Totally Focused. Totally Independent.

# SHORT CIRCUIT BULLETIN

29 March 2023

## Short Circuit Decrement Curves and Fault Current Levels

### Mecc Alte Guidance Notes

Short circuits (full 3ph, 2ph L-L or 1ph L-N) within an electrical system – likely including the power supply and load/distribution, are, or should be, protected by safety devices such that: fault duration/equipment damage is minimised, and fault location is determined.

For the alternator – the driven power supplier, the impact of short circuit is both magnetic and mechanical in nature, and tests the durability of its design.

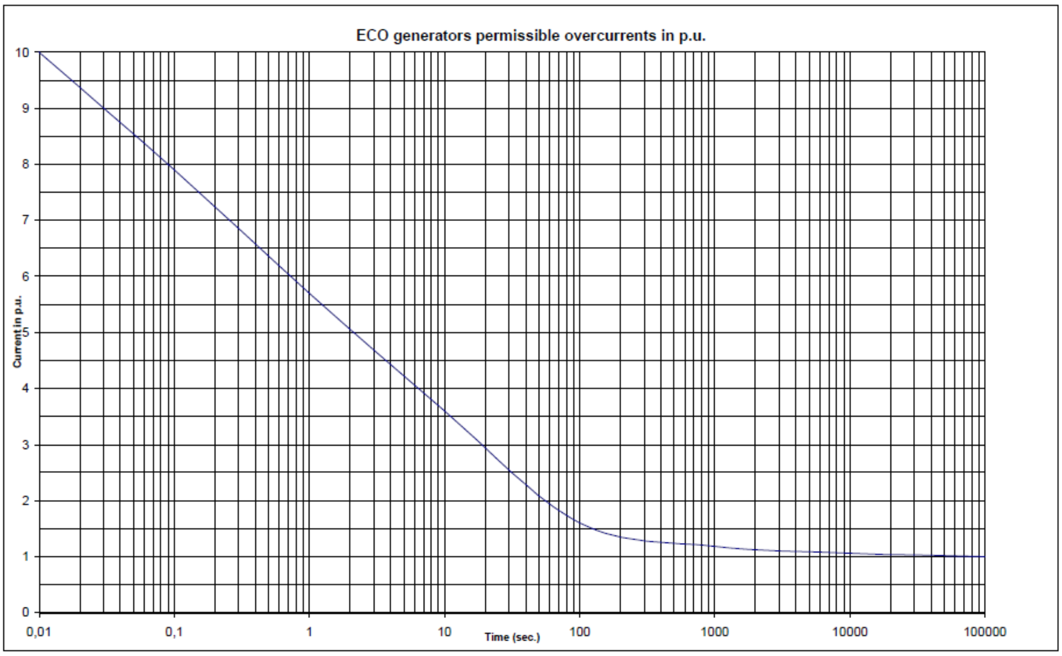
In normal operation, the voltage is maintained with varying load by combination of armature (stator) reaction/armature self-induction, to load change (counter e.m.f [electro-motive force] and an impressed field (rotor) excitation, producing a magnetic field in the rotor poles. The effect is to maintain a nominal voltage in all load conditions.

The armature reaction is sometimes represented by an effective self-induction where the e.m.f. is generated from the magnetic flux of the armature reaction. This is known as 'synchronous reactance'. Although similar, the armature reactance and armature self-induction differ in their response to certain operating conditions: self-inductance reacts almost immediately whereas reactance follows after a certain time. The effects to the field winding are more gradually as the magnetic field reacts more slowly with the counter e.m.f. in the armature + impressed field excitation.

The extreme case is when an alternator is short circuited. At the first instance the current is limited only by self-induction, and the magnetic field still has full strength; the field exciting current is increased by the e.m.f. generated in the field circuit by the armature reaction. Gradually, the field exciting current and the field magnetism die down to the values corresponding to short circuit conditions. So, the momentary short circuit current of an alternator is far greater than the permanent short circuit current. When short circuited at full load it is usually from 3x to 15x as great as full load current depending on the position of the current wave when the fault occurs.

The fault currents at time ~zero, to a time allowed within an alternator's 'thermal damage curve' are represented within the 'short circuit decrement curves'. These curves are presented within the Mecc Alte datasheets and are specific to each model, and frequency. The 'thermal damage curve' for Mecc Alte is generic for all Mecc Alte AVR/brushless alternators from 4kW to 5MVA. The curves themselves are produced during type tests and based on reactance values and time constants recorded. These values are also presented within the Mecc Alte datasheets.

