WHITE PAPER

Solid State Relays (SSR) fundamentals

celduc® relais

03-2026

Table of contents

Introduction

In the ever-evolving landscape of electronic systems, the **solid state relay (SSR) stands as an evidence to innovation** and efficiency. Unlike their electromechanical counterparts, SSRs leverage semiconductor switching elements such as thyristors, triacs, diodes, and transistors to control electrical power without the need for moving parts, giving rise to a **practically unlimited operating life, no arcs** (explosion-proof) and fully molded, therefore, ideal for harsh atmospheres (dust, gas, etc), **noiseless, resistant to shocks and vibrations**. This fundamental difference not only extends their operational lifespan but also enhances their reliability and performance in a myriad of applications.

The journey of the solid state relay began in the early 1970s, marking a significant shift in how we approach electrical switching. By eliminating mechanical wear and tear, SSRs offer faster switching speeds and greater durability, making them indispensable in modern automation, industrial control, and consumer electronics. Their ability to manage both AC and DC loads with precision and minimal maintenance has revolutionized the way we think about electrical control systems by being able to choose the switching moment: zero cross tripping on resistive loads and zero-current switching preventing sharp instantaneous variations of interference-generating current. This is an essential factor with the new directives pertaining to electromagnetic compatibility (EMC), both in terms of conducted and radiated disturbances.

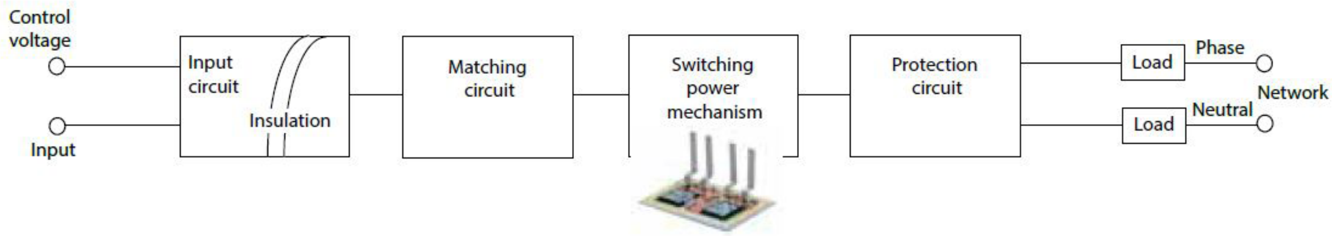
Since their introduction, SSRs have been introduced specially in microprocessors-based equipment due to their precision capabilities for process control, industrial, automation, medical and other equipment, considering that SSR capitalize the advantages of semiconductor switching in a convenient package, very low control power directly adapted in terms of voltage and current with the logic outputs of electronic systems, giving rise to an extremely simplified control circuit with no relay coils that always tend to generate «interference».

As we delve deeper into the intricacies of solid state relays, we uncover a world where efficiency meets reliability, and innovation drives progress. This serves as an introduction to the remarkable capabilities of SSRs, setting the stage for a comprehensive exploration of their design, operation, and applications.

celduc® relais manufactures an **extensive range of solid state power relays up to 130 amps,** single phase, two-phase or three-phase, input/output interface modules and a range of upgraded solid state relays designed for improved control of certain loads when it comes to power, speed, starting or rotation direction control.

I/ Solid State Relays Architecture

A solid state relay is an electronic device which depends on electrical, magnetic and optical properties of semiconductors and electrical components to accomplish the isolation and relay-switching functions, its construction showed below is constituted by **4 main sections**:



<u>Example : AC SSR</u>

1. Input circuit types
2. Optocoupler = Insulation
3. Switching options according to load type
4. Power switching element
5. Output protection

- **celduc® relais** voltage range
- Overvoltage
- EMC / Safety standards
- **celduc® relais** solutions

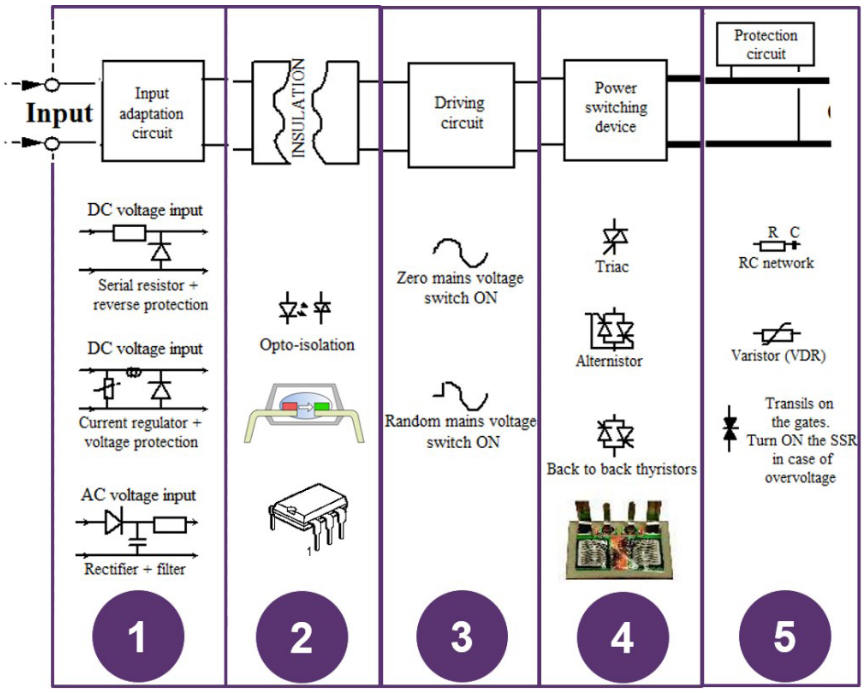


Fig.1

Compared to electromechanical relays (EMR), the SSR provides a substantial reduction in electromagnetic interference. Controlled turn-on of SSR at zero-crossing point of the AC line serves to reduce the high inrush current associated with capacitive and lamp loads. Also, the zero current turn-off feature provided by thyristors used in AC solid state relays, provides an important improvement over the arcing contacts of the EMR.

A/ Input circuitry

This circuit provides the galvanic insulation between the input circuit and the rest of the mounting. It is based on optical device called an optocoupler (figure 2). Input current, limited by the resistor R, proportional to the control voltage is applied to a light-emitting diode (LED). The light acts on a photosensitive component which transmits information to the output element. Considering that operating current is usually 2 to 3mA , the power required for the control is in fact very low. As the LED takes currents from 2 to 30mA, control voltage parameter is between 4V and 30VDC. A diode in serial or anti-parallel mounted on the LED, protects input circuit from a reversed polarity input connection. For alternating voltage control, a rectifier bridge, filter and resistor are placed (figure 3). Therefore, LED control of the photocoupler shows negligible variations. Wide range on current similarly allows deviations from 17 to 80VAC or 90 to 240VAC. A certain amount of **celduc® relais**® relays have a built-in LED to display the state of the input. The optocouplers used in the our SSR comply with the VDE0805 standard and have an input/output insulation > 3750VRMS and very low input/output capacity with a very high immunity level : >10 000V/s.

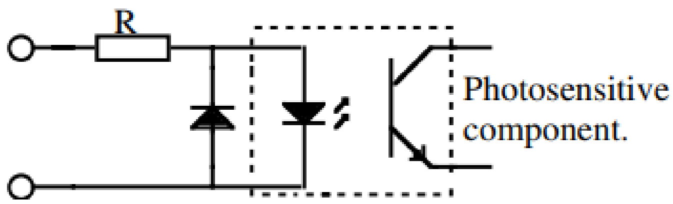


Fig.2

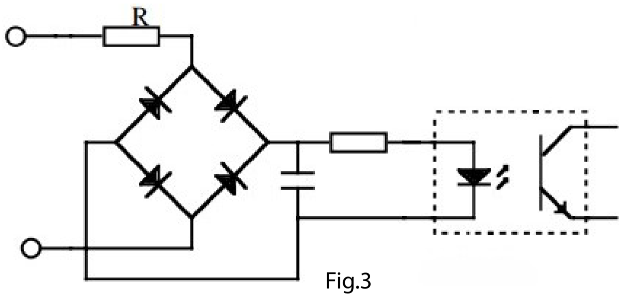


Fig.3

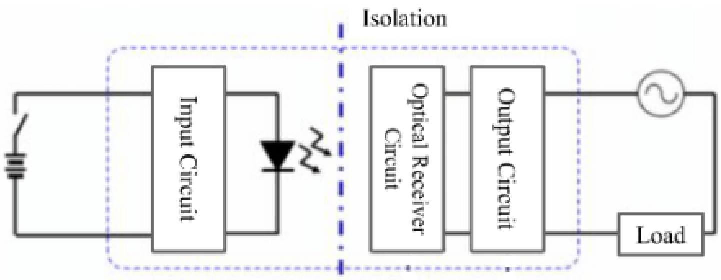
B/ SSR input operation

1. Coupling types

Input to output isolation is achieved by optical coupling or by an oscillator-transformer combination. Optical and transformer configurations provide similar input to output electrical isolation (between 1.5kV to 4kV), preventing high voltages or currents which might damage the input circuitry. Isolation between input / output to case is commonly specified the same value as input to output isolation.

a) Optical coupling

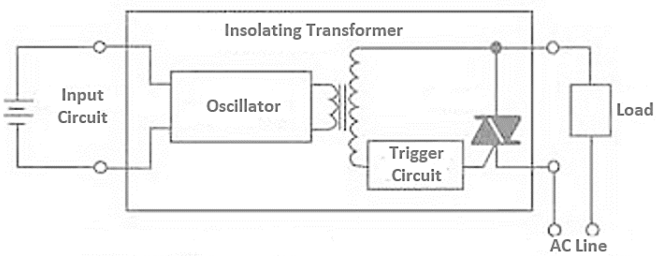
This design involves the use of light to transfer signals between the input and output circuits, ensuring electrical isolation. This is typically achieved using a light-emitting diode (LED) and a photosensitive semiconductor device. When an electrical signal is applied to the input of the SSR, the LED emits light. This light is detected by the photosensitive device on the output side, which then generates an electrical signal to control the load.



b) Transformer coupling

While opto-coupling is the most used isolation system by SSR manufacturers, transformer coupling also is used where its advantage of the direct control signal drive feature is required. This type of coupling involves a transformer with low-loss, high-frequency characteristic. The DC input is taken by an oscillator, while the transformer output is rectified and applied as a drive power to the output semiconductors.

Transformer coupling provides a high input / output gain efficiency and also permits lower output off-state leakage. Since most SSR applications require DC control, the main disadvantage is the need of an oscillator in the primary and a rectifier/filter in the secondary, since the oscillator can generate a very low level of EMI noise that might be undesired for some sensitive applications, however, transformer coupling in SSRs is a robust and reliable method for achieving electrical isolation and efficient power transfer. By leveraging the benefits of transformer coupling, SSRs can provide enhanced performance and longevity in a wide range of applications.



2. Zero-cross control

The power switching action takes place at the start of the half-cycle following by the application of the control signal. The switching of the power component is only allowed in the area around the zero crossing. This area is still called the «zero crossing window» or sometimes the «zero crossing level». **celduc® relais** solid state relays have a very low zero crossing level (usually <10 Volts). This control parameter prevents sharp current variations on all the resistive loads (Fig. 4) such as lamps, heating elements and increase the lifetime of switching components. This control circuit is also suited to manage capacitive loads with a few extra precautions (special application note available on request). **celduc® relais** solid state relays can also be used on inductive loads, even though the zero cross control is not optimized for such type of applications.

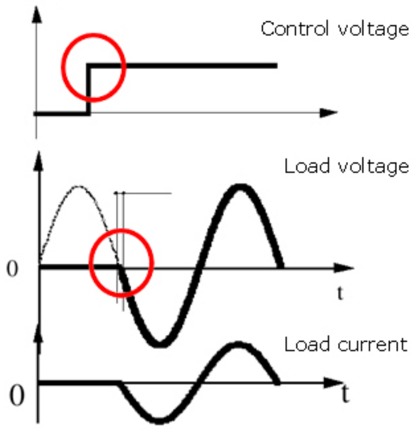


Fig.4

3. Random control (Instantaneous)

The power switching action takes place from the application of the control voltage (100 s). This control circuit is mostly suitable for inductive loads, due to the dephasing between the current and voltage. (Fig. 5)

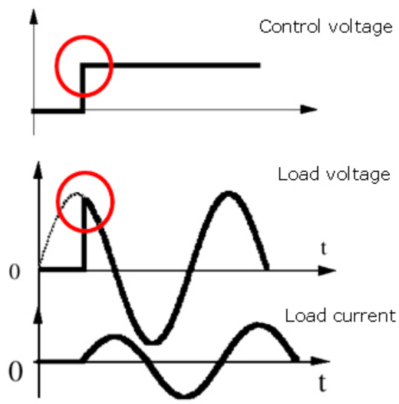


Fig.5

4. Peak control voltage

The power switching takes place at the voltage peak of the half-cycle following by the application of the control signal. This control circuit is particularly suitable to manage transformer type inductive saturating loads. This prevents the transformer from become saturated and also significant magnetizing current peaks (Fig. 6). Special application note on request.

