PROTECTION OF SOLID STATE RELAYS FROM SHORT-CIRCUITS OF THE LOAD

Solid state relays have had a bad reputation for a long time since replacing electromechanical relays directly by solid state relays without taking particular precautions can lead to improper operation of installations.
Solid state relays have progressed a great deal (voltage, leakage current resistance, reliability, etc), however there is always the problem of protection when it comes to a short-circuit of the load. A short-circuit of the load is an exceptional phenomenon for devices such as motors, however, nonetheless frequent on resistors or incandescent lamps

HOW TO PROTECT A SOLID STATE RELAY FROM SHORT-CIRCUITS OF THE LOAD :

During a short-circuit, the line must be protected according to the standards in force (NFC15100 & CEI 364) and therefore have a device capable of stopping the current within a short period of time thereby protecting persons and equipment.
This breaking device must be all the more rapid if it is associated to a conventional thyristor or triac type solid state relay as these components can only withstand a limited peak current.

When there is a short-circuit on the line, the waveform obtained (fig 1) depends on the presumed short-circuit current of the line (current called Icc and reached if the device has no protection).
We will see how to determine this a bit further on.

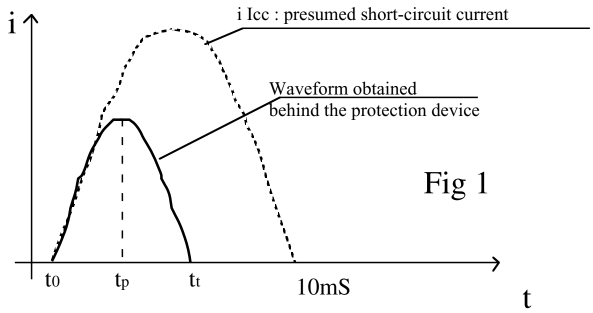

Fig 1

The rapidity of the protection device is characterised by the quantity $\int_{t_0}^{t_t} i^2\,dt$ which is the sum of préarc I^2t ($\int_{t_0}^{t_p} i^2\,dt$) and arc I^2t d'arc ($\int_{t_p}^{t_t} i^2\,dt$) .

This I 2 t value called thermal stress is used to verify that the components of the circuit are duly protected.
This I 2 t characteristic is only valid if the duration of the current surge is of a short duration (<10ms) . Beyond this, the RMS value of the current must be taken

celduc RANGE	NEW RANGE						
RELAY RATING	12A	25A	40A	45/50A	75A	95A	125A
I^2t (A^2s)	72	312	610	1500	5000	11000	20000

In the event of a risk of short-circuits on the load celduc can successfully recommend the use of FERRAZ ultra high speed fuses specified with a I 2 t less than that of the solid state relay.

celduc recommends the use of FERRAZ high speed fuses, the specifications of which can be found hereinafter. All the fuses recommended have been tested in the FERRAZ laboratory in coordination with the relays.

Ultra high speed fuses always present problems for fitters and during servicing they are very often replaced by conventional fuses which do not necessarily protect the solid state relay. There are also ageing phenomena of fuses due to thermal fatigue.
On the other hand, these fuses are difficult to use on motor type loads with significant inrush currents.

celduc is working on self-protected solid state relays however, the current technology is to the detriment of the drop in voltage at on-state and therefore a bigger heatsink with extra costs that remain high.

THE SOLUTION : **SOLID STATE RELAY ASSOCIATED TO A HIGH SPEED CIRCUIT-BREAKER :**

Mechanical circuit-breakers have made a great deal of progress. Very compact, modular circuit-breakers can now be found with thermal and magnetic tripping meaning they are capable of breaking on a surge but also on a short-circuit. Their breaking capacity is more and more efficient and reaches 15 to 25 kA in Icu current (ultimate current for which it is preferable to change them) and 10 to 20 kA in Ics current (operating switching current). The magnetic tripping depends on the type of circuit-breaker.
New high speed circuit-breakers of the "Z curve" type, adapted to the protection of semiconductors, trip at a current corresponding to 2 to 3 In . These circuit-breakers (ABB, MERLIN GERIN, KLOCKNER & MOELLER, ...) are in fact "short-circuit current limiters".
They are designed to limit the breaking time and the value of the short-circuit current in order to simultaneously reduce the on-state thermal stress (on-state I^2t) .
The short-circuit current limitation value and the breaking time are of prime importance in protecting downstream circuits from the damage incurred by short-circuits of the load.

CHOICE OF CIRCUIT-BREAKER ASSOCIATED TO SOLID STATE RELAY :

In order to determine the circuit-breaker, you must know the presumed short-circuit current (called Icc or Iq), calculated at the point where it is installed. Fitters usually know this presumed short-circuit current at a given point of the installation, however, you can refer to the appendix document. The circuit-breaker must have a breaking capacity at least equal to Icc at the point where it is installed in compliance with the standards in force. It is the residual short-circuit current which must be taken into account to determine the degree of coordination and selectivity.
The value of the residual short-circuit current and its breaking time mainly depend on this residual short-circuit current Icc and the type of circuit-breaker.