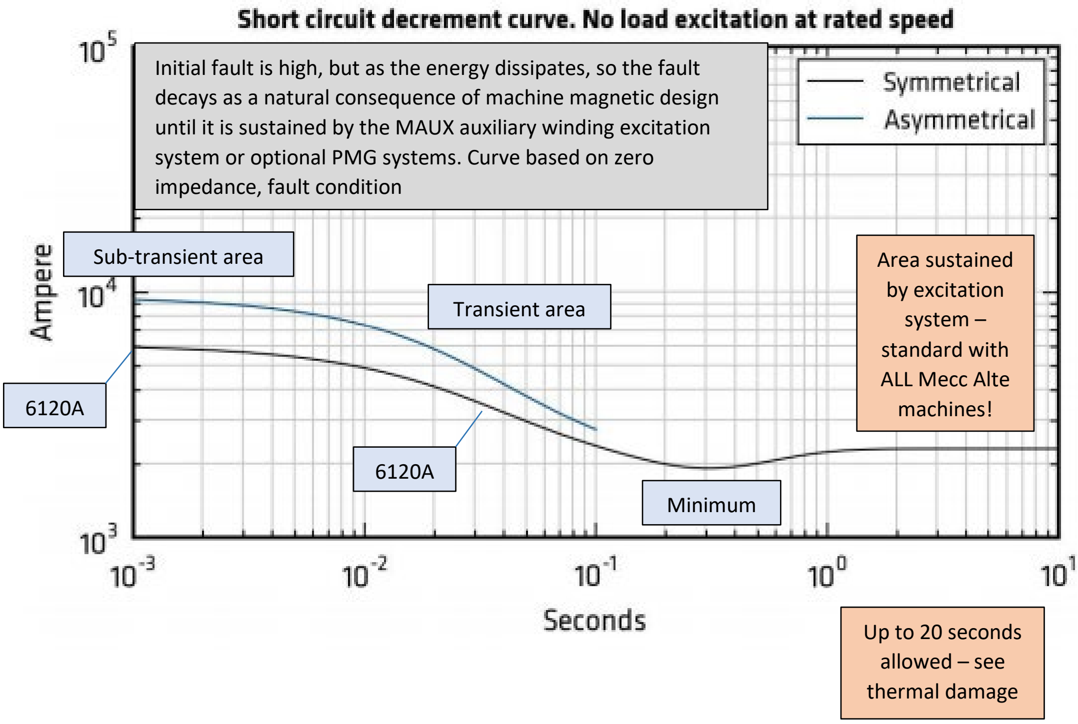
## Mecc Alte Thermal Damage Curve




Take note that this curve is drawn for the following conditions:

1) 40°C maximum ambient temperature with cold windings.
2) 1 p.u. current is referred to class H rating and standard output voltages.
3) For overload and short circuit capacities of each alternator do reference to the relative sales literature.
4) The curve must be considered only as an help in the selection of protective devices; this means that the values read from it must not be taken as absolute.

## Typical Short Circuit Decrement Curve for an ECO40-3S/4B 500kVA 400V 50Hz Alternator:



Totally Focused. Totally Independent.

Note: Above values are taken at or very close to the alternator terminals. Any extended system included and protected will have a system impedance 'Z' as will earth if the fault is to earth.

Note: The minimum point of the graph is the part of the cycle the AVR recognises the fall in voltage and increases excitation in 'failed' an effort to increase terminal voltage. This results in forced current from the AVR/MAUX(PMG) combination. In such conditions the MAUX derives its power from the ever present 3rd order harmonic.