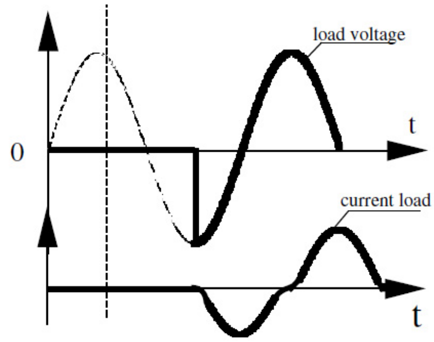


Fig.6

5. Advanced solid state relays control

Models incorporating more sophisticated or specific interfacing functions such as:

- Soft start motor control
- Light or speed control (phase angle controllers, Fig. 7)
- Heating power control (standard «syncopated» full wave pulse controllers, Fig. 8)
- Suitable for the switching of loads supplied with DC
- Suitable for interfacing electronic circuits with power circuits, (both Input and Output).

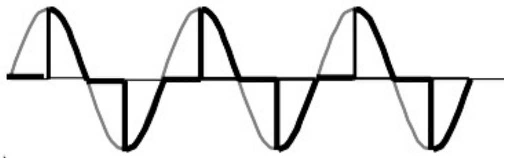


Fig.7

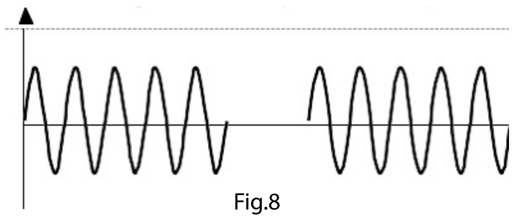


Fig.8

C/ Power switching

SSR designation (AC or DC) describes output switching type as opposed to its input control voltage characteristics, which can also be AC or DC.

AC switching can be structured either using transistors or thyristors in bridge or inverse-parallel configurations. Transistors have added the capability of switching DC as well as AC and they are not susceptible to regenerative rate effects (dv/dt) associated with thyristors. However, thyristors have the advantage on AC due to their higher current, surge and voltage capabilities, therefore, power transistors are presently best suited to DC switching.

1. DC SSR

Usually in DC SSR, the degree of amplification is directly related to the small available optocoupler current. As result, the higher output current rating, the more stages of gain required. As long as polarity is observed, the load can be switched in series with either of the relay output terminals, as in the case for AC SSRs.

The switching element can be a BIPOLAR, MOSFET or IGBT transistor according to the models working in saturated or blocked state. For a DC SSR, the positive load terminal (labeled +) is facing towards the positive terminal of the power supply. If the load terminals are reversed, it will immediately turn on. Some DC SSR has a diode inside of the SSR that allows current to flow freely through it when the SSR is connected incorrectly. This feature is included to prevent that a wiring mistake would destroy the transistor in the DC SSR.

The DC SSR can be installed on either side of the load, and it will work properly, but there is an advantage to installing the SSR between the power supply and the load. If the load is connected to the power supply, it will always have a potentially dangerous voltage on it, even when it is not operating. The protection on these relays is generally a parallel mounted «free wheel» diode on the load if it is inductive.

celduc® relais range of DC relays is currently limited to 100V 60 A or 200V 20A (see specifications of DC relays). Alternatively, **celduc® relais** engineers special relays to specifications adapted to specific applications: automotive relays, DC motor controls (speed and rotation), renewable energies.

2. AC SSR (SCR & Triac)

Most common output devices used in AC SSR are silicon-controlled rectifiers (SCRs) and triacs, both are part of semiconductor switches family whose bistable state depends on regenerative feedback. Nevertheless, SCRs-thyristors attractiveness for SSR lies in the ability to switch high power loads, with values up to 125 Amp and high AC lines voltages up to 660Vac, with less 50 mA of gate drive. In addition, they can withstand one-cycle peak-current surges in excess of around 10 times of their-steady state ratings. Thyristors are control gate diodes. They are conductors in one direction only. Two thyristors should be mounted back-to-back to transmit the 2 half-cycles (Fig. 9)

The regenerative (latching) characteristic of the thyristor provides its high current and surge capability, but it's also responsible for the thyristor's sensitiveness to sharply rising voltages, a less desirable characteristic known as dv/dt or rate effect. Unlike a transistor, the SCR cannot be biased to remain in the transitional zone between its blocking and on states. Once regeneration is initiated by an applied gate signal, the transition is rapid, controlled only by internal positive feedback. The magnitude of the gate turn-on signal depends very little on the anode (collector) current, since conduction is controlled internally, however, it is radically affected by gate impedance, anode voltage and junction temperature.

Triacs are semiconductors controlled by the gate capable of conduction in both directions. One single Triac can switch the 2 half-cycles of an alternating network (figure 10).

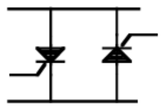


Fig.9 : Back-to-back thyristors

Fig.10 : Triac

These switching elements have a function in common, they only conduct when suitable current is applied to the control electrode (gate). Once in-state conduction, it is maintained, even if there is no gate current, up to zero, or up to at least a current value less than its holding current. In a solid state relay this holding current is usually specified and it is useful when the relay is pulse controlled and it must not be considered as the minimum working current of a solid state relay. Indeed, when the control is applied permanently, if the current is less than the holding current, it is the pilot control circuit of the power component which provides the conduction of the current on the load. SCR and Triac use similar drive circuits, as well, they have equivalent noise and transient susceptible areas.

There are 2 other paths to induce power switching components to conduct, however, those hinder an adequate use and must be avoided :

- **Arcing by dv/dt (static):** With the component in the blocking state (no subjected to control signal), if a sudden variation of voltage is applied across device terminals, Anode / Gate parasite capacity generates a gate current ($i = Cdv/dt$) likely to lead to the conduction of the semiconductor during a mains half-cycle.
- **Arcing by peak voltage:** If a significant voltage higher than the maximum allowable voltage (Max. Peak Voltage) is applied, there is an avalanche effect on the semiconductor and it turned into conduction state. This arcing can be destructive if it is followed by a significant current. Standard Triacs also have other disadvantage, when a Triac is conducting, at the time where the current is cancelled, a voltage must not be reapplied too fast across device terminals as this might stop blocking state. Then, by switching off an inductive load (whatever the type of relay), the mains voltage is instantaneously reapplied when the current is absent, due to the dephasing between the current and voltage. The resistance of a Triac during this reapplication of voltage called dv/dt on the switching ((dv/dt)c), mainly depends on the slope of the current at the time of blocking ((di/dt)c), see Fig. 11. This is the reason why Triacs are mostly used only for small currents.

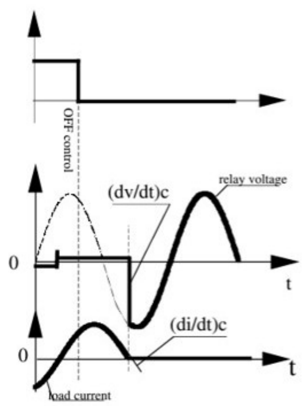


Fig.11 :
Switching off an inductive load

II/ Solid state relays characteristics

Initial page of an SSR datasheet defines the package style, switching type (AC or DC) and the current / voltage switching range for a particular model or family devices. There are many housing styles as well as are terminals configuration and mounting types. Terminals configuration such as Screw, Wire Quick Connect, Fast-on, Pins are the most common used and adequate for certain application ranges. Figure 12 shows the optimum load current range for each package, which will provide an application effectiveness and mounting style in function of load current. Current range limits are shown for each group mounted on the appropriate heatsinking (if applicable), both those are still constrained by environmental conditions (ambient temperature, air flow, cabinet size and ventilation).

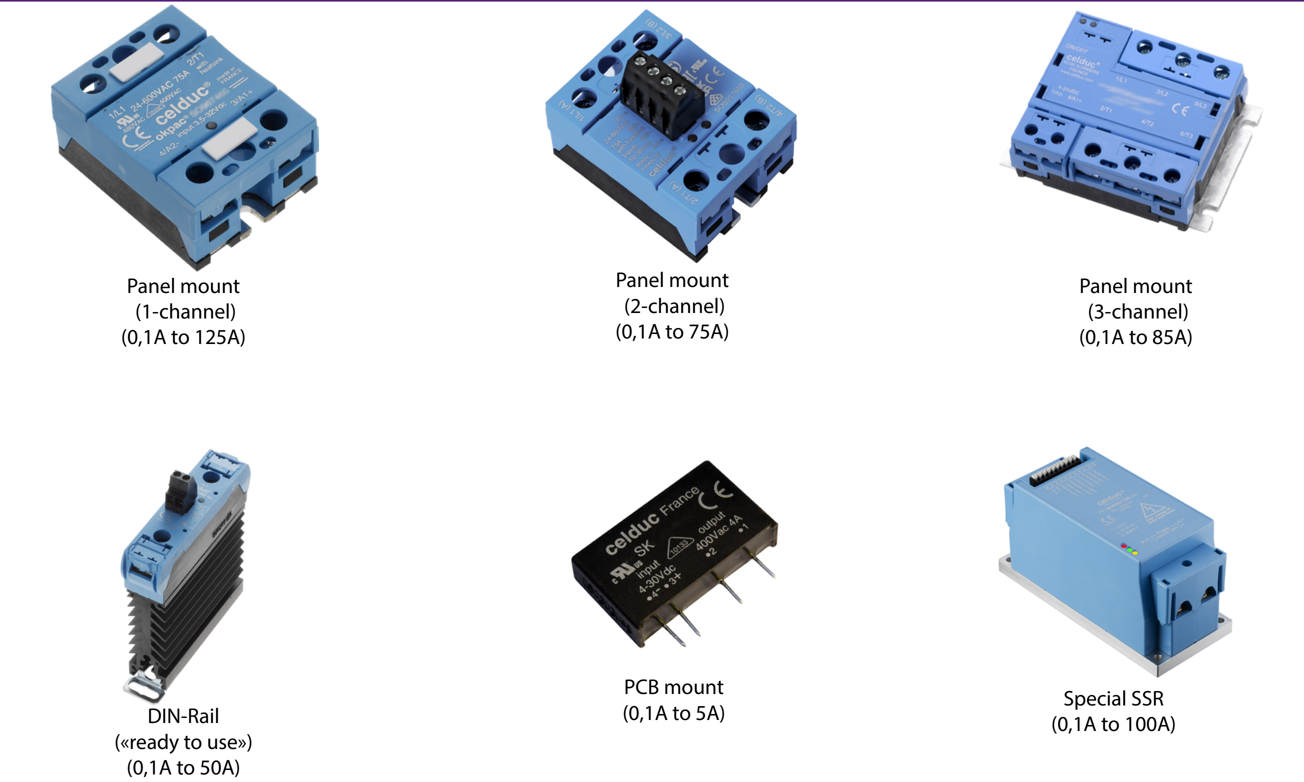


Fig.12 : SSR types per package and terminals configuration

Specifications for solid state relays are by nature more complex than those for electromechanical relays, mainly due to the semiconductors characteristics and operational parameters. Each SSR type has a very specific set of specifications which are variations of load current, voltage and input ranges.

A/ Input specifications

- **Control Voltage Range** – The range of voltages that must be applied on input terminals to maintain an “On” condition across the output terminals.
- **Maximum Turn-on Voltage** – The range of voltages that must be applied on input terminals to maintain an “On” condition across the output terminals.
- **Minimum Turn-off Voltage** – The range of voltages that must be applied on input terminals to maintain an “On” condition across the output terminals. In the threshold between turn-on and turn-off voltages (around 2 volts), the SSR can be in either state.
- **Maximum Input Current** – The maximum current drain on the driving circuit, usually specified at two point within the control voltage range (output assumed to be in the on state unless for normally closed versions). This parameter defines the input power requirements.

- **Minimum Input Impedance** – Minimum impedance at a given voltage, which defines input power requirements, as an alternative or in addition to Input Current parameter.
- **Maximum Turn-On Time** – The maximum time between the application of turn-on control signal to the transition of the output to its fully conducting state.

- **Maximum Turn-Off Time** – The maximum time between the removal of turn-on control signal to the transition of the output to its blocking state.

B/ Output specifications

- **Operating Voltage Range** – The range of voltages that must be the output, over which the SSR will continuously switch, block or other intended function. Frequency parameter is either included or specified separately (AC models).

- **Maximum Load Current** – Is the maximum continuous load current that SSR can deliver, which might be restricted by thermal constrains of heatsink, ambient temperature and other environmental or installations conditions. The current which flows in the SSR must not exceed the maximum current of the power component during permanent operation. This current is directly proportional to the size of the silicon chip mounted in the solid state relay and depends on the heatsinking system. **celduc® relais** usually uses well-sized chips with respect to the maximum current stated. To better understand the actual size of the chips used by SSR manufacturers, it is interesting to compare the surge values (Itsm and I^2t parameters), which are the values directly related to the size of the semiconductor. **celduc® relais** range is 4A- 12A-25A-50A-75A-95A-125A. However, the maximum current may only be reached if the temperature of the power component does not exceed the maximum allowable value (usually 125°C).

