n° 182

LV circuit-breakers confronted with harmonic, transient and cyclic currents

Michel Collombet

A graduate engineer from the INPG in 1968, he joined Groupe Schneider in 1975 as manager of digital electronic developments in **SES (Electronic Safety Systems).** He is currently in charge of electronic developments in the Low Voltage Power Components Business Unit (DBTP).

Bernard Lacroix

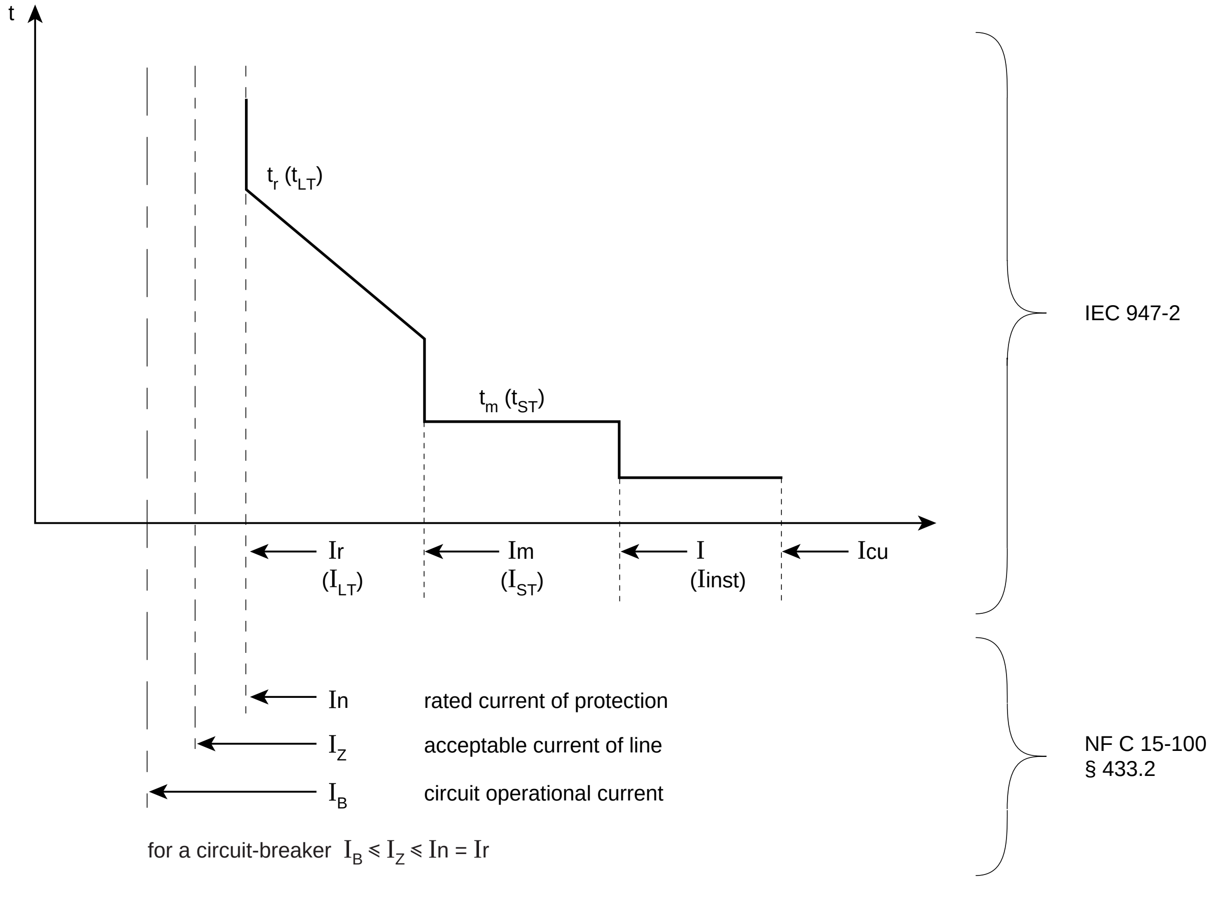
A graduate engineer from ESPCI in 1974, he joined Groupe Schneider in 1981 as a sales engineer in the UPS division and later as sales manager in the «people protection products» division. In 1991 he was appointed as head of specfication in the LV Power distribution business.

E/CT 182, first issued april 1997

glossary

ASIC	Application Specific Integrated Circuit.
IIR filter	Infinite Impulse Response.
GFP	Ground Fault Protection.
I	instantaneous magnetic protection tripping threshold.
Icu	ultimate (maximum) breaking capacity of a circuit-breaker.
Im	magnetic protection setting or Short Time (I_{ST}).
Ir	thermal protection setting or Long Time (I_{LT}).
t_m	time delay setting of a magnetic trip unit or Short time protection (t_{ST}).
t_r	setting (if required) of the thermal protection delay or of the time delay of the Long Time protection (t_{LT}).

Other current quantities are defined in the IEC 364 installation standard as in the figure below.



LV circuit-breakers confronted with harmonic, transient and cyclic currents

contents

Development of loads, a result of the technological breakthroughs of the last decade, has led to an increased number of constraints in electrical power distribution. Protection devices have had to adapt accordingly, particularly with regard to three phenomena:

- high harmonic currents due to multiplication of non-linear loads using power electronics (rectifiers, switch mode power supplies,...);
- transient currents caused by energising loads with a high inrush current such as capacitive loads, LV/LV transformers;
- cyclic currents resulting from a marked increase in load automatically in repetitive cycles (welding robots, wave train heating).

The purpose of this Cahier Technique is to show how electronic control units take these new requirements into account and tend to replace thermal-magnetic trip units. It also shows how the possibilities of digital technology have turned these control units into «intelligent, communicating» sensors/actuators.

1. review of the LV circuit-breaker

role of a circuit-breaker

The main role of a circuit-breaker is to protect the electrical installation, and the conductors placed downstream, against abnormal operating conditions such as overloads and short-circuits. In order to perform this function effectively, the circuit-breaker's trip unit must take load development into account.

This development is characterised by:

■ increased harmonic «pollution»
Development of power electronics and thus of non-linear loads (data processing machines, rectifiers, dimmers, choppers) and the progress made in load technology (discharge lamps, fluorescent lamps,...) have increased the strength of harmonic currents in distribution power networks.

■ more frequent «transient» currents due to standard and new loads generating high inrush currents:

□ capacitors for compensation of the cos φ (whose reference value has risen), LV/LV transformers,

□ but rectifiers with front end capacitors are also becoming increasingly common (lamps with electronic starter, computers...).

■ loads controlled in «cycles».
Ever increasing automation results in greater repetition of operations of loads such as process motors, production robots, heat regulation by wave trains...

This development is accompanied by a demand for increased continuity of service. Consequently:

■ to avoid undervoltage and improve continuity of service, replacement sources such as generator sets need to be installed. These sets have specific features that the protection device has to incorporate, for example a higher source impedance which increases disturbances due to harmonic currents and reduces the value of the fault currents, thereby modifying the setting value of the protection devices.

■ to avoid untimely tripping to satisfy safety and comfort requirements in the service sector, and in view of the cost of power failure in industry, it is vital to trip only when the risk is real.

technology / organisation of an LV circuit-breaker

Circuit-breakers from 1 to 6300 A are extensively used in LV installations.
The trip units for these circuit-breakers are produced using two technologies:

■ thermal-magnetic trip units. Mainly used for domestic and industrial ranges with small ratings. On modular type devices the trip unit is built into the circuit-breaker.