## Determining Fault Current Levels

The above decrement curve is based on 400V 50Hz nominal and full 3ph short circuit, Wye connection. It is common to use coefficients for other voltages and faults 2ph L-L and 1ph L-N. These are shown as follows:

| *50 Hz* | | *60 Hz* | |
|---|---|---|---|
| *Voltage* | *Factor* | *Voltage* | *Factor* |
| *380* | 0.93X | 415 | 0.85X |
| *400* | 1X | 440 | 0.90X |
| *415* | 1.04X | 460 | 0.95X |
| *440* | 1.10X | 480 | 1X |

| | *3 phase* | *2 phase L-L* | *1 phase L-N* |
|---|---|---|---|
| *Istantaneous* | 1X | 0.87X | 1.30X |
| *Minimum* | 1X | 1.80X | 3.20X |
| *Sustained* | 1X | 1.50X | 2.50X |
| *Max Duration* | 20 sec. | 10 sec. | 4 sec. |

The 0.87X in 2ph L-L faults based on reactance values X''d and $X_2$ being the same. In practise this is not so and $X_2$ is ~1.5X X"d values. See notes further on example reactance values. To know the precise 2ph L-L fault multiplier, use this formula:

((X"d+$X_2$)/X"d)/1.732, so we have:

((11.8+17.3)/11.8)/1.732 = 1.424, so 1.424, So 1/1.424 = 0.7X instead of 0.87X!

Note time to clear fault changes based on type of fault!

## Reactance & Time constants- Class H / 400V

| Unsaturated (ref. EN60034-4) | | | ECO40 1S4 B | ECO40 2S4 B | ECO40 3S4 B | ECO40 1L4 B | ECO40 1.5L4 B | ECO40 2L4 B | ECO40 VL4 B |
|---|---|---|---|---|---|---|---|---|---|
| **Xd** | Direct-axis synchronous reactance | % | 286,7 | 240,1 | 258,7 | 246,3 | 270 | 234,9 | 175,9 |
| **X'd** | Direct-axis transient reactance | % | 23,3 | 22,1 | 21,7 | 20,1 | 19,8 | 18,7 | 16,7 |
| **X"d** | Direct-axis subtransient reactance | % | 14,7 | 12,5 | 11,8 | 10,6 | 10,5 | 9,52 | 9 |
| **$X_2$** | Negative-sequence reactance | % | 19,1 | 18,2 | 17,3 | 13 | 12,4 | 14,6 | 12,5 |

For the instantaneous sub-transient 3ph short circuit current we then have:

(1/0.118 (X"d 11.8% in p.u.)) x ((500 x 1000) / 400 / 1.732)
8.48 x 721.7A
= 6120A

For the transient 3ph short circuit current we then have:

(1/0.217 (X'd 20.7% in p.u.)) x ((500 x 1000) / 400 / 1.732)
4.61 x 721.7A
= 3327A

Note: The asymmetric part of the curve is around twice that of the symmetric part, and may be considered as an extreme for the breaking state of system electrical conductors. It is not usually considered in the electrical system short circuit protection.

Note: All Mecc Alte alternators have the ability to support >300% sustained short circuit, based on its Class H industrial rating, for up to 20 seconds. So, no cost option and allows flexibility in any stock holding without need to upgrade AVR and/or add PMG – for example. Although 300% is regularly requested for up to 10 seconds, it is not an industry standard, with the exception of marine alternators.

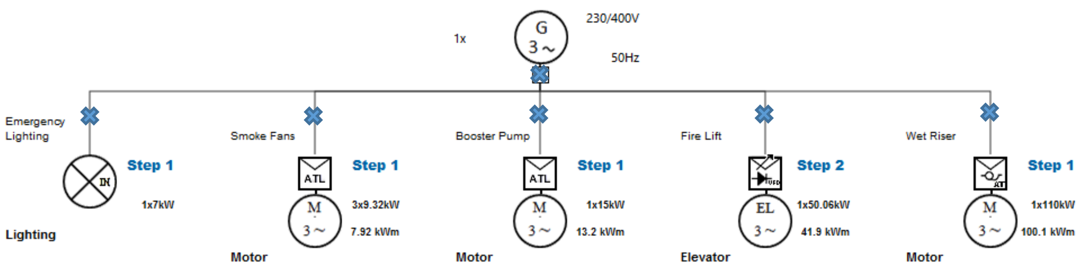
## Short Circuit (and Overload) Protection

External 'system' protection devices with correct discrimination are essential for the safe operation of power generator, distribution and load. It is an extremely detailed study with modelling tools typically used. The Mecc Alte digital regulators (DSR/DER1/DER2/MAVR) have a protection circuit for "short circuit" condition. To be 100% clear, this looks at the voltage output and sees it fall markedly in short circuit conditions. After a time delay it then cuts excitation for a pre-set time, re-excites, and so on. This allows external genset controllers / external relays to operate either, because current is forced between each cut off, or the genset controller to see the excitation cut.