- **Thermal Fatigue Phenomena** – Electronic power components which withstand many hot to cold thermal cycles and vice versa, which might be the case for solid state relays under relatively continuous on/off operation, undergo a thermal fatigue phenomenon likely to affect the lifetime of the component, due to thermo-mechanical stress induced by constant temperature changes. AS A GENERAL RULE, SOLID STATE RELAYS SHOULD BE ALWAYS OVERSIZED. IT IS ADVISED TO DULY COOL SSR FOR AN ADEQUATE FUNCTIONALITY.

- **Minimum Load Current** – Is the minimum load current required by SSR to operates as intended, this specification in combination with maximum load current parameter provides the "Operating Current Range".

- **Transient Overvoltage** – Is the maximum allowable excursion of applied voltage that an SSR can withstand without damage or malfunctions while maintaining its off state. Excess of this transient value might tur on the SSR without damage if current conditions are met. The transient period will depend of some SSR characteristics such as internal bias dissipation capability and installed protections.

- **Maximum Surge Current (Nonrepetitive)** – Is the maximum allowable current flow for a specific period or time that an SSR can withstand without damage or malfunctions. Usually specified as a peak value and graphed on current vs time curves. SSR control might be lost during and immediately after surge.

- **Maximum Overcurrent (Nonrepetitive)** – Similar to previous, but typically specified as an RMS for an specific duration period. The duty cycle is not necessarily specified for nonrepetitive values, but is considered to last in order of certain seconds and related to the cooling time required by the semiconductor junction.

- **Maximum On-State Voltage Drop** – Is the maximum peak voltage which is present across the SSR output terminals at full rate load current.

- **Maximum I^2t** – Is the maximum nonrepetitive pulse current capacity of the SSR used for fuse selection and expressed as amperes square seconds (A^2s) with a stated pulse width.

- **Thermal Resistance Junction to Case** ($R\Theta jc$) – This parameter defines the temperature gradient between the semiconductor junction (Tj) and the SSR case (Tc) for given power dissipation. ***RΘjc*** is used to calculate required heatsinking for specific current and ambient temperature values in function on components operational limits.

- **Power Dissipation** – Is the maximum power dissipation (watts) resulting mainly from the effective voltage drop (power loss) in the semiconductor, usually expressed in curves over the current range of the SSR.
- **Maximum Zero Voltage Turn-On** – Is the maximum off-state voltage present across the output terminals prior to initial turn-on, following the application of a turn-on control signal. This parameter is used to define the permissible turn-on window.

- **Maximum Peak Repetitive Voltage** – Is the maximum off-state voltage present across the output terminals prior to initial turn-on at each subsequent half cycle following the initial half cycle, with a turn-on control signal applied. Most common practice is to utilize semiconductors with a voltage withstanding double that peak voltage of the application. For this reason, **celduc® relais** recommends 600V relays on 12-280VAC applications; 1200V relays on 24-520VAC applications and 1600V relays for 600VAC applications.

- **Maximum Off-State Leakage Current** – Is the maximum off-state leakage current conducted through output terminals, with no turn-on control signal applied. This parameter is usually specified at maximum rated voltage over the operational temperature range. Leakage current of the switching component exponentially varies with the junction temperature, then, it stays very low if the junction temperature remains at a reasonable level. On **celduc® relais** new SSRs generation, this parameter is less than 0.2mA, so the improvement of this parameter allow to minimize RC protection network. This drives to a maximum reduction in this current leakage due to the RC, which relies on the mains voltage and the frequency of the network. Ic = 6.28 x U x C x F. This leakage circuit may be harmful in pilot controlling very low loads (small solenoid valves, etc.) as this current may suffice to maintain the load supplied, so this reduced leakage current value allow **celduc® relais** SSRs to properly operate with very small loads. , ce courant est inférieur à 0,2 mA, ce qui permet de minimiser les réseaux de protection RC.

- **Minimum Off-State dv/dt** – Is the rise rate of applied voltage across output terminals that an SSR can withstand without turning on when there is no turn-on control signal applied, expressed as a minimum value at maximum rated voltage in terms of volts per microsecond (V/µs).

C/ General Parameters

- **Dielectric Strength** – Also called "isolation voltage", this parameter is expressed as voltage (RMS) at 50/60 Hz and indicates the minimum value that any SSR can withstand without breakdown. **celduc® relais** SSR have an insulation voltage between input and output of 4000VAC . The output / heatsink insulation specification is in the range of 2,500VAC to 4,000VAC depending of the model construction, in compliance with the European and International standards. Standard EN60947 specifies the voltage assigned to shock resistance = U_{imp}. Most of **celduc® relais** models are specified at U_{imp} = 4000V and are designed for a pollution degree 2 as per IEC664-1.

- **Insulation Resistance** – Is the minimum resistive value (expressed in ohms) measured at an specific voltage value.

- **Maximum Capacitance Input to Output** – VIs the maximum value of capacitive coupling between control and power output terminals.

- **Ambient Temperature Range** – Is the surrounding ambient temperature limit, usually specified for operating and storage conditions. The maximum operating temperature may be further restricted by environmental conditions and heat sinking and dissipation capability aspects.

D/ Selecting the adequate SSR

During a solid state relay selection process, designers must consider at the beginning the main specifications and operation ranges required for their specific application such as input, output, load and installation requirements. **In many cases the load will drive the SSR package.** Generally, load currents above 8 Amps require a heatsink, regardless of the SSR current rating.

For instance, if a 10 Amp SSR has a free air rating of 6 Amps at 40°C ambient temperature, whereas a 40 Amp SSR in the same package has a 8 Amp rating at the same environmental conditions, the small improvement observed comes from a slightly lower dissipation but, it cannot be higher because both SSRs are thermally similar and have the same case to air interface. This reflects the fact that f**ull SSR capabilities can be only reached by an adequate heatsink** to maximize this interface efficiency to remove the heat from power element inside of the SSR.

By having selected a suitable SSR package and terminals configuration, the next parameters to consider are **insulation, input drive parameters and output voltage and current.** Isolation value and input parameters are normally very straight forward to identify, in other hand, output parameters require a more minacious selection in function of each application. Most SSR manufacturers, have similar operating voltages and currents ranges, however, **transient overvoltage** or blocking ratings may vary as much as 200V, which in some installations, this difference could represent a difference between a reliable installation with an adequate overvoltage safety margin or one inadequate installation highly vulnerable to sever malfunction due to voltage spikes. Then, if transient overvoltage capacity is too low, it may even preclude the use of a and external transient suppressor for protection against such spikes.

SSR load current range selection must consider the installation requirements and the influence that load might have on its performance, such as **physical space required** due to the need to pair the SSR with an adequate heatsink. **Minimum and maximum steady-state load current parameters**, but also **non-repetitive and repetitive surge current capability** are also important factors to take in mind.

III/ Solid state relay protections

A/ Noise Susceptibility

Failure level of an SSR due to noise is not catastrophic, unless it happen to mis-trigger during a point in the line cycle when an excessive high current surge might occur (for instance, a cold tungsten filament can cause can generate an instantaneous current flow of 20 times its rating at a peak line voltage). Other remote possibility is a repetitive mis-triggering of one polarity that might cause an inductive load to saturate and thereby draw destructive over-currents to SSR and the load.

In most cases, a malfunction due to noise is only temporary, such as turning on when the SSR should be off, and vice-versa. There are specific tests that might performed to determine the specific level of susceptibility. Some of the techniques used to reduce noise in the coupler and drive circuits are also effective against false triggering caused by voltage transients in the input lines. For instance, when a capacitor is added the response time which is not very critical for AS SSRs may be lengthened, probably from few microseconds to tenths of milliseconds. Because of this delay, voltage transients or burst of shorter duration are rejected, thus improving noise immunity in respect to time. To responding to the amplitude of a transient, a thyristor can mis-trigger when the rate of rise (dv/dt) of a transient or applied voltage exceeds certain limits. Transient suppressors are effective against the former and the RC snubber improves the tolerance of an SSR to the latter.

B/ dv/dt (Rate Effect)

The rate effect in thyristors (dv/dt) is caused by capacitive coupling within the device structure between the high terminal (anode) and the gate, which could result in self-induced turn-on if the SSR dv/dt limits are exceeded. The expression dv/dt defines a rising voltage versus time expressed in volts per microsecond ((V/µs), Fig.13. When applied to an AC SSR as "static" of "off-state" dv/dt, represents the parameter which defines the maximum allowable rate of rise of voltage across the output terminals that will not turn-on the SSR.

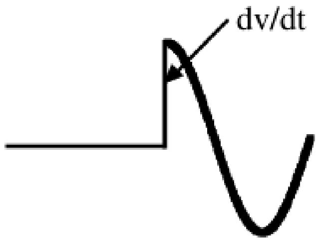


Fig.13

When critical operational parameters and limits of an SSR are properly specified, including load power factor, temperature range, the effect of commutating dv/dt has already been considered in the design, for instance when the output device is a triac, a snubber is considered essential for inductive loads to equalize the performance of dual (inverse-parallel) SCRs. While snubber might be unnecessary for SCR commutation, it is often included to improve static dv/dt withstand capability, also the snubber will provide some immunity to brief voltage spikes as well as facilitate the use of transient suppressors.

C/ RC Network (Snubber)

The internal RC network (snubber) used in AC SSRs is an important implementation in **transient voltage and dv/dt suppression**. It is capable to manage effectively with two facets of a voltage transient, by slowing down the rate of rise seen by the thyristors and sensitive drive circuits, but also limits the amplitude to which it can rise. Nevertheless, the protection has a limit, since a prolonged transient or pulse will eventually escalate up to blocking voltage potentially causing a breakdown

Since mentioned effects can appear due to switching on, switching inductive loads, mains interference,

celduc® relais relays have been improved in terms of resistance to these factors by enabling the RC network to be reduced substantially or practically eliminated. **celduc® relais** guarantees its relays for immunity in compliance with standard EN61000-4-4, which corresponds to quick transients. The majority of relays are guaranteed with resistances without arcs at 2kV (even 4 kV), whereas the test is performed with rising times to within a nano second.

D/ Suppressors & VDR Protection

For applications where overvoltage transient occur, probably mis-triggering the SSR, some elements of suppression beyond the capabilities of the snubber are effective. The usual technique is to add a clamping device across the SSR terminals that will absorb the transient energy above a predefined level. When activated, some suppression devices such as spark gaps will drop to a very low impedance, transferring most of the transient to the load as if the SSR had turned on. Other, such as Zeners and MOVs will conduct only the predefined level and above, sharing the transient with the load, which is the most common approach. If in particular application it is deemed unacceptable for the load to receive any transient energy, the only solution might be suppression of the transient source or an SSR with a blocking capability higher than the transient

Since distribution networks are after «polluted» by high amplitude interference voltage pulses (Fig 14). These voltage peaks are harmful for the semiconductors used in solid state relays. **celduc® relais** recommends the **use of varistors (VDR) placed at the power terminals of solid state relays. A varistor is a non-linear component the resistance of which varies with the voltage**.

At nominal voltage, the varistor is practically not conductive. At high voltage of interference, it represents a low impedance which limits the voltage surges to acceptable values for the relay. **celduc® relais** installs a varistor on some ranges of relays as standard and as an option on others (low quantities), then, these are strongly recommended to be used on other portfolio products. European mains voltages 230V – 10% in single phase and 400V – 10% in three phases requires 275V varistors on the 230V network and 460V varistors on the 400V network. There are different sized varistors which absorb either more or less energy. **celduc® relais** recommends the use of at least size «14».

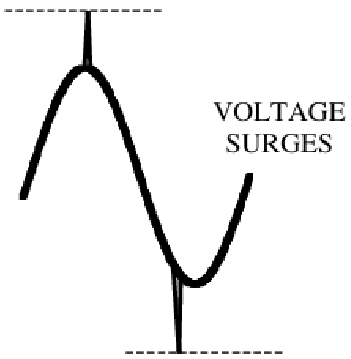


Fig.14

E/ Diodes and Zener

A diode across the load is the most effective way of suppressing the hundreds of volts of back EMF that can be generated by a coil when turn-off. The disadvantages of this method are the SSR is not fully protected from other transient sources and the drop-out time of the load (solenoid, EMR, etc.) may be extended by several milliseconds. If a prolonged drop-out time is objectionable, it may be considerably reduced by the diode-Zener circuit. The diode in each case should have a voltage rating (PIV) greater than the maximum operating load voltage, while the Zener value (Vz) should be no greater than the SSR breakdown voltage minus the load voltage. Some allowances should be made for the higher Zener values that occur at peak (pulse) currents and at elevated temperatures.

The general rule in the selection of protective diodes and Zeners is consider their peak non-repetitive (pulse) current ratings should be equal to or greater than the maximum load current. Conservative steady-state power ratings for these devices may be determined from the following equation:

$$P_{\mathrm{watts}} = \frac{I_L L^2}{t_r}$$

where
I_L = Load current in DC Amps
L = Load inductance in Henrys
tr = On / Off repetition rate in Seconds

Example: Load with a resistance of 8 ohms and an inductance of 0.004 Henry is being driven by a 32V DC supply while being switched on and off 8 times a second:
I_L - 32 Volts / 8 Ohms = 4 Amp
tr = 1/8 = 0.125 Second
P = 42 x 0.004 / 0.125 = 0.758 Watt
Then a protective diode or Zener rated at 1 Watt rating would be adequate.