■ electronic control units. Formerly reserved solely for high current rating circuit-breakers, there is a marked trend (see fig. 1) towards this type of trip unit as it is a solution offering a high degree of flexibility and is becoming increasingly affordable.

In point of fact, the use of digital technologies and in particular use of simple Application Specific Integrated Circuits (ASIC) enables:

■ universal trip units to be produced providing greater setting facilities,

■ more data to be processed,

■ the communication required for installation control and monitoring to be performed.

Thermal-magnetic trip unit

These trip units contain bimetal strips and an electromagnet coil, normally mounted in series with the circuit requiring protection.
The higher the overload, the quicker the reaction of the bimetal strip. The coil reacts almost instantaneously to high overcurrents according to the electromagnet principle.

Control unit

These trip units contain sensors, processing and control electronics and an actuator (see fig. 2).

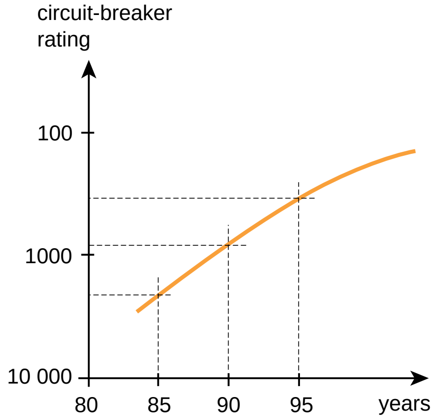


fig. 1: development of control units.

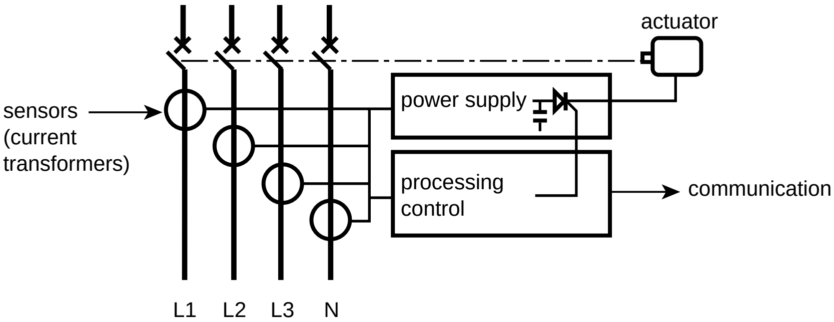


fig. 2: functional modules of a control unit.

■ sensors.
Current sensors first process the current image to be measured and then, to ensure optimum dependability, supply the trip unit with electrical power (self powered trip units).
As these sensors have to perform this dual function (trip unit measuring and power supply), they use a magnetic circuit (« iron CT»).

■ data processing.
Processing contains the following functional features (see fig. 3):
□ function ①: digitise the signal supplied by the sensor using an analog/digital converter to monitor current evolution in real time,
□ function ②: compensate for CT saturation, if any. In point of fact magnetic core CTs can be saturated for high current values, a phenomenon which is amplified in the event of a temperature rise (see fig. 4),
□ function ③: calculate the RMS value of the primary current,
□ function ④: compare the RMS value with the thresholds previously set by the user. According to the value, this comparison is made with or without a time delay. If overshooting occurs the electronics send an electrical order to an actuator which will then convert it into a mechanical action to unlatch the circuit-breaker.

■ actuator.
The actuator is confronted with the problem of having to produce a major force instantaneously... without, however, consuming too much electrical current. Its action is equivalent to making an effort of several Newtons over a few millimetres, in other words producing several joules for a few milliseconds, i.e. several hundred Watts!
Actuator efficiency must therefore be outstanding, a fact which rules out the use of electromagnets (coils) and calls for systems with potential energy.
This ensures that ultra-rapid unlatching of the circuit-breaker is possible in all circumstances.

current measurement

Thermal-magnetic trip unit

In this type of trip unit the bimetal strip does not supply current values but thermally and mechanically reacts to its effects.

■ thermal.
Heating of a bimetal strip uses the same principle as for conductors, i.e. the temperature rise is proportional to the energy supply ($J = RI^2t$) generated by the flow of a constant current (I) for a given time (t). Tripping thus occurs for an energy J_0, thus defining a relationship t = f(I).
The standard (IEC 947-2) characterises this relationship by a specific point (I,t) corresponding to a 30 % overload for a period of 2 hours. This parameter determines the bimetal strip and thus the rating of the thermal trip unit.

In practice, a bimetal strip is:
□ directly heated for small circuit-breakers: the current flowing through the circuit-breaker pole crosses the bimetal strip in its entirety. In this case the bimetal strip time constant is low and can be compared with that of the protected cables,
□ indirectly heated for large circuit-breakers: a wire through which the current to be monitored flows, is placed in the immediate vicinity of the strip.

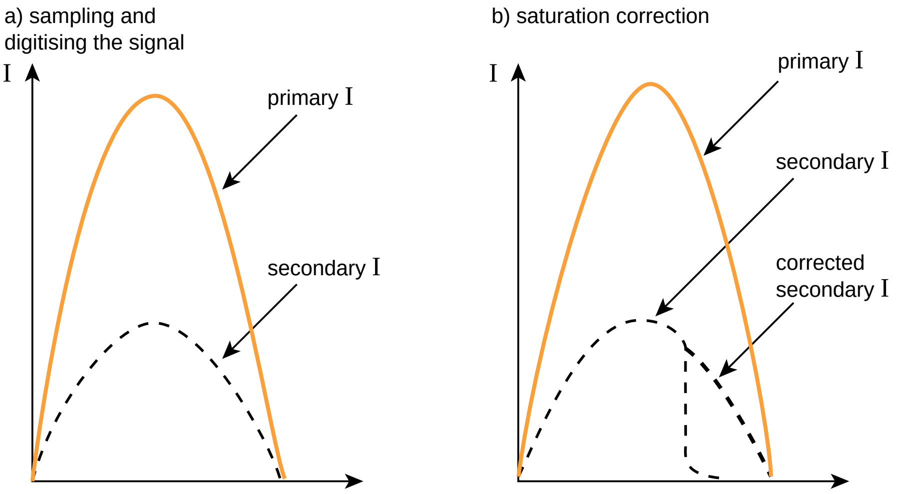


fig. 4: sampling and correction of CT saturation (if any).

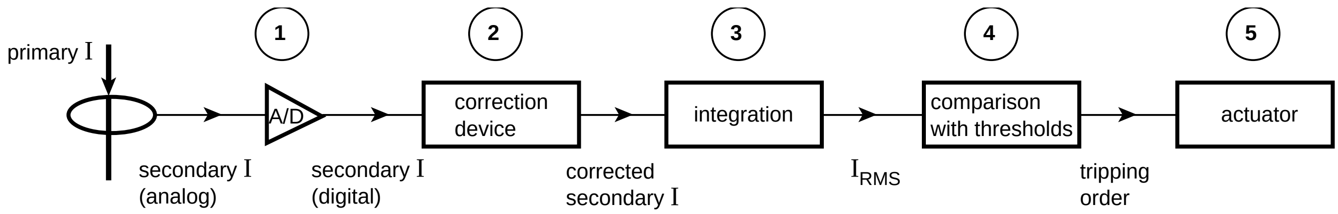


fig. 3: functional diagram.

The distance (resulting in a thermal impedance) introduces a delay in heating the strip thus increasing its time constant. However, this time constant is normally far lower than that of the protected cables.
In both cases, the thermal time constant of the bimetal strip cannot be adjusted.