The footnote to this is that anything other than a full 3ph short circuit may have a residual voltage higher than the protection circuit trip level, such as 2ph L-L or 1ph L-N. So, this built-in protection for the alternator should NOT replace external protection devices in the best electrical engineering practises!

## External Breakers/Relays

The high current forced during short circuit will generally be enough to trip the magnetic element of the circuit breaker within a power supply/load scheme, such as:




Circuit breaker

Each branch of the supply system is then protected, and with careful discrimination through breaker/relay settings, any faults can be isolated and identified in order to maintain supply elsewhere and to rectify the fault.

As mentioned earlier, all Mecc Alte machines are excited in a manner (MAUX or PMG) where current is sustained following the natural X"d, X'd influences to the initial part of the decrement curve. Some manufacturers offer self-excited (shunt) machines as a standard up to ~600kVA, where the current is not sustained. So, after a few cycles the amps continue to decay.

This means that any connected protection system has a much narrower window of time/current opportunity to activate – typically 0.025 seconds. Certainly (if arguably), the sustained current is a better and safer selection!

Most circuit breakers show current as a percentage of the breaker rating. The available fault current must be converted to a percentage of the circuit breaker rating. Let’s take a 180kVA ECO38-1S/4A. It has an X”d value of 10%, which is an instantaneous current, which is 10x nominal current (symmetrical):

$$\text{Fault Current as \% of breaker rating} = \left[\frac{10 \times \text{Rated Alternator Amps}}{\text{Say a 50A branch breaker}}\right] \times 100\%$$

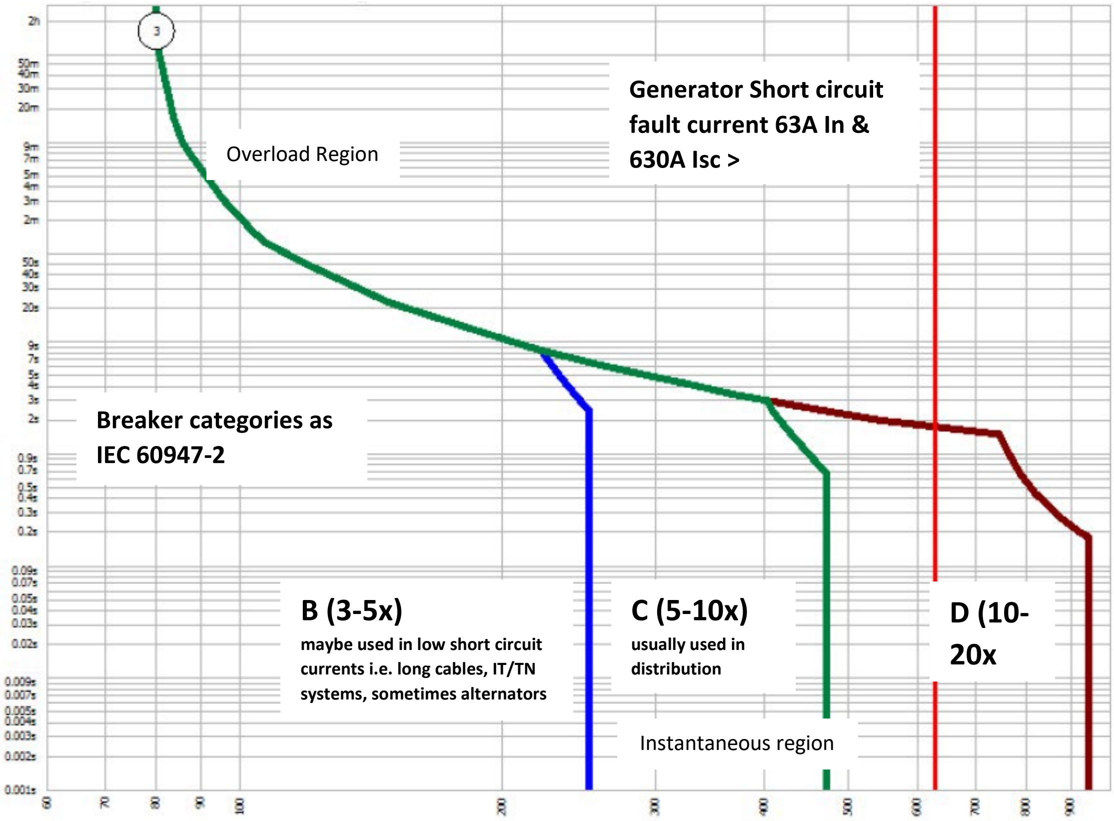
$$\text{Fault Current as \% of breaker rating} = \left[\frac{10 \times 260\text{A (400V)}}{50}\right] \times 100\% = 5200\%$$