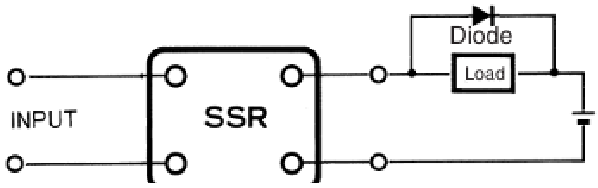


Fig. 15 SSR-Diode Circuit

F/ MOVs (metal oxide varistors)

Devices such as metal oxide varistor were developed to provide needed protection in some of its more severe environments. MOVs, as its name implies, it's composed by metal oxides, primarily zinc oxide, sintered (fused) by high pressure and temperature into a ceramic material. The medium power types, ranges from 3 to 300 joules (Watt/Seconds), are generally formed in the shape of a disc 0.3 to 1 inch in diameter. With radial leads and a hard epoxy coating, they closely resemble disc ceramic capacitors and can be physically mounted in a similar manner.

A MOV can be used across the incoming line to suppress external transients before those access the system, across the load to suppress load generated transients or more frequently across the SSR to protect it from all transient sources. In the latter case, the MOV can be mounted to the same SSR output terminals as the load wiring. With the impedance of the load in series with the MOV to limit current, a 30-joule unit is usually adequate for brief spikes and also small enough to be supported by its own leads. Some manufacturers provide the MOV with preassembled spade lugs to facilitate ease of mounting to SSR screw terminals and also to the barrier strips of microprocessor input-output systems. When an MOV is connected across the power line, the current limiting impedance will be only the power generating source in addition to the wiring. In order to absorb the high energy line transients from such a low impedance source, the larger platform (300 to 600 joule) MOV may be required. The greater expense of such device might be justified in that suppression across the line is required in one place only. Spark gaps might also be considered, and may even be a better solution in this heavy duty application.

Some loads generated voltage transients are generally not a problem with the sinusoidal waveform of the AC line and the typical switching characteristics of the SSR. Nevertheless, MOV can be used effectively across such loads as transformers and switching power supplies where spikes, too fast to be absorbed by the transformer. When used across the load, the MOV will not protect the SSR against line-borne transients, oppositely, it might enhance them by shunting the filtering effect of an inductive load. While a particular situation might dictate where an MOV should be used, the first choice appears to be across the SSR terminals. The electrical characteristics of the MOV are essentially voltage-dependent, nonlinear resistor. When properly applied, the MOV impedance at nominal steady-state voltages should be so high that only a few microamperes of leakage current will flow. As a voltage of either polarity approaches its clamping voltage, the MOV rapidly becomes a low impedance, causing current flow to increase at a much faster rate than the increase in voltage. The amplitude of the instantaneous transient voltage across the SSR is the ratio of the IR drops across the MOV and the load-source impedances.

In order to select the correct MOV for a specific application, it required to have some data of the source impedance and the pulse power of the transient. In the case of internally generated system transients, some estimates can be made when circuit parameters are known and statistical data and waveforms are available.

For incoming line-borne transients, MOV selection is far more difficult since the nature of the transients and the characteristics of the power source are generally unknown. With very little data, assumptions are made using data collected on the amplitude and rate of occurrence of typical power-line voltage transients in various locations over long periods of time. Such assumptions on wave shape are also made by using industry standard pulses, typically 20 to 50 microseconds, a suggested source impedance is sometimes included, often in the region of 50 to 150 ohms, but also, an impedance may be estimated from the KVA rating of the power supply (if it is known).

When the MOV is placed across SSR output terminals, it has the security of a minimum known load impedance, in addition to the possibly unknown source impedance in series. Any inductance in the load will tend to further increase its impedance to fast rising transients and enhance the effectiveness of the MOV. As previously mentioned a 20 to 30 joule MOV placed across the output terminals will be satisfactory for most applications, according to the collective field experience of a number of SSR manufacturers. By selecting the MOV for voltage, its maximum continuous RMS voltage rating should be just above of the highest expected line excursion, like 130V RMS, for the nominal 115V line and 250V RMS for the nominal 220V line. To ensure complete protection the SSR transient (blocking) voltage rating must be greater than the MOV clamping voltage. To divert the transient, MOV must be conducting heavily in the ampere region before reaching the SSR breakdown voltage. **The use of the MOV is a must in the case of a Solid state reversing contactor. Relays with internal TVS must not be used in motor reversing applications.**

Where MOVs are specified for unknown conditions, it is good practice to reference an existing transient test specification where duration, waveform, and source impedance are accurately defined. Such a measure ensures that the values chosen will perform reliably in a given situation, and also allows reproducibility by providing a standard for comparison. A commonly used test is the IEEE C37.90.1 2012 Surge Withstand Capability (SWC) test. The transient described in this test is an oscillatory (ringing) burst starting at 2.5-3 KV peak and decaying to 50 percent in 6 microseconds at a frequency of 1.0 to 1.5 MHz. The transient is applied to the SSR for a minimum of 100 bursts for 2 Seconds from a generator with a source impedance of 150 Ohms. When the source impedance is known, the minimum peak current that must be conducted by an MOV to prevent breakdown of an SSR for a given voltage transient can be calculated. Then, for an SSR with a 600-volt transient (blocking) rating, using the parameters from the test described above, the current determined by:

$$I_{MOV} = \frac{E_S - E_{SSR}}{Z_s}$$

I_{MOV}= (3000 – 600) / 150 = 16 Amp minimum

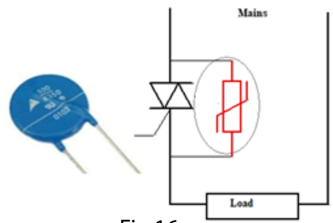


Fig.16

Then, a MOV with 6 amperes minimum at less than 600 volts must be used.

Since MOV is not indestructible manufacturers ratings should be consulted, especially where transients are known to exist and are also predictable. Besides the allowable number of pulses during the MOV life, the frequency might become a factor if the transients occur in rapid succession. A pulse train can cause the energy requirements of the MOV to increase radically, by as much as the product of the single pulse energy (Watt/Seconds) and the number of pulses per second. The MOV selected must have a continuous (average) power dissipation rating (PAV) equal to, or greater than, the created by the pulse train. Individual MOV specifications should be consulted for precise information regarding energy absorption, clamping properties and dimensions, since the relationships of these parameters will vary. When the MOV is used beyond its specified ratings, it will eventually fail, usually in the shorted mode.

G/ Fuses

During a short-circuit event, 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 reduced period of time thereby protecting persons, device and equipment. This cut-off device must be faster if it is associated to a conventional thyristor or triac type solid state relay, as these components can only withstand a limited peak current.

During a short-circuit on the line, the waveform obtained (Fig 17) depends on the presumed short-circuit current of the line (I_{cc} inrush current reached if there is no protection device). The rapidity of the protection device is characterized by the quantity i2 dt which is the sum of the pre-arc I^2t plus the arc I^2t. This I^2t value called thermal constraint, is used to verify that the components of the circuit are duly protected. This I^2t characteristics is only valid if the duration of the surge is of a short duration (<10ms) . Beyond this the RMS value of the current must be considered.

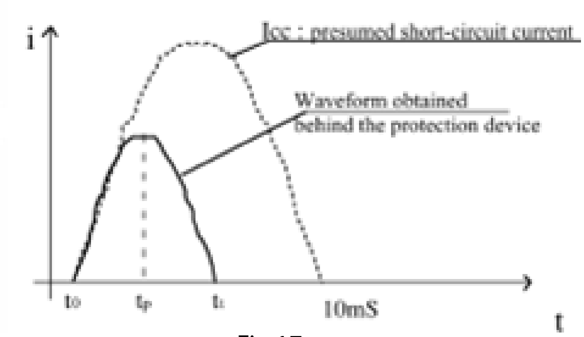


Fig.17

In the protection of SSRs it is essential that the let-through current of the fuse during fault conditions remain within the surge withstand capability of the output semiconductor (usually a thyristor for AC SSRs, Fig 18). In order to coordinate the fuse ratings with those of the SSR, the SSR data sheets generally use similar terms for fusing, such as I^2t (A^2s), a common expression in defining fuse performance. For fuses, I^2t is the measure of let-through energy in terms of current versus time, so it is based directly on the output thyristor's single-cycle peak surge current.

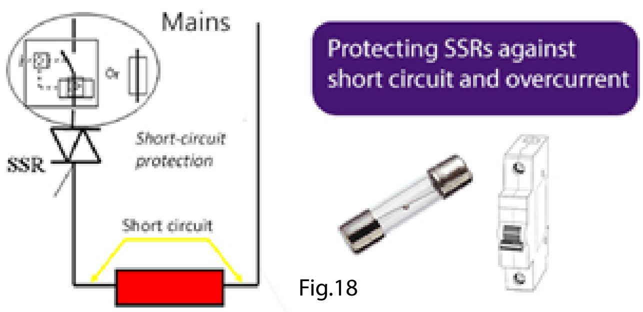


Fig.18

The procedure is to select a fuse with an I^2t let-through rating that is less than the I^2t capability of the SSR, for the same duration. As a further point of interest, the SSR surge ratings are usually based on thyristor specifications that stipulate an after-surge reverse-blocking capability, even though most SSR specifications do not reflect this. When a series fuse opens, there is no further demand for conduction or blocking and consequently the thyristor can withstand a higher surge than the published ratings. The surge current for a thyristor is approximately 20% higher if no voltage is applied immediately after a current surge lasting one half cycle or less. This means that SSRs can be considered to have higher current capability and therefore higher I^2t ratings when protected by a semiconductor fuse. The 20% higher values may be considered as built-in conservatism when selecting the right fuse.

Another factor that affects the fuse to SSR match is that their ratings are based on different waves-shapes, triangular for the former and sinusoidal. However, the difference is small and in any case the thermal effect of the fuse let-through I^2t will be less than that of an equal I^2t value for the SSR

Below are **the main parameters used in the selection of a fuse** :

1. Fuse voltage rating
2. Fuse current rating
3. Available system fault current
4. Fuse peak let-through current
5. Fuse total clearing (or let-through) I^2t
6. I^2t or surge withstand capability of SSR

The fuse voltage rating must, of course, at least be as high as the system voltage, and the current rating greater than the steady-state value of the load current. Consideration must also be given to system start up and normal operational current surges, such as motor starting, to avoid nuisance fuse blowing under worst case conditions.

The I^2t values of the **celduc® relais** relays are the most efficient on the market.

celduc® relais range :

Relay Rating	12Amp	25Amp	4a Amp	50Amp	75Amp	95Amp	125 Amp
I^2t (A^2s) (<10ms)	72	312	610	1500	5000	11000	20000

There are recommended fuses adapted to the solid state relays for each type of load:

- Resistive load: Use FERRAZ GRB or GRC fuses
- Motor: Use standard «am» fuses with adaptation of the rating of the relay.

As a general rule, a correct safety margin of fuse I^2t value would be <1/2 I^2t relay.

One important factor must be taken into account and it's the thermal fatigue of the fuse. For this reason all the associations proposed by **celduc® relais** have been tested in the FERRAZ laboratory to confirm an adequate fit and reliability.

IEC publication IEC60947-4-3 (2020) makes a distinction between two different types of protection, (called "coordination"), which are designated types "1" and "2".

Coordination Type 1: Lrequires that, under short-circuit conditions, the device shall cause no danger to persons or to the installation and may not be suitable for further service without repair and replacement of parts.

In application: For loads where the risk of short circuit is low, coordination Type 1 can be used. In this case, the SSR is chosen in compliance with the load and the protection is chosen to protect the installation. But in case of short-circuit, the SSR can be in short-circuit and must be replaced for further service.

Coordination Type 2: requires that, under short-circuit conditions, the device shall cause no danger to persons or to the installation and shall be suitable for further use.

In application: For loads where the risk of short circuit is more important, coordination Type 2 must be used. In this case, the SSR is chosen in compliance with the load and the protection device to have the right protection for the installation and the SSR.

That means the protection device must react before the SSR is damaged. In case of short circuit, the SSR will be correctly protected and will be suitable for further use.

H/ Circuit Breaker

celduc® relais current portfolio offers self-protected solid state relays, however, build-in protection technology influence drop in voltage at on-state status, therefore, a bigger heatsink and in consequence added costs might an outcome, therefore, a **solid state relay properly paired with a high-speed circuit breaker can be a suitable solution.**

Mechanical circuit-breakers have positively evolved. Very compact modular circuit-breakers packages can be found with thermal and magnetic tripping, capable of breaking-on a surge, but also a short-circuit. Their breaking capacity reaches 15 to 25 kAmp in Icu current (Ultimate current at which it is preferable to be replaced) and 10 to 20 kA in Ics current (Operating switching current). The magnetic tripping depends on the type of circuit-breaker.

Newest high speed circuit-breakers «Z curve» type, trip at a current corresponding to 2 to 3 In . These circuit-breakers (ABB, MERLIN GERIN, EATON, ...) 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 two factors of the on-state thermal stress (I^2t on-state). The short-circuit current limitation value and the breaking time are crucial in protecting downstream circuits against the damage induced by short-circuits of the load.