■ magnetic
If a short-circuit occurs, the fault current flowing through the coil creates a magnetic field sufficient to cause the displacement of a moving blade which then releases the spring latching mechanism and opens the contacts with a sudden movement.
The threshold is set at the air gap. Once the set threshold is exceeded, operating time is more or less constant (a few milliseconds to 50 milliseconds) (see fig. 5).

Thermal-magnetic trip units do not measure the value of the monitored current.

Electronic trip unit
■ thermal protection (Long Time protection).
The electronic trip unit uses the heating and cooling model of a conductor.

In actual, fact it **models** the temperature of the conductor by calculating its heating in real time according to its thermal equation. A good approximation considers the heating and cooling of a cable between t and t + dt takes place in accordance with the following physical principles:
□ heating:
results from supply of calories mainly by joule effect: $A\, i^2 dt$.
A = constant function of resistance, mass, specific heat of the conductor,
□ cooling:
results from losses due to conduction, convection and radiation.
These losses are practically proportional to the difference in temperature between the conductor and ambient temperature, i.e. to heating θ i.e. in all $- \lambda\, \theta\, dt$, where λ depends on the physical and geometrical characteristics of cable installation.

The thermal equation of the cable is thus:
$d\theta = A\, i^2\, dt - \lambda\, \theta\, dt$ or

$$\tau \frac{d\theta}{dt} + \theta = \tau\, A i^2 \quad (1)$$

where $\tau = 1/\lambda$ the thermal time constant of the conductor.
If we proceed by digital sampling at the frequency f such that dt = 1/ f, a digital equation equivalent to (1) is obtained:

$$\theta_{t+dt} = [1-\alpha]\; \theta_t + \beta\; i^2$$

where $d\theta = \theta_{t+dt} - \theta_t$,
$\alpha = 1/\tau f$ and $\beta = A\, dt = A/f$

i.e. $\theta_{k+1} = [1-\alpha]\; \theta_k + \beta\; I_k^2 \quad (2)$

if the measurement at instant t represents the kth measurement and at instant t + dt the k + 1th.
Resolution of this digital equation then allows **exact modelling of conductor heating.**

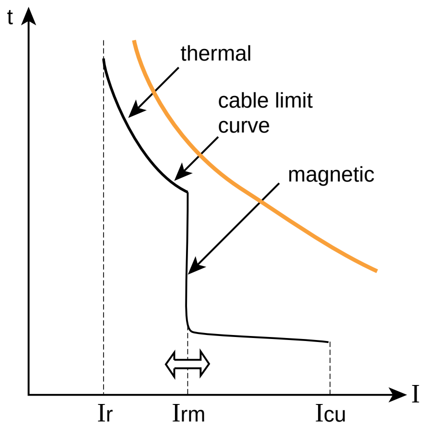
In fact equation (2) representing the temperature calculated by calibration is none other than the digital transfer function of a first order low pass filter (see fig. 6) to which I_k^2 is applied as an input signal, ie:

$$S_{k+1} = S_k + \gamma \left[I_k^2 - S_k \right]$$
$$= [1-\gamma]\; S_k + \gamma\, I_k^2$$

S_{k+1} represents the RMS value, Irms, of the current after k + 1 samples.

Consequently the installation of this filter simply gives the cable temperature by its equivalent in RMS value of the current.
□ advantages of digital technology:
- greatly simplifies calculation of I_k^2,
- calculates the RMS value, Irms, of the current, and thus the heating, over a period of time compatible with conductor time constants (several minutes to several hours as the heat inertia (τ) of conductors vary according to their size). This feature is built into the IIR (Infinite Impulse Response) filter of the calculation algorithm; the time constant is defined according to circuit-breaker sizing as this depends on the cross-section and heat inertia of the cables it has to protect,
- real time processing of the equation means this calculation is not dependent on power network frequency.
This electronic control, used to monitor evolution of conductor heating/cooling, is also known as the «thermal memory» of the control unit.

■ making the thermal protection: Long Time (LT) and thermal memory.
The thermal behaviour of a cable defined by equation (2) also corresponds to the long delay function of the electronic circuit-breaker. It protects cables and loads against overloads.
The temperature value θ or its current equivalent, Irms, calculated by digital filtering, is compared with the setting value of the long delay threshold, linked to the acceptable limit θm (see fig. 7), thus performing the digital equivalent of the bimetal strip function.



Ir = thermal setting
Irm = magnetic setting
Icu = ultimate breaking capacity

fig. 5: thermal-magnetic circuit-breaker tripping curve.

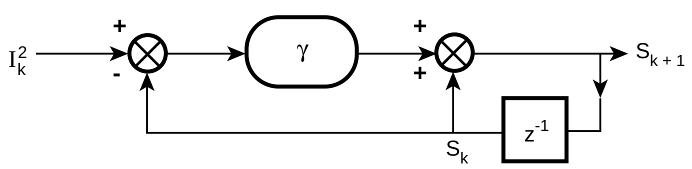


fig. 6: filtering algorithm (R) of the low pass digital filter.

Permanent knowledge of the cable temperature equivalent ensures not only that θm is not overshot but also offers new possibilities for load and cable protection such as:

□ overload information and protected feeder management.

Overload information is available when the setting current or certain preset thresholds have been overshot, thus enabling feeder load monitoring. The operator can thus anticipate tripping due to overload by shedding a non-priority feeder. This type of information starts opening out towards distribution automation systems,

□ storage of heating after power shutdown.

If an overload causes the circuit-breaker to trip or if the electrical power supply fails upstream (e.g. transfer to a replacement source), cooling continues to be monitored. However management is now different since the electronics is no longer supplied.

Immediately after breaking, conductor temperature is modelled by the discharge voltage of a circuit with a very high time constant (similar to the conductor thermal constant). When power is restored either by switching the circuit-breaker back on or by energising the load, the trip unit electronics will recover the residual voltage value. This value will then be used as a new initial temperature for conductors in the filtering algorithm modelling conductor heating.

■ short-circuit protection (Short Time - ST).

The short time function protects the power network against high overcurrents (in distribution normally around 10 In, adjustable by the user). Just as for long time protection, short time protection is achieved by filtering, however in this case the RMS value of the current is processed over a period of time (a few ms) compatible with the speed of intervention required for this function. An intentional delay that the user can adjust is also incorporated in the data processing function (see fig. 8).

■ instantaneous protection.

This provides protection against full short-circuits. The unfiltered peak value is the processed value and has no time delay.

The long time, short time and instantaneous protection make up «the» tripping curve of a circuit-breaker with an electronic control unit (see fig. 9).

We shall now see how disturbed currents and special applications are treated by a circuit-breaker with an electronic control unit.

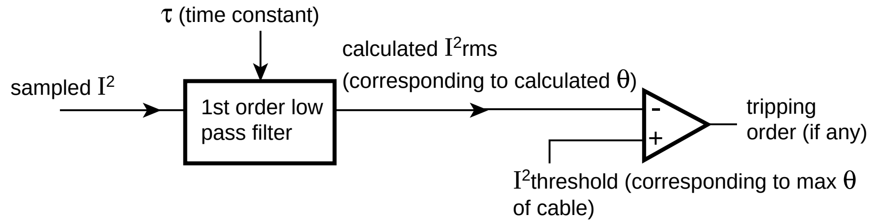


fig. 7: making the Long Time (LT) function.