Sustained short circuit current is 820A, so 3.15x In

$$\text{Sustained Current as \% of breaker rating} = \left[\frac{3.15 \times 260\text{A (400V)}}{50}\right] \times 100\% = 1638\%$$

Circuit breakers will have an activating envelope based on amps and time. You may also see different classes of the same breaker displaying differing characteristics. In the example above it is important to know the instantaneous peak amps at 5200% of breaker rating which causes a correctly selected breaker within 0.025 seconds. The same installation will sustain up to 1638% of the breaker rating up to 20 seconds (in the case of the Mecc Alte machine) and will open the breaker if not already done so earlier. Time to open the breaker is a consideration in breaker selection and site-specific needs and standards/norms to comply with. You will see references to Type B, C and D which all have a variation on the tripping envelope. There will also be short time delay (STD) alternatives for quick response and a narrower field of activation.

Below is a typical MCB miniature circuit breaker operating chart for 63A with different curves for Class B, C and D. At a prospective 630A (10x FLC) symmetrical short circuit capability from the alternator, the Type D is most suited. The thermal damage curve of the alternator would also require consideration to ensure the long-term thermal protection ‘protects’ without spurious tripping. The main tripping curve for the 63A MCB are shown overleaf.




Instantaneous region: This region and trip setting indicates the multiple of the full load rating at which the circuit breaker will open as quickly as possible. Breaker trip ratings are generally adjustable from 5x to 10x the breaker rating. You will sometimes see a dotted curve on the above representing the time to latch the breaker open (safe). In the above curves you would also usually see a 'foot' at the bottom of the curve adding a larger window to the current level, but still over a short time to around 0.025 seconds. This is the magnetic latch release area.

Long term region: Usually effected release by thermal bi-metal device and designed for longer term lower over currents to trip in case of overload. In case of successive trips, the bi-metal reaction is quicker having the advantage of protection cables as well as the alternator – as cables will retain over current heat based on previous overload condition.

