A, B or C, since maximum Isc must be broken with U/2 across the CB pole(s) in each case.

## 6.3 choice of protective device

for each type of possible insulation failure, the protective devices against short-circuits must be adequately rated for the voltage levels noted in table J6-4 above.

The choice of protective device depends on:

- the voltage appearing across the current-breaking element. In the case of circuit breakers, this voltage dictates the number of circuit-breaking contacts that must be connected in series for each pole of a circuit breaker, to attain the levels indicated in table J6-4;
- the rated current required;
- the short-circuit current level at its point of installation (in order to specify its s.c. current-breaking capacity);

■ the time constant of the fault current (L/R in milli-seconds) at the point of installation of the CB.

Table J6-5 below gives characteristics (current ratings, s.c. current-breaking capacity, and the number of series-connected contacts per pole required for a given system voltage) for circuit breakers made by Merlin Gerin.

## 6. protection of direct-current installations (continued)

J

### 6.3 choice of protective device (continued)

type	ratings (A)	sc current-breaking capacity kA for $L/R \leq 0.015$ seconds (the number of series-connected contacts per pole is shown in brackets)						thermal overload protection	coefficient for uprating the instantaneous magnetic tripping units*
		24/48 V	125 V	250 V	500 V	750 V	1000 V		
C32HDC	1 to 40	20 (1p)	10 (1p)	20 (2p)	10 (2p)			special DC	special DC
C60a	10 to 40	10 (1p)	10 (2p)	20 (3p)	25 (4p)			ditto AC	1.38
C60N	6 to 63	15 (1p)	20 (2p)	30 (3p)	40 (4p)			ditto AC	1.38
C60H	1 to 63	20 (1p)	25 (2p)	40 (3p)	50 (4p)			ditto AC	1.38
C60L	1 to 63	25 (1p)	30 (2p)	50 (3p)	60 (4p)			ditto AC	1.38
NC100H	50 to 100	20 (1p)	30 (2p)	40 (3p)	20 (4p)			ditto AC	1.42
NC100LH	10 to 63	50 (1p)	50 (1p)	50 (1p)	50 (3p)			ditto AC	1.42
NS100N	16 to 100	50 (1p)	50 (1p)	50 (1p)	50 (2p)			ditto AC	1.42
NC100H	16 to 100	85 (1p)	85 (1p)	85 (1p)	85 (2p)			ditto AC	1.42
NS100L	16 to 100	100 (1p)	100 (1p)	100 (1p)	100 (2p)			ditto AC	
NS160N	40 to 160	50 (1p)	50 (1p)	50 (1p)	50 (2p)			ditto AC	
NS160H	40 to 160	85 (1p)	85 (1p)	85 (1p)	85 (2p)			ditto AC	
NS160L	40 to 160	100 (1p)	100 (1p)	100 (1p)	100 (2p)			ditto AC	
NS250N	40 to 250	50 (1p)	50 (1p)	50 (1p)	50 (2p)			ditto AC	
NS250H	40 to 250	85 (1p)	85 (1p)	85 (1p)	85 (2p)			ditto AC	
NS250L	40 to 250	100 (1p)	100 (1p)	100 (1p)	100 (2p)			ditto AC	
NS400H	MP1/MP2-400	85 (1p)	85 (1p)	85 (1p)	85 (2p)			no thermal relay; provide an external relay (if necessary)	tripping units MP1/MP2/MP3 special for direct current
NS630H	MP1/MP2/MP3-630	85 (1p)	85 (1p)	85 (1p)	85 (2p)				
C1251N-DC	P21/P41-1250	50 (1p)	50 (1p)	50 (2p)	50 (3p)	25 (3p)			
M10-DC	1000	100 (3p)	100 (3p)	100 (3p)	100 (3p)	50 (4p)	50 (4p)		
M20-DC	2000	100 (3p)	100 (3p)	100 (3p)	100 (3p)	50 (4p)	50 (4p)		
M40-DC	4000	100 (3p)	100 (3p)	100 (3p)	100 (3p)	50 (4p)	50 (4p)		
M60-DC	6000	100 (4p)	100 (4p)	100 (4p)					
M80-DC	8000	100 (4p)	100 (4p)	100 (4p)					

table J6-5: choice of d.c. circuit breakers manufactured by Merlin Gerin.