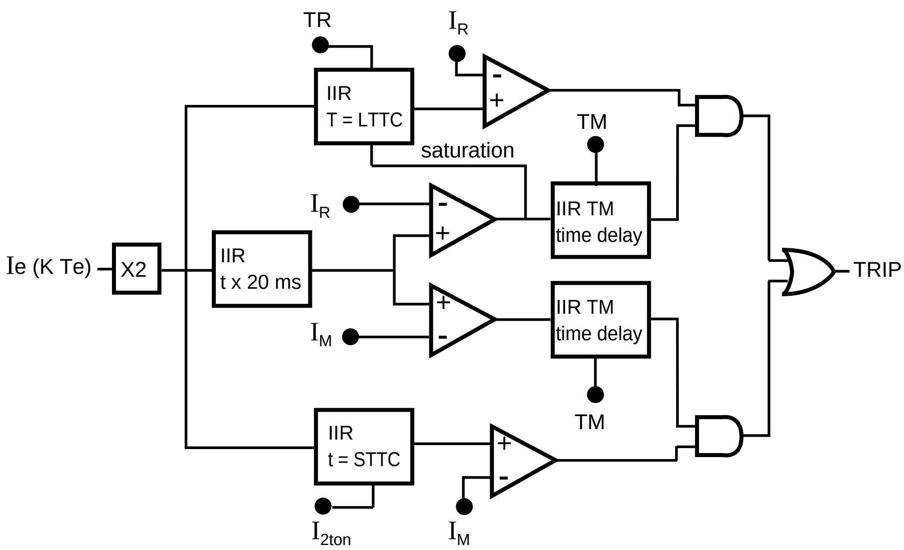


fig. 8: structure of the long and short delay filter assembly.

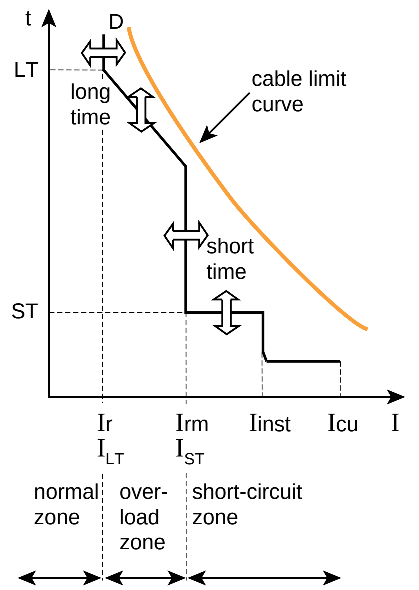


fig. 9: electronic circuit-breaker tripping curves.

2. harmonic currents

Development of loads and in particular the increasing use of static converters, means that the current encountered on distribution power networks are no longer perfect 50 Hz sinusoidal ones... far from it!
These currents have an adverse influence on measurement, especially in normal operation for monitoring of thermal effects: for fault currents in excess of 10 In their effect is virtually zero.

theoretical review of harmonic currents

Non linear and harmonic loads

Ohm's law formulates a proportionality (linearity) between sinusoidal current and voltage at mains frequency.

Some loads (said to be non-linear) deform the current sine wave and thus also the voltage sine wave.
This deformation is analysed using Fourier's serial decomposition which reveals «harmonic» currents which are superimposed on the initial sine wave (the fundamental) causing its deformation.

(Fourier's) harmonic decomposition

All currents and voltages in electrical power networks can be represented by the superimposition of a DC component, a sinusoidal component at mains frequency and a certain number of sinusoidal (harmonic) components with a multiple frequency of mains frequency. These quantities are formulated by Fourier's development of the current or voltage function y(t):

$$y(t) = Yo + Y1\sqrt{2}\sin(\omega t - \varphi 1) + \sum_{n=2}^{n=\infty} Yn\sqrt{2}\sin(n\omega t - \varphi n)$$

Yo = DC component amplitude,
Y1 = RMS value of the 50 Hz sinusoidal component (or fundamental),
ω = fundamental frequency,
φ_1 = fundamental phase shift Yn (for n > 1) = RMS value of the order n harmonic component,
$n\omega$ = pulsation of harmonic n,
φn = phase shift of harmonic n.

Ohm's law

In the presence of non-linear loads, Ohm's law is applied only between harmonic current and voltage of the same order «n» with an impedance value calculated for a pulsation equal to n times that of the fundamental:
Un = Z(nω) x In.
Deformation of the current waveform can be said to cause an equivalent deformation of voltage for each harmonic order, whose amplitude and phase depend on the value of the impedance for each harmonic frequency. There is no longer a simple relationship between the RMS values of both waves considered globally.

Distorted RMS current

$$Irms = \sqrt{I1^2 + I2^2 + I3^2 + In^2 + ...}$$

which can also be expressed by the different current total harmonic distortions h_{ni}: In/ I1:

$$Irms = I1\sqrt{1 + h_{2i}^2 + h_{3i}^2 + \ldots + h_{ni}^2 \ldots}$$

$$= I1\sqrt{1 + Di^2}$$

which reveals the current total harmonic distortion Di.

Current peak factor

for the fundamental,
Peak I1: $\sqrt{2}I1$ and the peak factor is $\sqrt{2}$.
For the total distorted current,

$$peak\ I = K\ Irms = K\ .\ I1\sqrt{1 + Di^2}$$

Harmonic effects

■ effect of the peak factor:
□ if the peak factor is greater than $\sqrt{2}$ there is a risk of untimely tripping if the protection deduces Irms from Ipeak.
□ if the peak factor is less than $\sqrt{2}$ there is a risk of overheating due to failure of the protection devices to trip;
■ heating.
For a given load, with a nominal current In at 50 Hz, the RMS current in the conductors will be higher as it is multiplied by $\sqrt{1+Di^2}$ resulting in:
□ additional losses and thus overheating of transformers, cables and generators,
□ magnetic losses, heating and stray torque in rotating machines;
■ circulation of high currents in the neutral in the presence of order 3 harmonics and their multiples.

Consequently thermal trip units must take the RMS value into account to protect conductors. Readers particularly interested in harmonics are invited to read Cahier Technique n° 152.

harmonic current generators

Rectifiers

Three-phase Graëtz bridge type rectifiers create harmonic distortions. This rectifier type which is relatively widespread in all industrial devices due to its economic nature, is however a source of disturbance for power networks.
These rectifiers are used in a wide variety of industrial applications such as variable speed drives, UPS and computer power supplies. They are also common in the service sector as a result of the proliferation of switch mode power supplies for office automation applications and fluorescent lamps with electronic ballast.
The shape of the input current greatly depends on the presence of a

smoothing reactor which most rectifiers do not have.

■ example 1: (see fig. 10)
Input current of a three-phase rectifier (unmonitored Graëtz bridge). Harmonic composition corresponding to the current in figure 10 is (as a percentage of fundamental amplitude and with phase shift with respect to the latter):

h_1	(50 Hz)	=	100 %
h_5	(250 Hz)	=	33 % (180°)
h_7	(350 Hz)	=	2.7 %
h_{11}	(550 Hz)	=	7.3 % (180°)
h_{13}	(650 Hz)	=	1.6 %
h_{17}	(850 Hz)	=	2.6 % (180 %)

total harmonic distortion:

$$D = \sqrt{h_3{}^2 + h_5{}^2 + h_7{}^2 + \ldots h_{17}{}^2}$$
$$= 6 \ \%$$

Irms = 106 % of Ih_1.
Imax/ V2 = 78 %.