Solid state relays are generally fitted after a series of protection and isolating devices and the cross section of the wires are already reduced which limits the short-circuit current to values under 5000 Amperes. Given these conditions, the I^2t values obtained using "Z curve" high speed circuit-breakers in the event of short-circuits of the load can be accepted by the celduc high I^2t solid state relays. To verify the level of protection, just refer to the manufacturers' curves which give :
o tripping curve ----> to check the surge protection (thermal)
example : A 16A circuit-breaker will trip with a surge of 30A in a maximum of 20 seconds.
o dynamic stress curve ----> to see the limiter effect of these circuit-breakers.
example : RMS Icc = 4000A ----> max. on-state Id =2400 Amperes for a 16A circuit-breaker.
o thermal stress curve I^2t ----> to determine the max I^2t accepted by the circuit-breaker and that goes through the solid state relay on a short-circuit according to the Icc of the line at the point of installation.
example : Icc = 2000A circuit-breaker rating = 16 A I^2t max = $3200A^2s$
Icc = 4000A circuit-breaker rating = 25 A I^2t max = $10000A^2s$
These values are the maximum given by the manufacturer. It is, nonetheless, to be pointed out that when using zero cross solid state relays associated with circuit-breakers, controlling the zero cross relay limits the thermal stress.

celduc has tested all its relays associated to ABB circuit-breakers in the ABB test laboratory and can guarantee the correct protection against short-circuits of the load with circuit-breakers.

celduc has developed high I 2 t relays in the same standard cases for the use of these circuit-breakers :

Relay 45/50A : I2t >1500A2s (typ >2000A2s)
Relay 75A : I2t >5000A2s (typ >7000A2s)
Relay 95A : I2t >11000A2s (typ >12500A2s)
Relay 125A : I2t >20000A2s(typ >21000A2s)

Short-circuit protection choice chart

The type of protection depends on the type of load.
The table below gives the protection recommended by celduc for :
* resistive loads without current surges : AC-51 with protection by high speed fuses or circuit-breakers
* motors : AC -53 with protection by fuses (the ratings of the relays are obviously oversized with respect to the surge current of the load).

Please consult us for other loads.

Relay rated current Courant spécifié du relais (*)	Ferraz fuse references (Mains Iq<10kA) Références du fusible Ferraz (Iq réseau<10kA)	ABB fast circuit breaker Disjoncteur rapide ABB (**)
12A AC-51	gRC 12A - 690V - 14x51 / I2t @ 400V ≤ 36A2s	
12A AC1 with/avec **2A AC-53**	gRC 8A - 690V - 14x51 / I2t @ 400V ≤ 36A2s	
25A AC-51	gRC 25A - 690V - 14x51 / I2t @ 400V ≤ 165A2s	
25A AC1 with/avec **3,7A AC-5**	gRC 16A - 690V - 14x51 / I2t @ 400V ≤ 165A2s	
40A AC-51	gRC 32A - 690V - 14x51 / I2t @ 400V ≤ 303A2s	
40A AC1 with/avec **5,2A AC-53**	gRC 20A - 690V - 14x51 / I2t @ 400V ≤ 303A2s	
45-50A AC-51	gRC 63A - 690V - 22x58 / I2t @ 400V ≤ 1353A2s	
45-50A AC1 with/avec **8,5A AC-53**	aM 12A - 500V - 14x51 / I2t @ 400V ≤ 1500A2s	
75A AC-51	gRC 80A - 690V - 22x58 / I2t @ 400V ≤ 3060A2s	S280Z16 (Iq≤2kA)
75A AC1 with/avec **11,5A AC-53**	aM 20A - 500V - 14x51 / I2t @ 400V ≤ 3700A2s	
95A AC-51	URD 125A - 600V - 22x58 / I2t @ 400V ≤ 10000A2s	S280Z16 (Iq≤5kA) / S280Z50 (Iq≤3kA)
95A AC1 with/avec **16A AC-53** a	aM 32A - 500V - 14x51 / I2t @ 400V ≤ 7900A2s	
125A AC-51	URD 135A - 600V - 22x58 / I2t @ 400V ≤ 12400A2s	S280Z16 (Iq≤7kA) / S280Z50 (Iq≤4kA)
125A AC1 with/avec **22,5A AC53**	aM 50A - 400V - 14x51 / I2t @ 400V ≤ 20000A2s	

(*) : AC53= squirrel cage motors according to IEC947-4-2 - Always use in conjunction with a motor protection overload relay
(**) : determination of Iq current : presumed short-circuit current (see last page)
FERRAZ FUSE SPECIFICATIONS : see next pages.

HOW TO DETERMINE THE PRESUMED SHORT-CIRCUIT CURRENT AT ONE POINT OF THE INSTALLATION

For this purpose, you must know the electrical installation of the area where the equipment is to be fitted.
To determine the presumed short-circuit current called Icc (or iq), you must roughly know the resistance (Rt) and the reactance (Xt) of the line.