\* These tripping units may be used on a.c. or d.c. circuit breakers, but the operating levels marked on each unit correspond to r.m.s. a.c. values. When used on a d.c. circuit breaker the setting must be changed according to the co-efficient in table J6-5. For example, if it is required that the d.c. circuit breaker should trip at 800 A or more the coefficient given in table J6-5 is 1.42, then the setting required will be  $800 \times 1.42 = 1,136$  A.

### 6.4 examples

#### Example 1

Choice of protection for an 80 A outgoing d.c. circuit of a 125 V system, of which the negative pole is earthed. The  $I_{sc} = 15$  kA.

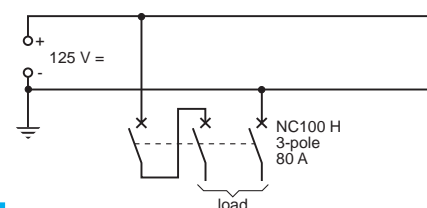


fig. J6-6: example.

Table J6-4 shows that the full system voltage will appear across the contacts of the positive pole.

Table J6-5 indicates that circuit breaker NC100H (30 kA 2 contacts/pole 125 V) is an appropriate choice.

Preferred practice is to (also) include a contact in the negative conductor of the outgoing circuit, to provide isolation (for maintenance work on the load circuit for example), as shown in figure J6-6.

**Note:** three contacts in series, which open in unison, effectively triple the speed of contact separation. This technique is often necessary for successfully breaking d.c. current.

#### Example 2

Choice of protection for a 100 A outgoing d.c. circuit of a 250 V system, of which the mid-point is earthed.  $I_{sc} = 15$  kA.

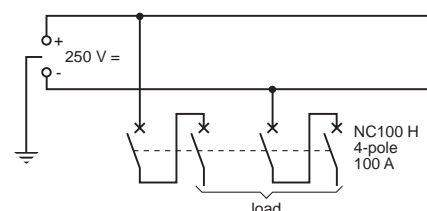


fig. J6-7: example.

Table J6-4 shows that each pole will be subject to a recovery voltage of  $U/2$ , i.e. 125 V for all types of s.c. fault.

Table J6-5 indicates that circuit breaker NC100H (30 kA 2 contacts/pole 125 V) is suitable for cases A and C, i.e. 2 contacts in the positive and 2 contacts in the negative pole of the CB.

It will be seen in the 250 V column that 4 contacts will break 20 kA at that voltage (case B of table J6-4).

## 6.5 protection of persons

The rules for protection are the same as those already covered for a.c. systems. However, the conventional voltage limits and the automatic disconnection times for safety of persons are different (see tables G8 and G9 of Chapter G, Sub-clause 3.1):

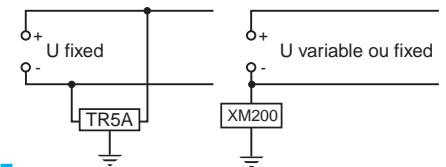
- all exposed conductive parts are interconnected and earthed;
- automatic tripping is achieved in the time-period specified.

RCDs are not applicable to d.c. circuits, so that in practice:

- the principles of the TN scheme are used for cases 1 and 2 of Sub-clause 6.2. It is then sufficient to check that, in the case of a short-circuit, the current magnitudes will be sufficient to trip the instantaneous magnetic relays.

The checking methods are identical to those recommended for an a.c. network.