This means that a control unit based on an RMS measurement using peak current would measure an RMS value of 78 instead of 106. The installation would be underprotected in this case.

■ example 2: (see fig. 11)
Input current of the three-phase rectifier of a variable speed drive for asynchronous motor.
Harmonic composition corresponding to the current in figure 11 is (as a percentage of fundamental amplitude and with phase shift with respect to the latter):

h_1	(50 Hz)	=	100 %
h_5	(250 Hz)	=	85 % (180 %)
h_7	(250 Hz)	=	72 %
h_{11}	(550 Hz)	=	41 % (180 %)
h_{13}	(650 Hz)	=	27 %
h_{17}	(750 Hz)	=	8 % (180 %)

total harmonic distortion in this case:

$$D = \sqrt{h_3{}^2 + h_5{}^2 + h_7{}^2 + \ldots h_{15}{}^2}$$
$$= 58 \ \%$$

Imax/ V2 = 203 %.

This means that a control unit based on an RMS measurement using the peak current would measure an RMS value of 203 instead of 158. The installation would be overprotected in this case.

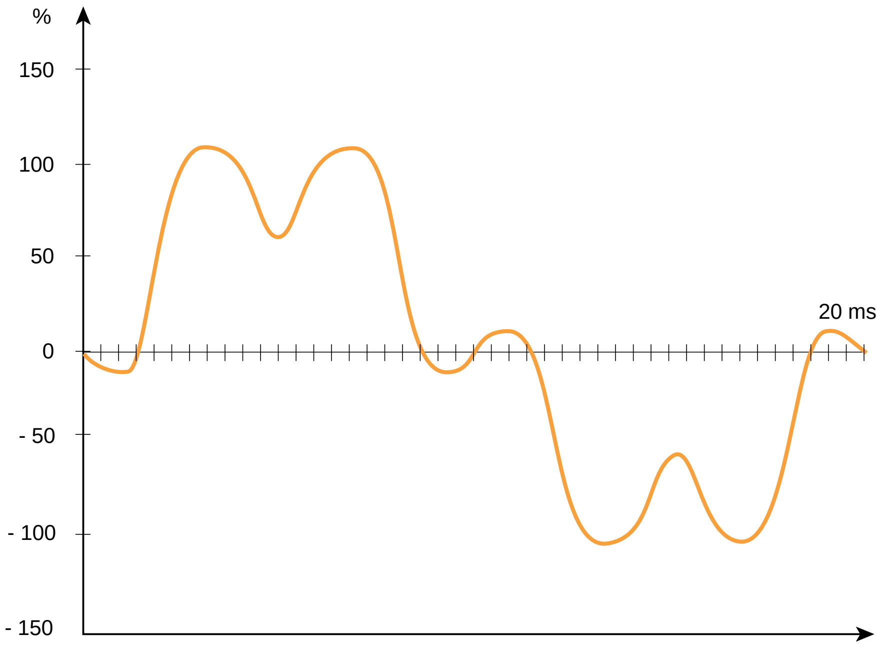


fig. 10: example 1: a rectifier.

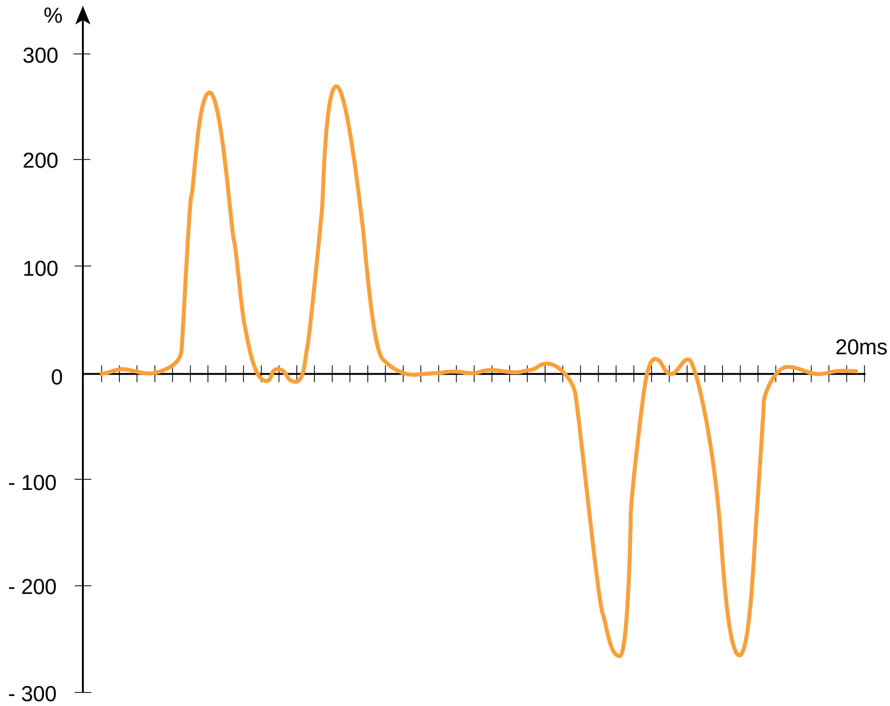


fig. 11: example 2: a variable speed drive with variable frequency.

Standard fluorescent lighting

The presence of harmonic currents is observed in steady state (see fig. 12). Harmonic composition for the phase current gives:

h_1	(50 Hz)	=	100 %
h_3	(150 Hz)	=	35 %
h_5	(250 Hz)	=	27 % (180°)
h_7	(350 Hz)	=	16.1 % (180°)
h_9	(450 Hz)	=	2.2 % (180°)
h_{11}	(550 Hz)	=	3.4 %
h_{13}	(650 Hz)	=	1.1 %

D = 42.6 %

Irms = 199 % of Ih_1 = 39 A.

Note that as these are well-distributed single-phase loads, the RMS current in the neutral is 33 A as a result of the third harmonic and its multiples, whereas it ought to be zero.

management of harmonic currents by LV circuit-breaker electronic control units

The first electronic control units used an analog technology. This solution consisted of implementing a simple RC filter in the measuring circuit behind a double wave rectifier. A technique which satisfied needs relatively well as long as harmonic phenomena remained marginal.

Technological progress and in particular ASIC type solutions integrating a large number of components, made rapid, ultra-fine signal sampling possible. Current use of a digital filter has simplified calculation of the RMS value and enables the conductor's thermal equation to be modelled (see para. 1).
The problem is then to define sampling frequency to obtain an accurate RMS value.

In order to calculate the real RMS value of a signal of fundamental frequency f loaded with harmonics up to order n, Shannon's theorem states that this signal must be sampled at frequency 2n f.

In practice the sampling chosen for electronic control units is 1600 Hz, thus enabling harmonic currents up to order 16 to be considered.

The above examples showed that harmonic currents over order 16 can be completely ignored.