In order to determine the circuit-breaker, the presumed short-circuit current (called I_{cc} or I_p) must be known and it has to be calculated at the point where its installed. Installers usually know this presumed short-circuit current at a given point of the installation, however, **celduc® relais** can be contacted for the specific application note. The circuit-breaker must have a breaking capacity at least equal to I_{cc} in compliance with the NFC standard 15-100/434-2-1 (CEI364). As an additional consideration, the residual short-circuit current must be taken into account to determine the degree of coordination and selectivity. The value of the residual short-circuit current and corresponding breaking time, depend on residual short-circuit current I_{cc} and the type of circuit-breaker to be used.

Solid state relays are generally fitted after a series of protection and isolating devices, in some cases corresponding cross sections of the wires are already reduced and this is a factor that limits the short-circuit current to values under 5000 Amp. Given these conditions, the I^2t values obtained using «Z curve» highspeed circuit-breakers in an event of short-circuit of the load can be managed by the **celduc® relais** high I^2t solid state relays.

To verify the level of protection, just refer to manufacturers' curves which might provide:

- Tripping curves, to check the surge protection (thermal).

Example: A 16Amp circuit-breaker will trip with a surge of 30Amp in a maximum of 20 Seconds.

- Dynamic stress curve, to review the limiter effect of these circuit-breakers.

Example: $I_{cc\ eff}$ = 4000Amp -> max ID on-state = 2400 Amp for a rated 16Amp circuit-breaker .

- 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 I_{cc} of the line at the point of installation.

Example: I_{cc} = 2000Amp circuit-breaker rating = 16 Amp I^2t max = 3200A^2s I_{cc} = 4000Amp circuit-breaker rating = 25 A I^2t max = 10000A^2s

Generally, these values are the maximum given by the manufacturer. Another relevant consideration when using zero cross solid state relays coordinated with circuit-breakers, by controlling the zero cross relay it will limit the thermal stress.

celduc® relais has developed high I^2t solid state relays, capable to be coordinated with these circuit-breakers :

- Relay 45/50Amp: I^2t >1500A^2s (typ >2000A^2s)
- Relay 75Amp: I^2t >5000A^2s (typ >7000A^2s)
- Relay 95Amp: I^2t >11000A^2s (typ >12500A^2s)
- Relay 125Amp: I^2t >20000A^2s(typ >21000A^2s)

A certificate from ABB laboratory has been drawn up in coordination with **celduc® relais** solid state relays to provide the short-circuit current limit values for the each relay rating, corresponding to high speed circuit-breakers shown below:

RELAY RATING	Limits of short-circuit current (Icc) or prospective current (Ip)	
	Circuit-Breaker Z16	Circuit-Breaker Z50
50A - 5000A2s	3000 Amp	2000 Amp
95A - 11000A2s	5000 Amp	3000 Amp
125A -20000A2s	7000 Amp	4000 Amp

Note: Additional coordination are possible, as in general the estimates short-circuit currents are lower. **celduc® relais** has awareness of many applications where the coordination of 50A relays rated at 5000A^2s with a Z16 circuit-breaker operates adequately.

IV/ Thermal management

A/ Heat Transference Principles

It is not uncommon for the life expectancy of electronic equipment to be at least 10 years, with many applications looking for 25 years or more. As such, **thermal considerations must be fully addressed at the design stage of the electronic circuitry.**

Heat transfer is energy in transit due to a temperature difference. The three fundamental modes of heat transfer are conduction, convection and radiation

1. Effect of Temperature on a Semiconductor

It is well known that the **useful life and reliability of semiconductors improves with lower operating temperatures.** The temperature of a semiconductor junction, Tj, is the main criterion for its reliability and performance. Its maximum allowable value, Tj (max), is specified by the semiconductor manufacturer.

2. The Generation and Removal of Heat in a Semiconductor

During energy conversion in a semiconductor, part of the electrical energy transforms to heat. This generation of heat, otherwise known as heat losses, is proportional to 1-e, where e is the semiconductor efficiency as specified by the manufacturer. **If not removed, this heat will cause the junction temperature to rise above that allowable, resulting in damage and eventual failure of the semiconductor.**

The typical 1.2-volt on-state drop (at maximum current) across the output terminals is responsible for most of the dissipation in both AC and DC SSRs, regardless of operating voltage. At lower currents the voltage falls slightly and creates a nonlinearity in the power dissipation versus current curves, as shown in data sheets.

3. Conduction

Heat transfer that occurs across a stationary medium is termed conduction. It is usually thought of as the heat transfer through solid materials, although it also occurs in fluids. Fourier's law describes heat flow, Q (heat energy transferred per second -Watts), through a solid layer as:

$$Q = \frac{k - A_c}{l}\left(T_1 - T_2\right)$$

where :
k - thermal conductivity of the solid, [W/m·K] or [W/m·°C]
A_c - cross-sectional area through which heat flowse, [m^2]
l - length through which heat flows,[m]
T_1, T_2 - temperatures on boundaries 1 and 2 respectively, [°C]

Here, T_1>T_2 since heat can only be transferred from a warm object to a cooler one.

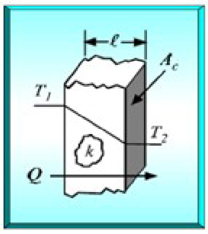


Fig 19.
Conduction through a solid of length l and area A_c

4. Convection

Convection is the mode of heat transfer that occurs at the interface between a solid surface and surrounding fluid. The fluid layers adjacent to the solid surface become warmer and flow away to cooler portions of the fluid. There are two distinct types of convection classified according to the mechanism of the fluid flow: namely, natural convection and forced convection.

Natural convection occurs when the fluid flow is a result of the natural buoyancy forces within the fluid.

Forced convection occurs when the fluid flow is caused by external means, such as a fan, pump or atmospheric winds.

Convection heat transfer is described by Newton's law of cooling as:

$$Q = hA_s \ (T_s - T_a)$$

where:

h - convection heat transfer coefficient, [W/m^2 · °C]

A_s - surface area, [m^2]

T_s – surface temperature, [°C]

T_a- ambient fluid temperature, [°C]

The convection coefficient, h, depends on the physical geometry (i.e., shape and length of the solid surface in the flow direction) and on the fluid thermo-physical properties (i.e., type of fluid and operating temperature). In the case of heatsinks, it also depends on the spacing between fins since this spacing establishes the cooling flow field.

5. Radiation

Radiation heat transfer is energy emitted by matter that is at a finite temperature, transported by electromagnetic waves. While the transfer of energy by conduction or convection requires the presence of a material medium, radiation does not. In that any object or body at some finite temperature emits radiation, that implies that every object or body is also the recipient of radiation from the bodies surrounding it, net radiation heat exchange between a surface and its surroundings, for which the relationship is given as:

$$Q = \varepsilon A_s \ \sigma(T_s{}^4 - T_{sur}{}^4)$$

where:

ε - emissivity, a radiative property of the surface, [-]

A_s - emitting surface area, [m^2]

σ- Stefan-Boltzmann constant = 5.67·10-8 [W/m^2·K^4]

T_s - emitting surface temperature in Kelvins, [K]

T_{sur} - temperature of surroundings in Kelvins, [K]

The emissivity of an object's surface is in the range 0 < e < 1, indicating how efficiently the surface emits compared to an ideal radiator.

One of the most important aspects to consider in the use of solid-state relays is the thermal design. It is essential that the user provide an effective means of removing heat from the SSR package. This is because of the relatively high dissipation, in excess of 1 watt per ampere, compared to milliwatts for the EMR.

The importance of using an adequate heat sink cannot be omitted, as it directly affects the maximum utilizable load current and/or maximum allowable ambient temperature. Lack of attention to this de tail can result in improper switching or even total destruction of the SSR. With SSR loads of less than 5 amperes, cooling by free flowing convection or forced air currents around the basic package is usually sufficient. At higher currents it becomes necessary to effectively expand the exposed radiating surface area by means of a suitable heatsink. This requires that the SSR be firmly mounted to a smooth flat surface on a good heat conductor such as copper or aluminum, plus the use of a thermally conductive compound to improve the interface. Using this technique, the SSR base to heatsink thermal resistance ($R_{\Theta BS}$) is reduced to around value of 0.1°K/W (Kelvin per watt). This is usually presumed and included in any given thermal data. The values that are determinable by the user are the base to heatsink interface ($R_{\Theta BS}$), as previously mentioned, and the heatsink to ambient interface ($R_{\Theta HA}$).

B/ Voltage Drop at ON State

At on state, solid state relays have residual voltage, this drop in voltage at the ON state is in phase with the current and takes on the form shown in figure 20 :

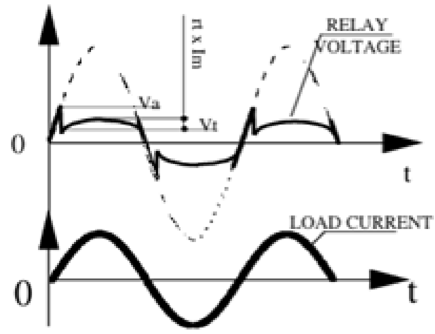


Fig. 20

V_a : the arcing voltage or minimum voltage required to send a correct control to the power component (appears on each zero crossing of the current). This voltage has been reduced as much as possible on the **celduc® relais** solid state relays (usually 7 to 8V instead of 20V), this improvement reduces the deformations of the mains sine wave and the level of conducted emission (EMC). This voltage (not to be confused with the zero cross voltage which only takes places on the half-cycle after the application of the control) calls for a minimum working voltage of the solid state relays, usually 12 VAC.

V_t : Threshold voltage is a parameter derived from junction of the semiconductor, usually 0.8 to 1 V. (This voltage parameter drops with the temperature in a ratio of 2mV/°C.

R_t : Resistance at the ON state of the semiconductor and connections, usually has a value of 5 to 30µΩ according to the rating of the relay.

C/ Thermal Calculations

1. Reminders of Ohm's law

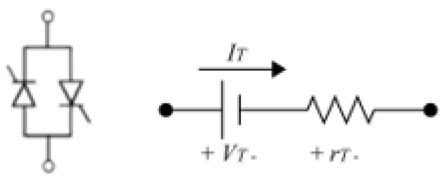
$\Delta T = R_{th} \times P_D$ where :

ΔT = Difference of temperature between the junction and the ambient air

R_{th} = Junction to ambient air thermal resistance. It can be equivalent to several serial mounted thermal resistors

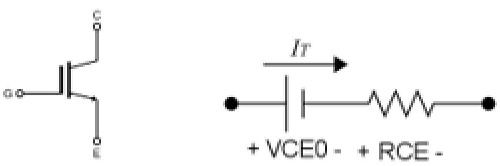
P_D = Power dissipated by the relay. Expressed in Watts (joules per second), corresponds to the thermal current or the calories to be discharged from the relay, mainly depends on the current crossing the relay.

- __THYRISTOR :__



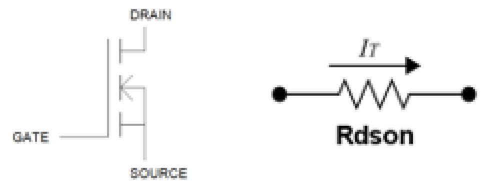
$$P_D \text{ (Watts)} = 0.9 \times V_t \times I + rt \times I^2$$

- __IGBT :__



$$P_D \text{ (Watts)} = V_{CE0} \times I + R_{CE} \times I^2$$

- **MOSFET :**



$$P_D \text{ (Watts)} = R_{dson} \times I^2$$

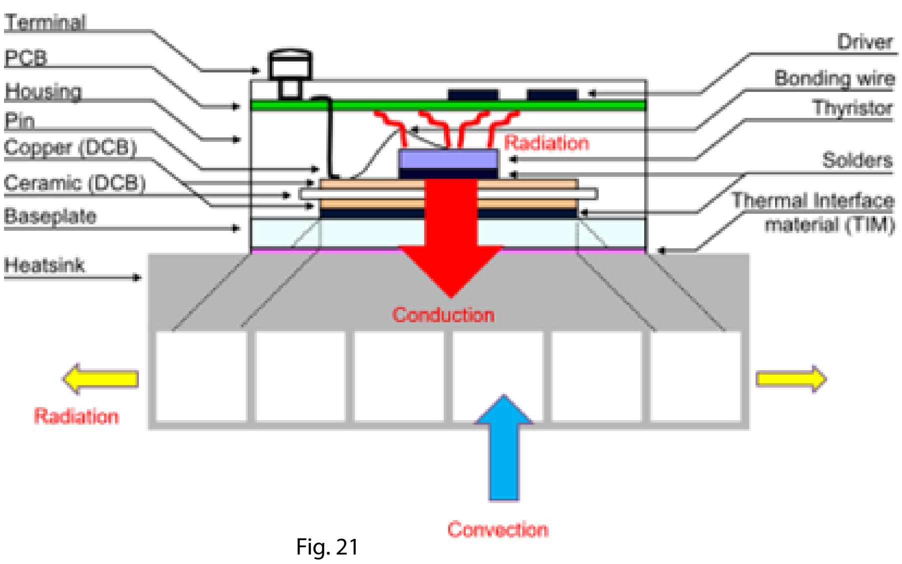


Fig. 21

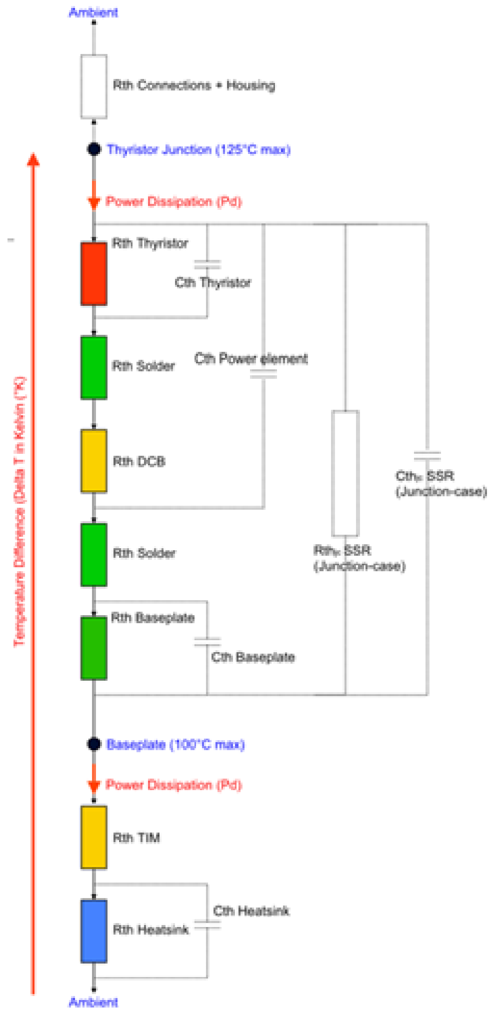


Fig. 22

As the power components are inside a housing (Fig. 21), they are not able to radiate and therefore most of the thermal energy is consumed by conduction.