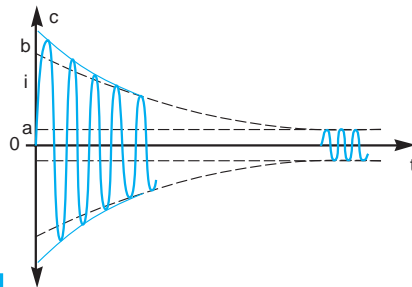
- principles of the IT scheme for case 3 in Sub-clause 6.2,
  - the insulation level of the installation must be under permanent surveillance and any failure must be immediately indicated and alarmed: this can be achieved by the installation of a suitable monitoring relay as shown in Chapter G, Sub-clause 3.4,
  - the presence of two concurrent faults to earth (one on each polarity) constitutes a short-circuit, which will be cleared by overcurrent protection. As for the a.c. systems, it is sufficient to verify that the current magnitude exceeds that necessary to operate the magnetic (or short-time delay) circuit breaker tripping units.



**fig. J6-8: insulation (to earth) monitors for an IT direct-current installation.**

# 7. short-circuit characteristics of an alternator

The characteristics of a 3-phase alternator under short-circuit conditions are obtained from oscillogram traces recorded during tests, in which a short-circuit is applied instantaneously to all three terminals of a machine at no load, excited (at a fixed level) to produce nominal rated voltage. The resulting currents in all three phases will normally\* include a d.c. component, which reduces exponentially to zero after (commonly) some tens of cycles. The curve shown below in figure AJ1-1 is the current trace, from which the d.c. component has been eliminated, of a recording made during the testing of a 3-phase 230 V 50 kVA machine. The definitions of alternator reactance values are based on such "symmetrical" curves.



**fig. AJ1-1: short-circuit current of one phase of a 3-phase alternator with the d.c. component eliminated.**

\* unless, by chance, the voltage of a phase happens to be maximum at the instant of short-circuit. In that case, there will be no d.c. transient in the phase concerned.

The reduction of current magnitude from its initial value occurs in the following way. At the instant of short-circuit, the only impedance limiting the magnitude of current is principally\*\* the inherent leakage reactance of the armature (i.e. stator) windings, generally of the order of 10%-15%.

The large stator currents are (practically) entirely inductive, so that the synchronously rotating m.m.f. produced by them acts in direct opposition to that of the excitation current in the rotor winding.

The result is that the rotor flux starts to reduce, thereby reducing the e.m.f. generated in the stator windings, and consequently reducing the magnitude of the fault current. The effect is cumulative, and the reduced fault current, in turn, now reduces the rotor flux at a slower rate, and so on, i.e. the flux follows the exponential law of natural decay, its reduction rate at any instant depending on the magnitude of the quantity causing the phenomenon. Eventually, a stable state is reached, in which the (greatly reduced) rotor flux produces just enough voltage to maintain the stator current at the level of equilibrium between the three quantities, viz. current, flux and voltage. The reduction of fault current therefore is caused by a diminution of the generated e.m.f. due to armature reaction, and not, in fact, by an increase in impedance of the machine (that is why the term "effective reactance" was used in Chapter J Sub-clause 1.1).

\*\* the sub-transient reactance, which is defined later, is very nearly equal to the leakage reactance.

As shown in figure AJ1-1, the current reduction requires a certain time, and the reason for this is that, as the rotor flux begins to diminish, the change of flux induces a current in the closed rotor circuit in the direction which, in effect, increases the excitation current, i.e. opposes the establishment of a reduced level of magnetic flux. The gradual predominance of the stator m.m.f. depends on the overall effect of rotor and stator time constants, the result of which is the principal factor in the "a.c. current decrement" shown in figure AJ1-1.

If, during a short-circuit, there were no eddy currents induced in the unlaminated face of round-rotor alternators, or in damper windings (see note 1) of salient-pole alternators, the envelope of the a.c. current decrement would be similar to that of curve b in figure AJ1-1, i.e. the so-called transient-current envelope.

The presence of either of the two features, mentioned above however, gives rise to the sub-transient component of current (curve C). The effect is analogous to that of the closed circuit of the rotor-excitation winding described above (i.e. the induced currents oppose the change), but having a very much shorter time constant.