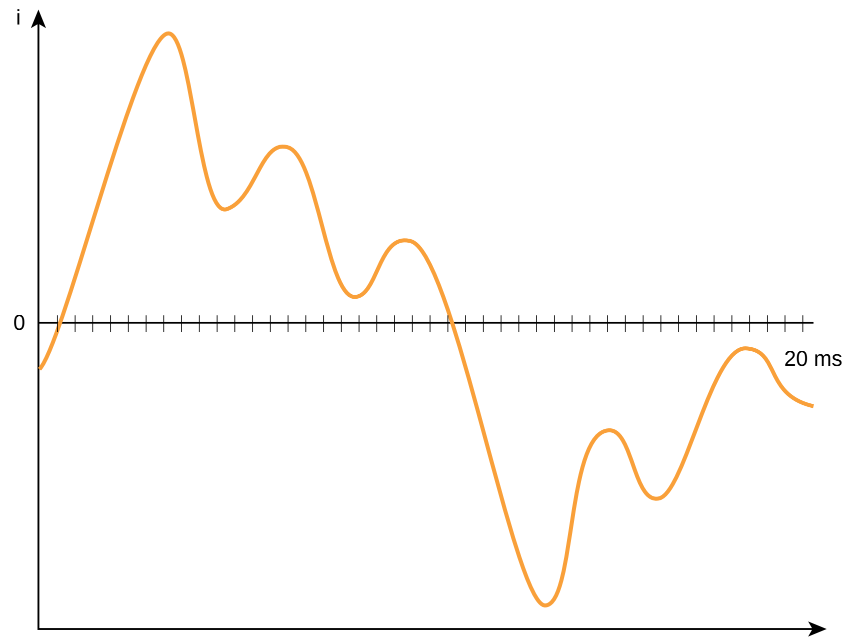


fig. 12: fluorescent lighting.

3. transient and cyclic currents

For some feeders the main problem is to clearly distinguish the normal energising current from the fault current. The loads presenting this type of problem are mainly LV/LV transformers, motors, tungsten and fluorescent lamps,...
Another problem to solve is how to properly protect the cables feeding cyclic current loads. This chapter will deal with both these problems.

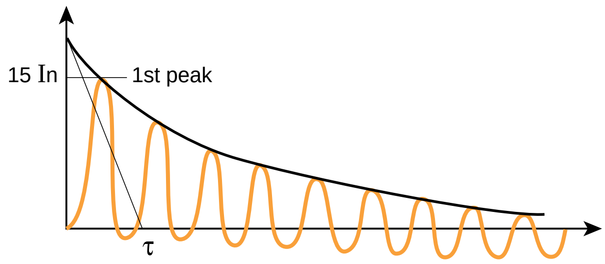


fig 13: transformer energising.

inrush current examples

LV/LV transformers
A transformer primary is a choke with a magnetic circuit. On energising a dual phenomenon may occur:

■ first the creation of the load current (transient state) of an LR circuit (with the characteristics in steady state of the transformer primary);
■ second, due to the presence of the saturable magnetic circuit, a high current peak, according to the time of energising, due to saturation of the magnetic circuit.

The result is an inrush curve of the type shown in figure 13, composed of a series of peaks absorbing one another in accordance with an exponential law.
The first current peak frequently reaches 10 to 15 times transformer rated current and even more than 20 times nominal current for the smaller ratings (⩽ 10 kVA). The inrush current is quickly damped with a time constant of a few dozen ms.

To give an example: for a 50 kVA LV/LV transformer, the peak is around 15 In and the time constant for the phenomenon 20 ms (see fig. 13).

Motors
Asynchronous motors account for 90 % of motors used. This motor type presents a current inrush on startup whose envelope curve has the form of figure 14 (for direct starting). An excitation peak (8 to 12 In) followed by a starting current (from 5 to 8 In) (see fig. 14).

Fluorescent lighting
Fluorescent lamps also absorb a very high thermal current on energising.

Switch mode power supplies
This power supply type, for example on computer load input, presents peaks of around 10 In during energising (capacitor load through a rectifier).

It should also be pointed out that the inrush current of many loads after a short power cut is greater than the initial energising current: the standard example is the capacitor bank which remains charged.

Digital electronics has enabled short time protection to be suitably adapted to distinguish transient currents from short-circuit currents (see fig. 5).

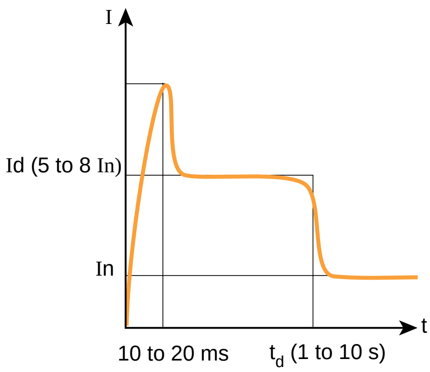


fig. 14: motor energising.

management of transient currents by LV circuit-breaker electronic control units

Let us now see how an electronic control unit manages transient currents greater than the short time threshold.

If the current exceeds the threshold Im, the control unit uses IIR filtering to calculate over a very short period (a few ms) the RMS value of the current, thus " smoothing " this overload.
This kind of time delay depends on the energy of the transient current.

■ in the case of a normal transient current supplying considerable power in a very short time, then rapidly decreasing, the tripping threshold is not reached. Consideration of the energy of the peak (and not of its peak value) lets this transient pass even if it lasts several periods, whereas a magnetic trip unit would have tripped (see fig. 15).

■ if the transient turns out to be a persistent fault (see fig. 16), the short time delay function filter continues to increment very quickly, thus causing rapid tripping once the threshold is overshot. This technique also allows special fault currents to be monitored, for example the current resulting from the stalled rotor of a motor.

cyclic current loads

Intermittent operation of a motor or a load causes rapid heating particularly if the energising currents are high.
Supply cables, like loads, undergo the same current stresses but not necessarily the same heating (different thermal time constants). Some loads have specific protection.
The overcurrent value that can be withstood by a cable depends on initial heating and on the cooling period elapsing between two consecutive overcurrents.
Thus a cable can be sized for the energy it conveys if the cycle is less than its thermal time constant.
Using the thermal equation model of a cable, cyclic heating of a cable can be represented by a curve of the type shown in figure 17.

This is the case for example of welding machines, static switches with wave trains or motors with cyclic starting.

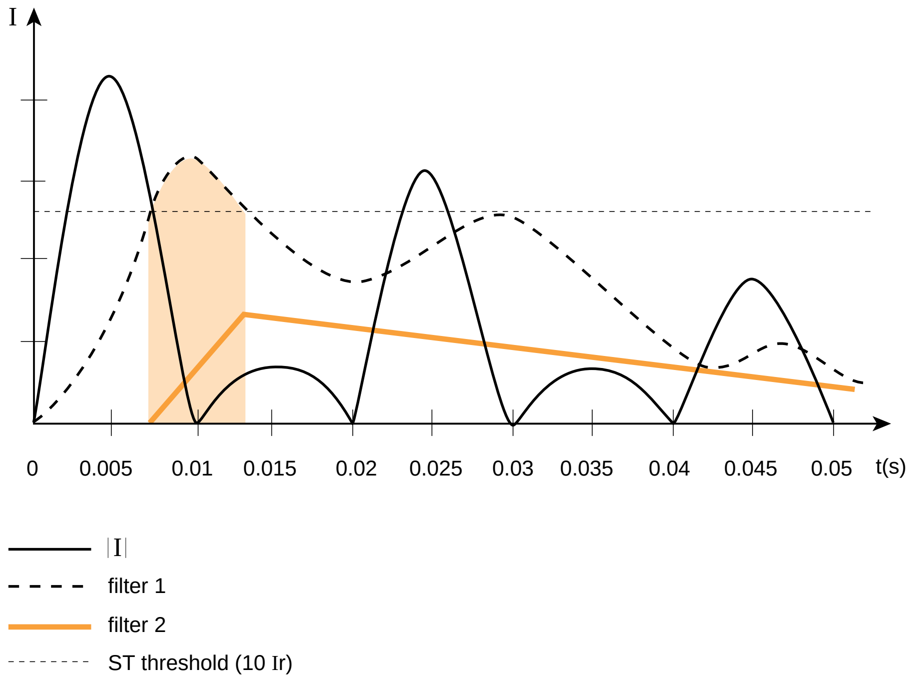


fig 15: transient current solved by «smoothing» the IIR filter.