Nevertheless, environment inside of the SSR housing is heated by the power element and there is small radiation if air is present.

The resistors corresponds to the resistance to transmit the heat (Fig. 22). The capacitors, combined with the resistors corresponds to the thermal inertia (reaction time).

2. Modules without external heatsink

For these cases the resin, internal heatsink (baseplate or built-in heatsink) and enclosure act as a dissipator to transmit heat to the surrounding environment. For example in a SK package, the junction to ambient air thermal resistance is in the region of 20 to 25 °C/W.

Max P_D = = (Max. junction temperature - Ambient temperature) / 20 max

P_D = (110 - 30) / 20 = 4 Watts, hence max. rms I at 30°C ambient temperature is 4 Amp. For each SSR, a curve specifies the maximum current according to the ambient temperature and built-in or external heatsink.

3. SSR with baseplate mounted on heatsink

The heatsink can be determined either by calculation or directly from the derating curves provided by celduc® relais. To simplify calculation and considering that SSR is properly mounted on heatsink (i.e. mounting SSR using thermal conductive grease / silicon grease or thermal interface recommended by **celduc® relais** and applying the required mounting torque to ensure adequate pressure between SSR baseplate and heatsink mounting surface), the thermal mounting resistance can be considered usually as 0.1 - 0.2 °C / W.

In general, the known elements are the power to be dissipated (P_D):

P_D = 0.9 x V_t x I + rt x I x I (determined according to the RMS current crossing the relay) and the ambient temperature (T_{amb}).

The max junction temperature (T_{jmax}) and junction to case thermal resistance values ($R_{thj/b}$ou $R_{thj/c}$) are given in the **celduc® relais** specifications.

$R_{th} < T / PD$

Besides, the temperature of the relay, therefore, the heatsink must be limited to max T_{case} (90 or 100°C), also given in the specifications.

R_{th} heatsink < (max T_{case} - $T_{Ambient}$) / P_D

Example :

SSR rated as next:

RMS I = 20A -> PD = 24 W (for a relay with Vt = 1V and rt = 15 µΩ) @ Max ambient T = 30°C

If $Rt_{h\ j/c}$ =1.1°C/W; T_j max = 125°C; $T_{case\ max}$ = 90°C; $R_{Thermal\ Interface}$ = 0.1 °C/W

$$\sum R_{th} < \frac{125 - 30}{24} = 3.9°C/W \rightarrow R_{th(heatsink)} < 3.9 - 1.1 - 0.1 = 2.7°/W$$

Considering max temperature at case:

$$R_{th(heatsink)} < \frac{90 - 30}{24} = 2.5°/W$$

The adequate selection is a heatsink R_{th} < 2,5°/W (ie. **celduc® relais** heatsink of 2 °C/W)

4. Mounting on sink plate or cabinet wall

Some thermal curves without heatsink are given for olid state relays. When mounted on the backplate or a cabinet wall, the SSR - plate contact must adequate.

An aluminum backplate of reasonable thickness (3-5 mm) with dimensions of 150mm x 150mm corresponds to approximately 4 °C/W, if it's in contact with ambient air.

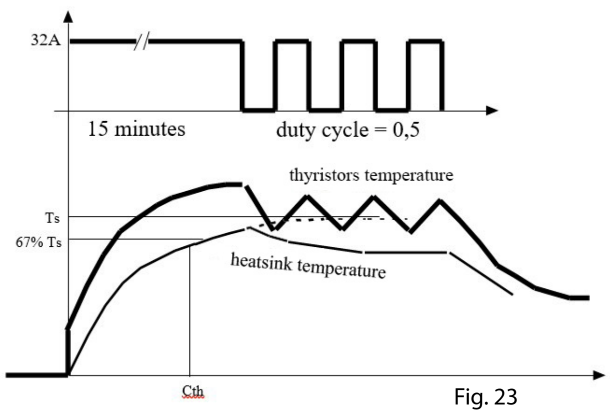
An aluminum backplate of reasonable thickness (3-5 mm) with dimensions of 300mm x 300mm corresponds to approximately 2 °C/W, if it's in contact with ambient air.

In all cases, user must perform a test and measure the heat on the SSR baseplate. For instance steel plate with similar dimensions to examples given above will have greater thermal resistance.

5. SSRs array on common heatsink

There are some applications where various solid state relays are mounted on one heatsink fixed to backplates of cabinets. This solution optimizes space by maximizing heatsink thermal capacity at the time of equipment heating or preheating, when all the solid state relays are operating permanently. The value of the thermal constant of **celduc® relais** heatsinks is specified. C_{th} value (figure 23) corresponds to the time of the temperature rise on the heatsink: C_{th} = 67% the time that heatsink takes to stabilize (T_s value given in still air). In control mode, this mounting deliver a temperature rise with an optimum distribution of the heat over whole heatsink geometry.

To determine the heatsink characteristics, consider the total power to be dissipated for all the SSRs. Perform thermal resistance calculation required: R_{th} = T/ P_d. The safest approach is to conduct a temperature rise test at the worst operational conditions, to confirm that temperature of the heatsink does not exceed the maximum specified.



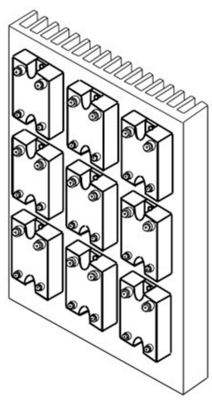
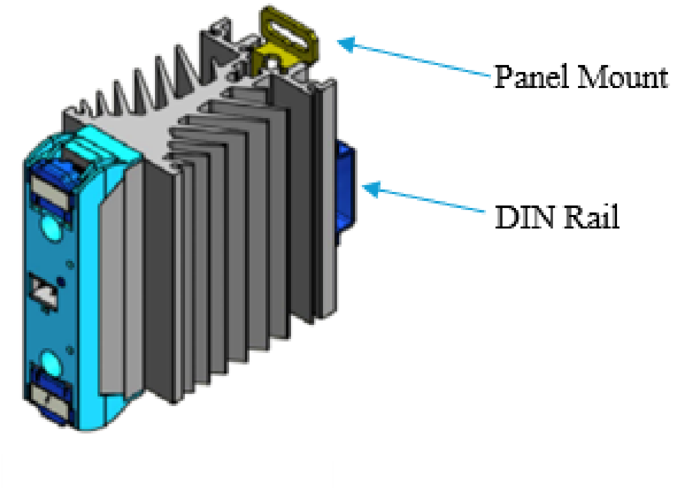


Fig. 23

6. Ready to use relays

celduc® relais offers a wide range of ready to use relays which can be mounted on a DIN rail or screwed on a panel or cabinet wall. The values of the switching current are directly specified in compliance with the European Standards, corresponding to limited temperature rises of maximum 50 °C for heatsink and maximum 50 °C for housing/cover, the corresponding derating curves included on each **celduc® relais** ready to use SSR indicate the ratings on which such model can operate in function of surrounding ambient temperature.



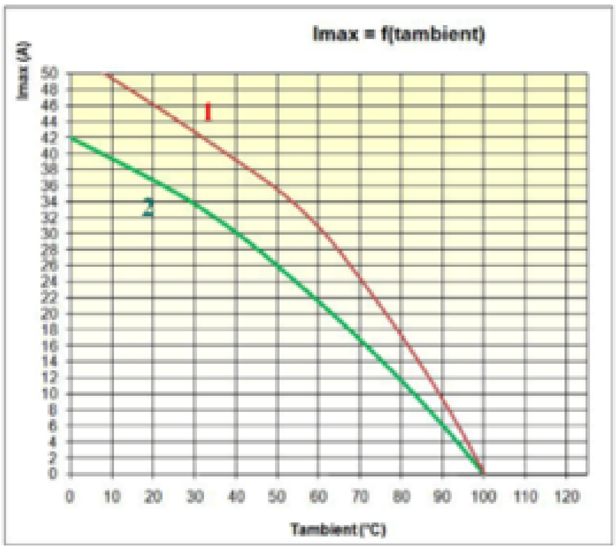


Fig. 24

7. Mounting and thermal considerations

The thermal interface (TIM) improves heat transfer between the SSR and heatsink. The thermal interface (TIM) improves heat transfer between the SSR and heatsink. As there are cavities between both surfaces and as the air is not good heat conductor, it's used to fill voids to maximize the heat transfer. The picture (Fig. 25) shows the action of the thermal grease (in orange), but it also shows as well that the heat transfer is better when metal surface is in contact with other metal surface. There are different types of thermal interfaces (TIM) such as Thermal Compounds and Thermal Pads.

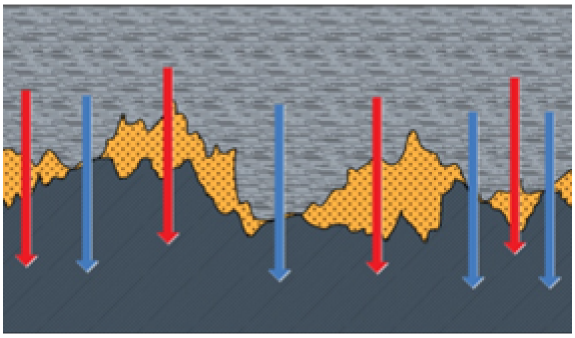


Fig. 25

Values of power dissipated according to the current crossing the relay are given for permanent operation on the derating curves specified by **celduc® relais**. For applications with intermittent operation, some datasheets curves provide the power rating with a duty cycle = t_{on} / t_{off} <1, but such values are only valid for short periods of time, meaning less than the thermal time constants of the heatsinks.

The thermal resistance of a heatsink is defined in determined mounting conditions to optimize its efficiency such as vertical mounting (Fig. 22). In the case of a severe atmosphere applications (cabinet with no air flowing), safe factor (20 to 30%) must be included when heatsink calculation is performed.

Thermal resistance values of **celduc® relais** heatsinks are given under natural convection conditions, in the vertical position (fins aligned with air flow) and inside of a cabinet.

Forced ventilation induced to SSR and heatsink (fan, blower, etc.) will allow to reduced heatsink size / volume significatively. For instance thermal resistance of a heatsink is divided by 2 with if an air speed of 1.5 m/s is induced and by 4 with an air speed of 5m/s is induced, however, these rough estimations only provides a guideline to include forced convection and a temperature rise test must be conducted to confirm optimal performance of heatsinking system

Finally, **the use of an oversized heatsink enhance the reliability and lifetime of solid state relays,** by reducing ΔT to ambient and by consequence thermal stress on SSRs components.

D/ Derating Curves

The free air performance of lower powered SSRs is usually defined on the data sheet by means of a single derating curve, current vs ambient temperature based on the applicable formulas, which is adequate for most situations. However, a single curve defining performance of a power type on a typical heat sink (i.e 2°C/W) is sometimes the only thermal information given. This may provide a means of comparison with another manufacturer's similarly defined part, but it is of little value in determining proper performance in a wide variety of real world applications.

A family of curves such as those shown in figure 26, while they may be less accurate, provide about the same flexibility as that obtained by calculation. This method of presenting information is particularly useful in that it shows graphically the relationships between all the previously discussed parameters in one, easy to read diagram..