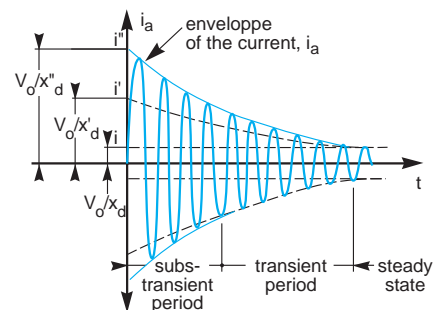
The overall a.c. current decrement is therefore composed of the sum of two exponentially-decaying quantities, viz. the sub-transient and the transient components, as shown in figure AJ1-2.

Note 1: Damper windings are made up of heavy gauge copper bars embedded in the pole faces of salient-pole rotors, to form a squirrel-cage "winding" similar to that of an induction motor. Their purpose is to help to maintain synchronous stability of the alternator.

With the rotor turning at the same speed as that of the m.m.f. due to the stator currents, no currents will be induced in the damper windings; if a difference in the speed of rotation occurs, due to loss of synchronism, then currents induced in the damper windings will be in a direction that produces a torque which acts to slow (an overspeeding rotor) or to accelerate (an underspeeding rotor). A similar, but much smaller effect occurs due to eddy currents in the surface of solid unlaminated rotors of turbo-alternators.

For advanced analytical studies of alternators, two component axes "direct" and "quadrature" are defined, and subtransient and transient reactances, etc. are derived for each component system.

In the simple studies needed for 3-phase symmetrical fault levels and for circuit-breaker performance based on such faults, the direct-axis component system only is required; this accounts for the suffix "d" of reactance values, shown in figure AJ1-2. Suffix "q" is used for quadrature quantities.



$x''_d$  = the sub-transient reactance  $V_o/i''$   
 $x'_d$  = the transient reactance  $V_o/i'$   
 $x_d$  = the synchronous reactance  $V_o/i$   
 $V_o$  = peak rated voltage of the alternator

**fig. AJ1-2: a.c. component of armature current versus time, in a short-circuited alternator (no d.c. transient is shown).**

The reactances are generally defined as r.m.s. voltages divided by r.m.s. currents. In the current trace of figure AJ1-2, however, it is simpler to use the projected peak values of current, so that  $V_0$  must be the rated peak voltage of the machine.

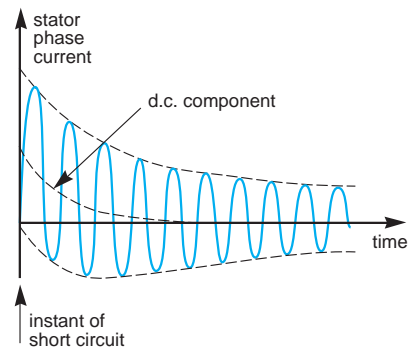
Note 2: in the definition of " $x$ " some authors use the actual voltage measured during the test, instead of  $V_0$ . Moreover,  $x_d$  is generally denoted by  $X_s$  and is referred to as "synchronous reactance".

### asymmetrical currents

As previously noted, in general, all 3-phases of short-circuit current will include a d.c. component. These components give rise to additional electro-dynamic and thermal stresses in the machine itself, and in circuit-breakers protecting a faulted circuit.

The worst condition is that of a phase in which the d.c. component is the maximum possible, i.e. the d.c. transient value at zero time (the instant of fault) is equal to the peak value of current given by  $V_0/x_d$ , as defined in figure AJ1-2.

A typical test trace of this condition is shown in figure AJ1-3.



The current envelope of an asymmetrical transient has the same dimensions about the d.c. transient curve, as the symmetrical envelope has about the current zero axis.

**fig. AJ1-3: a fully-offset asymmetrical transient fault-current trace.**

The consequence of asymmetrical transient fault currents and the standardized relationship between the symmetrical and asymmetrical quantities for circuit breaker performance ratings are given in Sub-clause 1.1 of Chapter C, and are illustrated in figure C5.