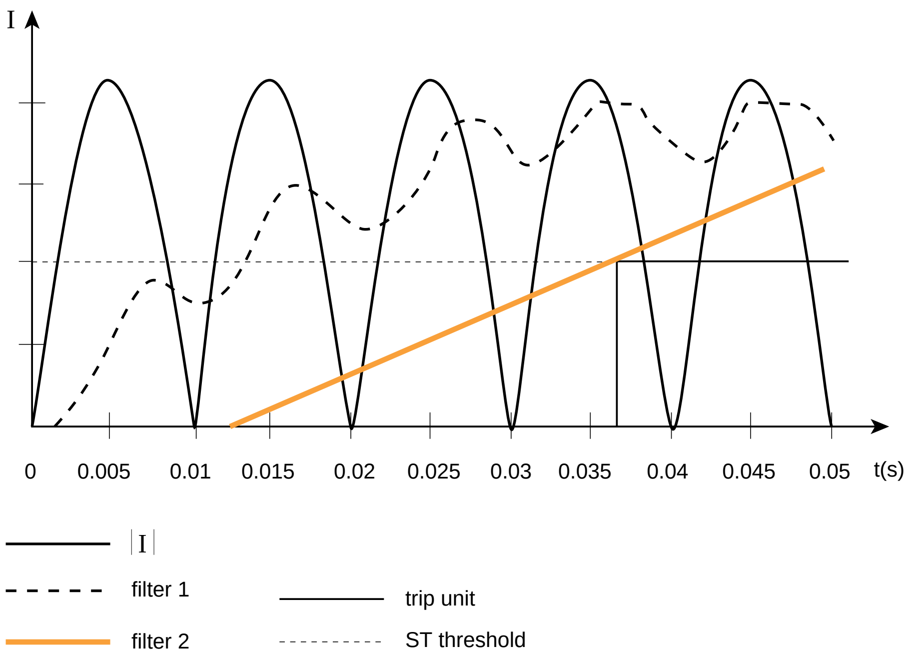


fig 16: persitent fault.

management of cyclic currents by LV circuit-breaker electronic control units

Digital control units take cooling status into account and accurately control thermal stress on conductors, as explained at the end of the first chapter. Whatever the characteristics of the cyclic current I/In, period, cyclic ratio, the cable is protected if the rated current of the protection (Ir) is correct. However to derive maximum benefit from cable possibilities without tripping the circuit-breaker and to limit stresses if a fault occurs, the extensive setting possibilities of the Long and Short Time protection must be used.

For example, figure 18 illustrates the extreme cases:

- high I/Ir but of short duration;
- I/Ir close to 1 but of long duration.

In this case, as for the inrush currents, we can observe the superiority of electronic control units as a result of the presence of the short time delay function, but above all due to the enhanced performance of its thermal function compared with bimetal strips.

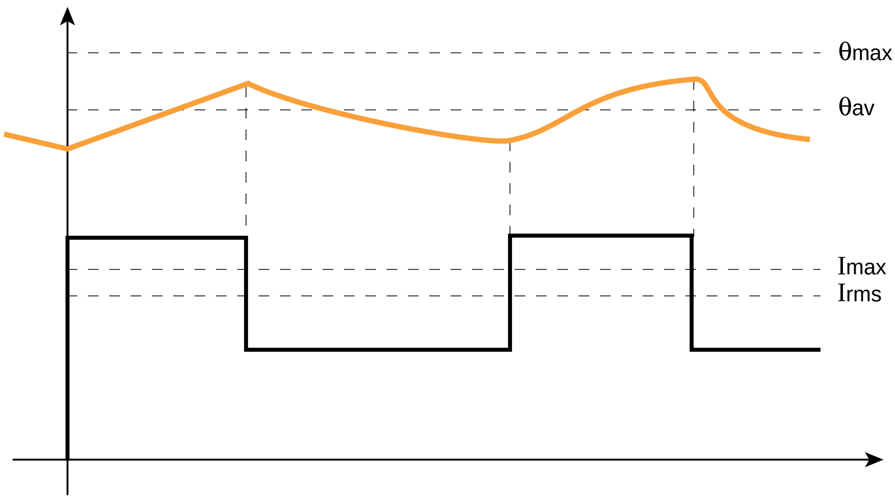


fig. 17: cyclic heating of a conductor with continous load plus cyclic load.

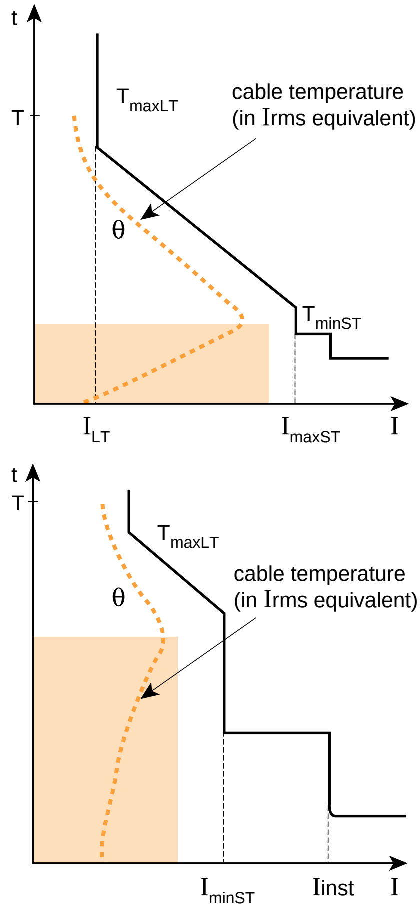


fig. 18: Long and Short Time settings for strong, short or meak, long cyclic loads (steady state).

4. electronic circuit-breakers: a wide range of possibilities

electronic circuit-breaker settings

Confronted with distorted, inconsistant currents, electronic control units simplify the task of installation designers and operators, by their ability to take real RMS currents into account, by managing overcurrents and by the flexibility and range of their settings.

Harmonic currents

Precise consideration of the effects of harmonic currents means that no special settings (linked to these currents) are required in the control unit.
The possibility of knowing the RMS current value in real time by electronic measurement enables fine adjustment of Ir if required. Moreover, digital technology allows this information to be easily transmitted to an ammeter (local or remote mode) or to a bargraph.

Transient currents

The possibility offered by electronics to distinguish transients from fault currents provides increased cable protection and avoids untimely tripping.

Cyclic currents

Adjustment of current Ir for precise conductor sizing is completely compatible with an installation presenting normal overloads by using the short and long delay protection settings.

Tripping curves

One of the advantages of electronic circuit-breakers is that they provide «universal» protection. With the same control unit, all operator needs can be taken into consideration thanks to the flexibility and wide range of the settings.
Electronics allow settings to be made in an extensive range for both time delay and thresholds.
Not only does this solve the problem of inrush and cyclic currents, but it is a definite advantage when implementing time discrimination.
It also allows a transformer, cable or generator to be protected using the same device (see figure 19 for an example).

the advantages of digital technology for dependability

Digital technology with extensive use of ASICs, makes it possible to perform a host of measuring, protection, control/ monitoring and communication functions.
In addition this technology provides greater reliability and immunity (electromagnetic compatibility) than discrete technologies.