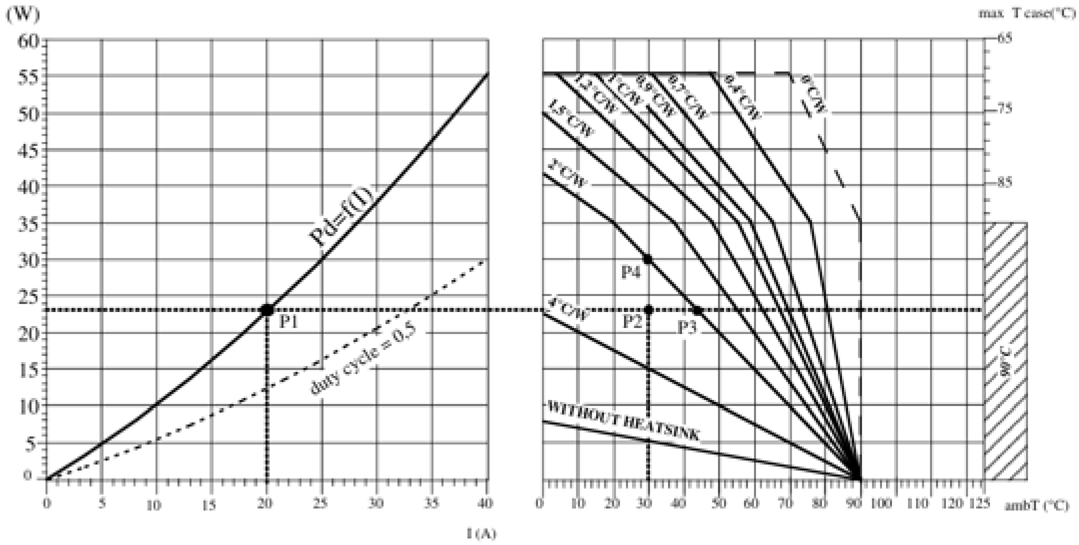


Fig. 26

The type of heatsink to be used can be determined directly according to the switched current and the ambient temperature. Previous example with RMS I = 20Amp and max. ambient temperature = 30°C.

<u>How to read the derating curve in figure 26 :</u>

1. Identify the current to be switched on the X axis of the left graph curve.
2. Plot a vertical line from this point up to the curve Pd=f(I). The power to be dissipated can be read on the ordinate..
3. From the point obtained (P1), a horizontal line is plotted to the right hand curve.
4. Identify the ambient temperature on the X axis of the right graph curve.
5. Plot a vertical line from this point until you meet the horizontal line previously plotted. This point (P2) determines the type of heatsink to the used.
6. Choose the heatsink corresponding to the curve located above this point. In the example 2°C/W.

It can be seen that with a heatsink of 2 °C/W and 20Amp, the ambient temperature should not exceed 43°C (P3). By using a heatsink of 2°C/W and an ambient temperature of 30°C the maximum current could reach 25 Amperes (P4).

It is to be pointed out that such determination is performed when permanent operation is involved.

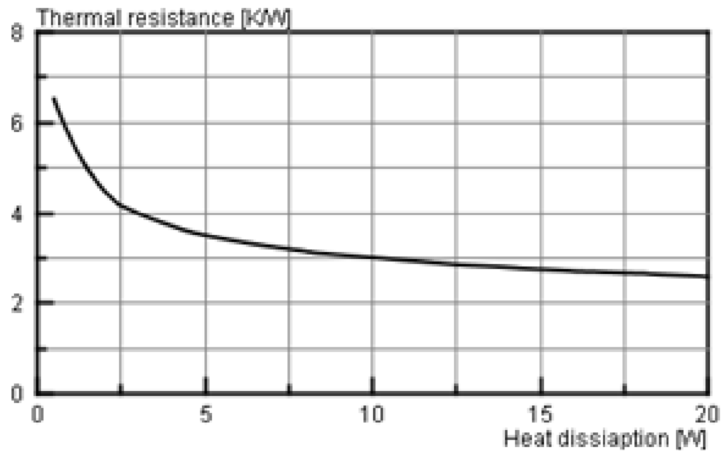
For intermittent uses duty cycle < 1, the mean power dissipated can be considered or use the «Power Dissipated» curve with the suitable duty cycle (in the above example: duty cycle = 0.5). This is only true if the duty cycle remains greatly inferior to the thermal constant of the heatsink. You must watch out for the pre-heating time of machines which may correspond to permanent operation. The Y axis of the right graph curve provides the maximum case temperature of the SSR (max T_{case}) in function of the power dissipated.

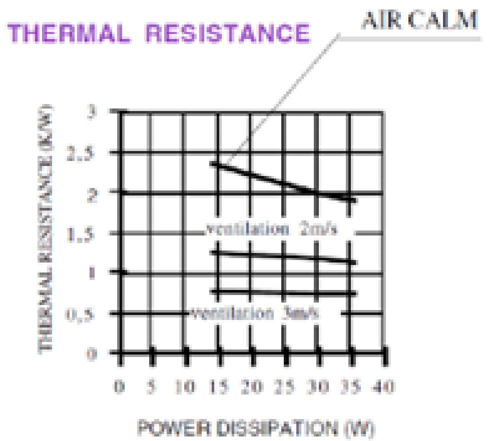
<u>Exemple:</u> for a mean P_D = 40W ==> T_{case} must not exceed 85°C.

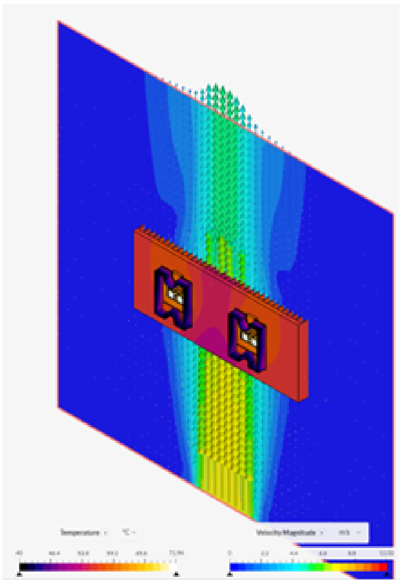
It is very important to understand that values specified in the thermal curves are those from heatsinks qualified by **celduc® relais** with the condition of use with our SSRs. The given thermal resistance is therefore a real value that guarantee the adequate heatsinking of the device.

The heatsinks characteristics that play a relevant role for the thermal resistance within corresponding data sheet are shown below.

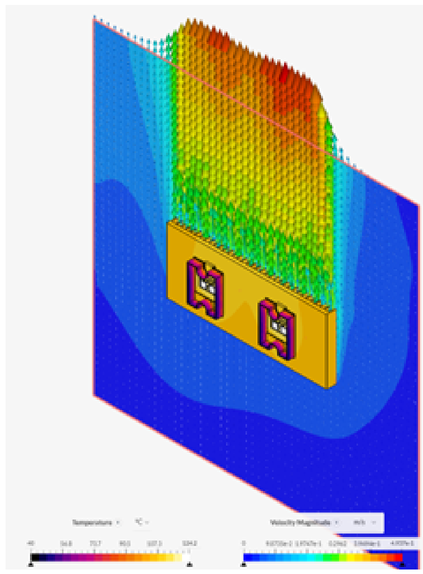
PFor instance, on below thermal simulations examples (fig. 27), 2 SSRs managing a load of 37 Amp each (44 Watts), mounted on the same heatsink, can have a different behavior in terms of thermal efficiency under Natural Convection (no induced airflow) and Forced Convection (induced airflow of 53 CFM through a 90mm fan), in consequence a large difference on $R_{\theta CS}$ value is observed for the same heatsink, since the airspeed is considerable higher on the forced convection scenario, so the heat removal ratio is much better.







Forced Convection $R_{\theta CS}$ 0.23°C/W



Natural Convection $R_{\theta CS}$ 0.81°C/W

Fig. 27

The case to heatsink ($R_{\theta CS}$) parameter is necessarily included in the determination of heatsinking because it is user controlled and can seriously limit the heat sink effectiveness. By following the prescribed technique of mounting the SSR on a smooth heat sink surface and using thermally conductive compound or pad, the value of $R_{\theta CS}$ will be small (around 0.1°C/W or less), thus allowing the use of a minimal heat sink. A value for $R_{\theta CS}$ pcan be found by measuring the differential temperature between case and heat sink (T_c - T_s) and dividing it by the junction dissipation (P watts):

$$R_{\theta CS} = \frac{T_c - T_s}{P}$$

Confirmation of proper heat sink selection can be achieved by actual temperature measurement on the case (metal base plate) of the SSR. Under worst case conditions the temperature should not exceed the maximum allowable case temperature shown in the right hand vertical scale of fig 27.

As a general rule, a heat sink with the proportions of the 50mm length of extrusion (curve (a)) is suitable for SSRs rated up to 10 amperes while the 100mm length will serve SSRs rated up to 20 amperes. For power SSRs with ratings greater than 20 amperes, a heavy duty heatsink becomes necessary. Not all heat sink manufacturers show their characteristics in terms of degrees °C/W; some show them as a temperature rise above ambient. In this case, a value for $R_{\theta CS}$ is found by dividing power dissipation (watts) into the temperature rise (°C).

If an SSR installation does not provide an adequate heat sink, a selection is made from the wide variety of commercial heat sink types that are available. Each configuration has its own unique thermal characteristic and is usually well documented with manufacturers' performance curves and applications data. Much useful thermal information is available from this source, including such details as mounting multiple units on a single heat sink. Most of the models are made from extruded aluminum. By using a search engine, many manufacturers are displayed.

It is very important to understand that if the final user bases his choice of the heatsink only based on the value of thermal resistance, must be advised that such selection is not simple and might be a source of confusion, as it can be considered as the right choice. For a better selection, one alternative is to ask the manufacturer to run basic simulations or even perform tests in real conditions directly on the application if possible.

V/ Special and Advanced Relays

A/ Interface Module SSR

These are input and output modules designed for control interfaces. The I/O module is a specialized type of solid-state relay designed specifically to meet the demands of the industrial control market. Solid state relay technology has a ready to use tool for interfacing modern computerized machine and process controllers with their respective loads and sensing switches. Solid state I/O modules are a benefit from the advances made in SSR technology, in the areas of circuit integration and automated assembly. While a number of different I/O package configurations appeared initially, they are now reduced to basic types, to provide standardization that is taking place in both physical and electrical parameters among manufacturers.

Most I/O modules are self-contained, and some include power terminals. They can be mounted individually or plugged into a mounting base (up to 24 modules for instance). The mounting base, which may also be used to accommodate power terminals and peripheral components, completes the wiring to these components, together with individual data traces and common bussing to the controller via a connector and single cable. The pinout is generally compatible with a number of manufacturers'. Some manufacturers offer adapter cables to expand their application capability. Others offer remote control systems for communicating over long distances. Each module contains all the necessary circuitry to provide complete interface between controller and load without the need for further design or additional circuitry.

To simplify assembly and field maintenance, modules are color coded and marked according to function. All modules are photo-isolated for electrical isolation (typically 1500 to 4000 volts RMS) between sensitive logic circuits and power lines, and have single (SPST) outputs. Multiple pole and special functions are not included since they are more easily configured in the processor logic, thus allowing for standardization and economies in the interface system.

There are mainly 4 On/Off types available:

- AC output modules
- DC output modules
- AC input modules
- DC input modules

1. Output Modules

Output modules are similar in function to conventional AC and DC solid-state relays. The types that are generally available can handle most power-switching applications found in machine and process control, up to 3 amperes at 40°C, AC or DC. Unlike input modules, standard output modules have four terminals (no logic supply requirements), with the internal or external status indicator driven by the control signal itself, usually in series with the positive terminal.

Driven from low-level logic command signals, output modules are designed to control power to loads such as motors, valves, and heaters, and generally include a high degree of noise rejection and transient voltage suppression. AC versions also include zero voltage turn-on to reduce surges and the generation of electromagnetic interference, as well as zero current turn-off, an advantage when switching inductive loads. Snubbers and filter components provide improved commutation and dv/dt performance and further improve immunity to transients and noise. DC outputs usually include a Zener diode for transient voltage protection.

2. Input Modules

Input modules are unique devices as those perform a reverse relay function in returning information from field contacts and loads to the control source. Through debounce and noise suppression circuitry, the modules convert power-level field control signals into electrically clean logic-level signals suitable for microprocessor and controller inputs. Input circuits include rectification and filtering of AC signals, and current limiting for DC signals to permit a wide range of control voltages and improved coupler lifetime. After being conditioned, the signals are photocoupled through driving stages to an open-collector logic output.

The open collector output can usually sink sufficient current to allow direct interface with any logic family operating within the voltage range of the output transistor. A third terminal in the output provides access to the logic supply for biasing purposes and for the open-collector output function. The LED status indicator, which is also in series with the logic supply, can either be an integral part of the module as shown, or installed on the module mounting board. The input signals, derived from limit switches, loads, thermostats or pressure transducers are used by the computing logic in its decision making process. In a programmable controller, this process might determine the sequence, timing, or accept / reject decisions, from which predetermined commands that ultimately drive output modules can be generated.

The new generations are fully compatible with commercial electromechanical relays. The condensed packaging and mounting board stacking permits the use of smaller enclosures. They have the advantage of replacing them along with all the assets of solid state relays. For instance, the SLA/SLD range is compatible with Siemens / Schrack / Finder relays RP/RT type.