CLASSIC DIAGRAM OF AN INSTALLATION :

Rt et Xt expressed in mΩ

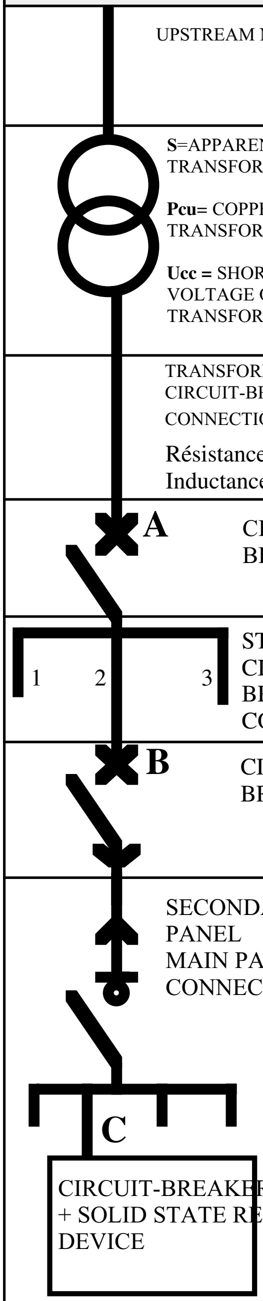

DIAGRAM AND PART EXAMPLE 2 OF INSTALLATION	THEORITICAL	EXAMPLE 1	EXAMPLE2
UPSTREAM NETWORK	OFTEN UNKNOWN AND SI P1=500MVA R1 =0,05 et X1=0,33	R1=0,05 X1=0,33	R1=0,05 X1=0,33
S=APPARENT POWER OF TRANSFORMER(KVA) **Pcu**= COPPER LOSSES OF TRANSFORMER (W) **Ucc** = SHORT-CIRCUIT VOLTAGE OF TRANSFORMER (in %)	$R2=\frac{Pcu \times U^2 \times 10^{-3}}{S^2}$ $X2 = \sqrt{Z^2 - R^2}$ avec $Z = \frac{Ucc}{100} \times \frac{U^2}{S}$	TRANSFORMER celduc **Immersed** 160kVA Pcu = 2350W U=410V Ucc = 4% R2=15,43 X2 =39	TRANSFORMER celduc dry 400kVA Pcu = 6000W U=410V Ucc = 4% R2=6,3 X2 =15,58
TRANSFORMER CIRCUIT-BREAKER CONNECTION (CABLES) Résistance R Inductance =0,5µH/m	$R3 = \rho \times L/S$ $\rho = 17$ X3 = 0,15L L = Length of cable (m) S = Cross section of cable (mm^2)	$S = 120\ mm^2$ L = 5m R3=0,7 X3 =0,75	$S = 240\ mm^2$ L = 3m R3=0,21 X3 =0,45
A CIRCUIT-BREAKER	OFTEN NEGLECTED see manufacturer	R4=0 X4 =0	R4=0 X4 =0
1 2 3 STAR 2 CIRCUIT BREAKER CONNECTION	$R3 = \rho \times L/S$ $\rho = 17$ X3 = 0,15L L = Lenght of cable (m) S = Cross Section of cable (mm^2)	$S = 70\ mm^2$ L = 8m R5 =1,94 X5 =1,2	$S = 150\ mm^2$ L = 6m R5 = 0,68 X5 = 0,9
B CIRCUIT-BREAKER	OFTEN NEGLECTED see manufacturer	R6=0 X6 =0	R6=0 X6 =0
SECONDARY PANEL MAIN PANEL CONNECTION	$R3 = \rho \times L/S$ $\rho = 17$ X3 = 0,15L L = Lenght of cable (m) S = Cross Section of cable (mm^2)	$S = 25\ mm^2$ L = 30m R5 =20,4 X5 =4,5	$S = 25\ mm^2$ L = 50m R5 = 34 X5 = 7,5 $S = 6\ mm^2$ L = 20m R6 =56 X5 =3
C CIRCUIT-BREAKER + SOLID STATE RELAY DEVICE	Rt = R1+R2+R3+... Xt = X1+X2+X3+... $Icc = \frac{U0}{\sqrt{3}\ \sqrt{Rt^2 + Xt^2}}$ in kA	**CALCULATION OF ICC** Rt =38,5mΩ Xt =45,8mΩ	**CALCULATION OF ICC AT POINT C** Rt =97mΩ Xt =27,8mΩ

To calculate the presumed short-circuit current at a given point of the installation, the sum Rt of the resistances upstream from this point Rt = R1+R2+R3+... and the sum Xt of the reactances upstream from this point Xt = X1+X2+X3+... (Rt and Xt are expressed in µΩ) are first calculated

then : $Icc = \frac{U0}{\sqrt{3}\ \sqrt{Rt^2 + Xt^2}}$ kA

U0 = Voltage between phases of the transformer (in general 410V at no load)

EXAMPLE 1

Icc = 3,9kA

EXAMPLE 2

Icc = 2,3kA

NOTE : Inductance of cables taken at 0.5 H/m, this may vary according to the type of cables and their arrangement..

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