A host of functions

Besides the functions for protecting live conductors against overcurrents and short-circuits, other functions are or can be integrated, for example:

■ ground fault protection (GFP): this function is often requested for installations in the USA,
■ load monitoring by calculating Irms/ I_{LT} which informs the user of the load level of the feeder in question,
■ actual short-circuit current,
■ number of operations (useful for maintenance management).

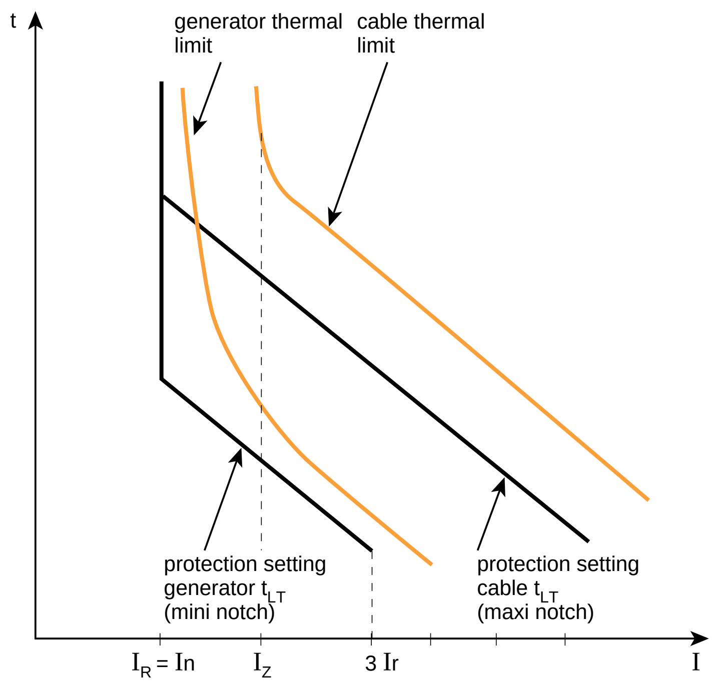


fig. 19: long time tripping curves of an electronic circuit-breaker protecting a cable or generator.

Reliability
Circuit-breakers must have a very high level of reliability. For this reason the integrated electronics are equipped with self-monitoring functions to indicate malfunctioning of the microprocessor or abnormal rise in temperature. It must also satisfy the tests defined in standards IEC 801 and IEC 1000, specifying the EMC withstand of devices and in particular immunity to magnetic fields.

communication by BUS

Digital technology and the position of the circuit-breaker in the electrical installation means that all relevant parameters required for proper power network operation are easily available on the Bus. Integrated digital electronics enable communication to electrical distribution management and supervision systems. The data transmitted provide information on the circuit-breaker environment:

- position of the setting switches,
- phase and neutral current values,
- overshooting of the load monitoring threshold,
- overload alarm,
- cause of tripping.

This information is collected in data logs to help the system operator and/or manager improve the management of his installation.

LV circuit-breaker standards

Industrial circuit-breakers meet standard IEC 947-2. The increasing importance of environmental problems and particularly of ElectroMagnetic Compatibility (EMC) has led standards authorities to include recommendations concerning these phenomena in circuit-breaker standards (see fig. 20).

electronic circuit-breakers: new possibilities available

The guarantee supplied by the standard
Compliance with standard IEC 947-2 and in particular appendix F, combined with suitable design, ensure the reliability of electronic circuit-breakers. Moreover the tests stipulated by IEC 947-2 guarantee installation designers and users **perfect adaptation of the protection function** (see Cahier Technique n° 150 for more details).

test	disturbances	tests performed
F.4.1	non-sinusoidal currents.	3 tests with peak factor ≈ 2 H3 ≈ 80 % ; H5 ≈ 50 % and H3 ⩾ 60 % + H5 ⩾ 14 % + H7 ⩾ 7 %.
F.4.2	sags and breaks.	current reduced by 30 % ; 60 % ; 100 % for 0.5 to 50 periods.
F.4.3	frequency variations.	circuit-breaker frequency range. 1 Hz steps.
F.5 F.5.2.2.1 F.5.2.2.2	conducted transients and HF disturbances: IEC 1000-4-4 rapid transients. IEC 1000-4-5 shock waves.	 5/50 ns wave (Fr: 2, 5 kHz) level 4 kV, 1.2/50 µs wave - 6 kV and 8/20 µs - 3 kA.
F.6	electrostatic disturbances IEC 1000-4-2.	 on 8 kV contact discharge.
F.7	electromagnetic field disturbances IEC 1000-4-3	from 26 to 1000 MHz. 10 V/m. amplitude modulation 80 % 1 MHz.

fig. 20: table showing EMC tests as in appendix F of standard IEC 947-2.

5. conclusion

LV circuit-breakers ⩾ 250 A, with electronic control units, are perfectly suited to the various constraints encountered in installations.
The current calculation power of the ASICs are responsible for considerable progress: thus:

■ despite the increase in harmonic currents, long time protection takes the real RMS value into consideration,

■ the thermal memory, more effective than indirectly heated bimetal strips, allows improved monitoring of cable temperature evolution particularly for loads with cyclic operation,

■ the short time protection settings ensure better management of energising currents than magnetic trip units,

■ the wide range of the various settings allows adaptation with cables of varying cross-sections and with generators.

In addition to these protection functions, digital electronics enable the circuit-breaker to transmit measurements, states, etc... by Bus, to have access to remote setting and naturally to be remote controlled. Present-day circuit-breakers have thus become intelligent sensors/actuators which, as part of Electrical Power Management (EPM), play a large role in simplifying operation of power networks and in increasing continuity of service.
One regret however... electronics are still too expensive to be used in circuit-breakers below 250 A ratings.

6. bibliography

Standards

■ IEC 947-2: Low voltage switchgear and controlgear - part 2: circuit-breakers.

■ NF C 63-120: appareillage à basse tension - 2ème partie: disjoncteurs.

■ IEC 364/NF C 15-100: Electrical installation of buildings.

■ IEC 801: Electromagnetic compatibility for measuring and control equipment in industrial processes.

■ IEC 1000: Electromagnetic compatibility (EMC).

■ IEC 50: General index of electrotechnical vocabulary.

Merlin Gerin Cahiers Techniques

■ Les perturbations électriques en BT, Cahier Technique n° 141 - R. CALVAS.

■ Development of LV circuit-breakers to standard IEC 947-2, Cahier Technique n° 150 - E. BLANC.

■ LV circuit-breaker breaking techniques, Cahier Technique n° 154 - R. MOREL.

■ LV breaking bu current limitation, Cahier Technique n° 163 - P. SCHUELLER.

■ Energy-based discrimination for low-voltage protective devices, Cahier Technique n° 167 - R. MOREL, M. SERPINET.

Other Merlin Gerin documents

■ Guide de l'installation électrique 07/91.

■ Les filtres IIR et FIR - E. SUPITZ.

■ La distribution électrique de qualité - D. FRAISSE.

■ L'électronique dans les disjoncteurs BT - D. FRAISSE.

Other external documents

■ Guide de l'ingéniérie électrique.

■ J3E n° 619.

■ Le contact électrique - M. RIVAL.

Réal. : Illustration Technique - Lyon
DTE - 04-97 - 1500 - Printing. : Clerc - Fontaine