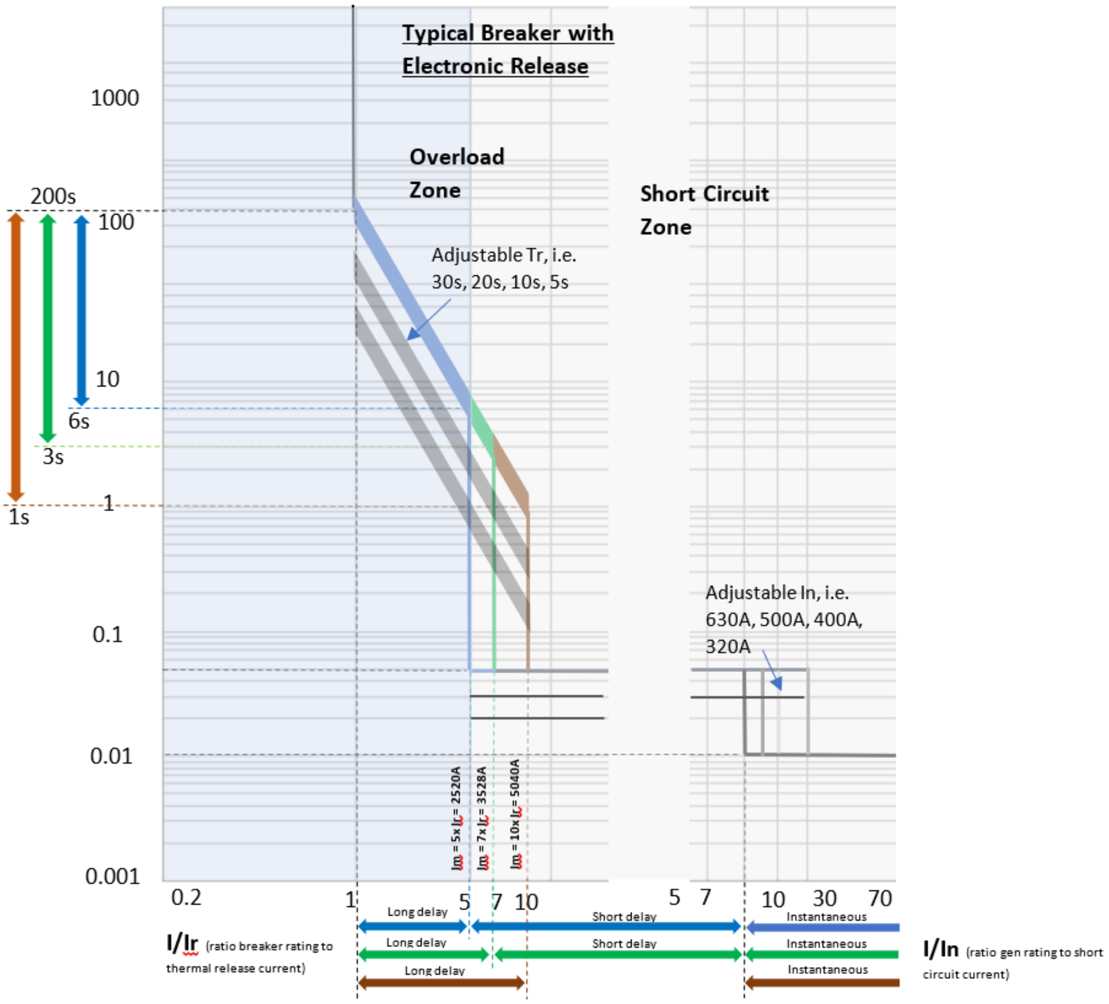
## Electronic Release Circuit Breakers

A more expensive option, but certainly one that can be fine tuned to the genset characteristics and for the discrimination between breakers. There is short circuit instantaneous/short delay area for the short circuit condition and then a longer time overload area. All are customisable within each nominal size breaker.

In the example shown, we have a 500A generator and a 630A electronic release circuit breaker.

The breaker option for nominal amps has a x0.8 setting and can be then set for 504A as Ir. The 1st part of the x-axis is the ratio I/Ir for the overload, the 2nd part for I/In ration for short circuit related directly to the generator – so all in multiples of breaker/generator nominal amps. So:

- At 504A, no tripping
- >504A then tripping between 1 and 200 seconds
- Short circuit 504 to <2520A trip in 6 to 200 seconds
- Short circuit >2520A to <5kA trip in 0.1 seconds
- Short circuit >5kA trip in 0.01 seconds




Settings will depend on the nominal current of the genset and the circuit breaker, the short circuit capability of the alternator (symmetrical), and short-term overload ability – thermal damage curve and peak transient overloads i.e. motor starting. We do not consider here the thermal stress curves for the interconnecting cables.

meccalte

Totally Focused. Totally Independent.

## Typical Breaker Nomenclature:

| | | |
|---|---|---|
| Category A | = | Type of breaker without Icw |
| Category B | = | Type of breaker with Icw |
| I | = | Actual current in Amps |
| Icc | = | Short circuit current |
| In | = | Rated current of a release (this identifies the rated current of the breaker equipped by the release in question) |
| Iu | = | Rated uninterrupted current of a circuit breaker (this identifies the 'size' of the circuit breaker) |
| Ir | = | Trip current in Amps, for protection against overloads in Amps |
| Im | = | Magnetic protection against short circuits in Amps |
| Function L | = | Ability to move the $Tr/I_1$ ($I^2t$ [K] function) curve (see electronic release curves) |
| Tr | = | Long delay adjustable in electronic release devices |
| Tm | = | Short delay adjustable in electronic release devices |
| $I^2t$ | = | Constant – adjustable via Tm |
| If | = | Fixed threshold instantaneous protection |
| Icn | = | Nominal breaking capacity in Amps |
| Ics | = | Standard breaking capacity as percentage of Icu |
| Icu | = | Ultimate short circuit breaking capacity of the circuit breaker |
| Icw | = | Short time withstand current. Value of short circuit current a category B breaker is capable of withstanding for a given period in kA. It enables breaker discrimination |
| Icm | = | Rated short circuit making capacity in kA peak. This is the maximum current intensity a device can make at its rated voltage according to the standards |