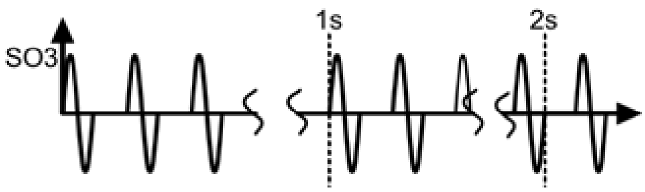
B/ Advanced SSR

celduc® relais portfolio offers more sophisticated relays as standard models such as analogical control:

- 0-10 VDC
- 0-5 VDC
- 4-20 mA
- Potentiometer
- PWM

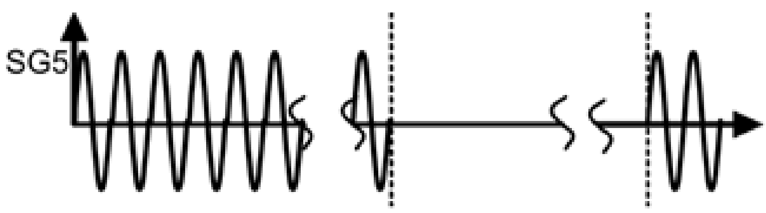
a) Full cycle fast burst control

For loads with an average time constant (IR lamps). Cycle time depending on mathematical calculations to avoid flickering problems.
Comparison for a setting at 50% :



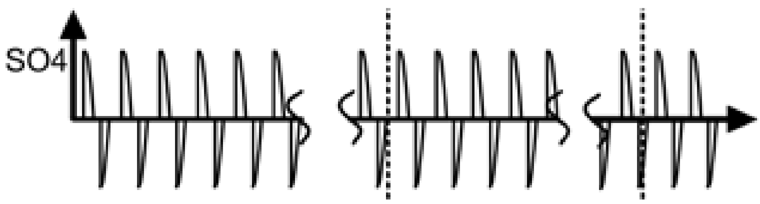
b) Full wave pulse control

Mainly for loads that react slowly regarding voltage variation (ovens, heating elements for plastic processing machinery).



c) Phase angle control

Mainly for loads that react quickly in function of voltage variation (lamps, motors for conveyors, actuators, compressors).



C/ Special, power electronic SSR, diagnosis & control modules

celduc® relais has the special asset of being able to meet with customers' specific requirements, hence the development of special relays. Few examples are:

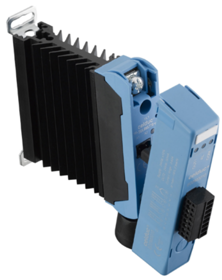
- **Current control relay:** The relay is controlled by the current (i.e. 6ARMS) instead of a voltage control.

- **AC/DC self-protected relays** (short-circuit , temperature and diagnostic)

- **Battery cherger choppers, power choppers up to 600kW**

- **ECOM module:**

-Communication through MODBUS RTU
-Can be used as a proportional controller (variable time duty cycle)
-Brings full diagnostic (Load, SSR, Fuse, Temperature)
-Use on standard SSR of the SU series



- **EIRC module**:

-Detection of external faults in the load circuit < 250ms or overvoltage/undervoltage/frequency out of range
-Modular heating control system in a low profile case
-Heating unit for a maximum of 12 IR Channel
-«Fast burst» firing method. U^2 type mains power variation correction (syncopated)
-Built-in protection using fuse
- Control using Profibus DP
-Prevents inrush currents when heating elements are switched

VI/ Reliability and Conformity

A/ Product architecture influence on reliability

Mounting technology (Competitors) => The «Standard» technology used by the majority of solid-state relay manufacturers, consist of conventional ceramic substrate and cathode connections known as «jumpers»: see mounting technology below (Fig. 28).

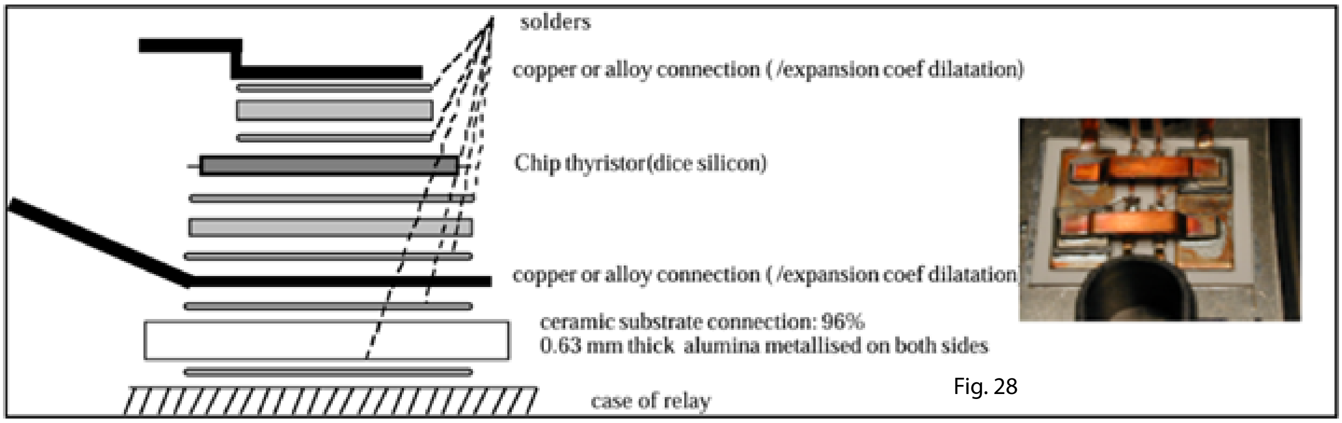


Fig. 28

This technology has the disadvantage of cumulating the number of layers with the increase of the junction/ case (Rthj/c), thermal resistance, of being limited in thermal stress (number of cycles according to the variation in temperature) and being difficult to automate (process reliability).

celduc® relais uses the most modern of technology for these solid state relays **DBC + WB (Direct Bond Copper + Wire-Bonding**). CMS, POWER HYBRIDS with technology DBC, which consist in thick layer of copper (usually 0.4 mm) directly imbedded onto the alumina substrate through a high temperature (approx. 1100°C) diffusion process (Fig. 29). It reduces the thermal impedances, and mechanical stresses due to a lower difference in temperature between the junction and the heatsink boosting an increase in the lifetime. The optimization of power element platform, newest technology and enhanced thermal dissipation drive to a maximum Power / Dimension ratio (Power Density). The future of power packages (MACROMODULES) is promising, thanks to the ability to integrate THE ELECTRONIC FUNCTION ON DEMAND with the advantage of a robust molded case. The use of this technology along with ASIC technology or microcontrollers allow the evolution of electronic selector switches Intelligent Devices with additional functions such as self-protection through diagnostics capabilities and communication with the peripheral equipment..

1. Insulating material and a layer of copper on each side.
2. Copper layer is applied by a diffusion process penetrating the ceramic giving rise to a very thermal homogeneous material.

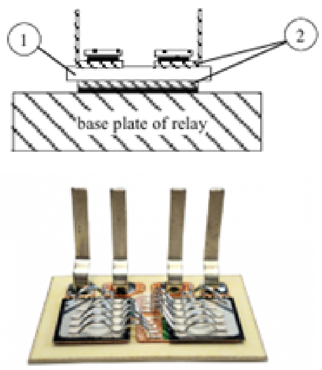
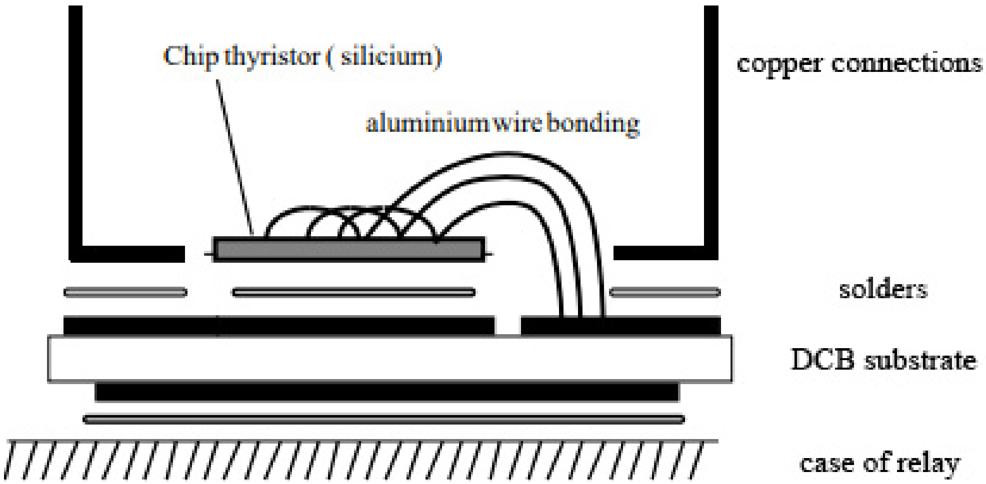


Fig.29 : DBC + WB (Direct Bond Copper + Wire-Bonding)

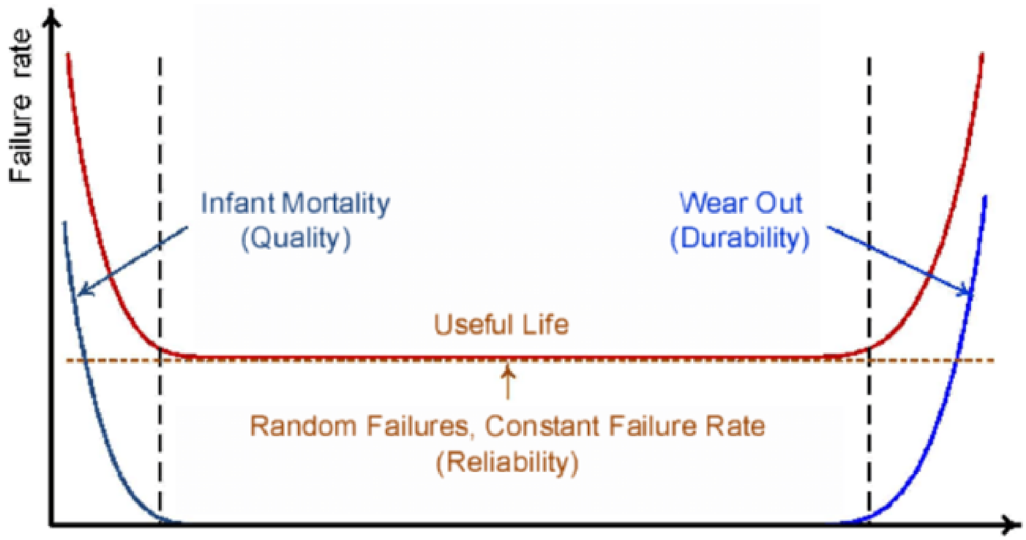
Thermo-Mechanical Stress Solution technology (TMS^2), the copper bridges are replaced by a multitude of bonding wires with several anchor points to withstand significant overload currents, which brings the following advantages:

- Well improved thermal resistance.
- Thermal stress divided by 2 or 3.
- Simplified mounting, with automation giving rise to total control of the production process.



B/ Reliability Testing, MTTF and expected operation life

The lifetime of a solid state relay is very high, if the device is used under correct operating conditions like specified voltage range, current and environmental conditions, the life expectancy is greatly higher compared to an electromechanical relay (no wear on the contacts becomes «virtually unlimited»). The «Bathtub Curve», simplified graphical representation of failure rate change over time is shown below.



Based on this model, over the years **celduc® relais** has taken in consideration next aspects to identify critical components and functional blocks:

- Use available data from previous design and analysis
- Establish base condition for component
- Define performance modes in terms of past levels of unsatisfactory performance
- Calibrate models to experience
- Model reasonable design scenarios and alternatives

SSR reliability is primarily related to the thermal fatigue (Irelated to adequate match of the relay with heatsink or heat removal platform, dark blue curve above) **and ageing of the optocoupler.** Over the past decades, electronics have progressed by leaps and bounds when it comes to reliability and components such as optocouplers now have a very high life expectancy. (**celduc® relais** exclusively uses Quality optocouplers with MTTF > 2 x 106 hours or 228 years).

Regarding thermal fatigue, **celduc® relais** has an extensive experience in the power field and provides a reliability curve of number of switching operations according to the variation in temperature based on most relevant factors:

1. Increase Average Strength: This approach is tolerable if size, weight, and cost increases can be accepted or if a stronger material is available.
2. Decrease Average Stress: Occasionally the average allowable stress on a component can be reduced without greatly affecting its performance.

3. Decrease Stress Variation: The variation in stress is usually hard to control. However, the stress distribution can be effectively truncated by putting limitations on use conditions.

4. Decrease Strength Variation: The inherent part-to-part variation in strength can be reduced by improving the basic process, holding tighter control over the process, or by utilizing tests to eliminate the less desirable parts.

The technology used is very relevant, so as close as temperature of the junction is from the temperature of the heatsink and the ambient the better, since every switching action subjects the thyristor chip to a variation in temperature due to local heating on the chip related to different factors, depending on the type of load, different scenarios of can be observed:

- This temperature variation is a resultant of the switched current linked to the load.

Examples below:

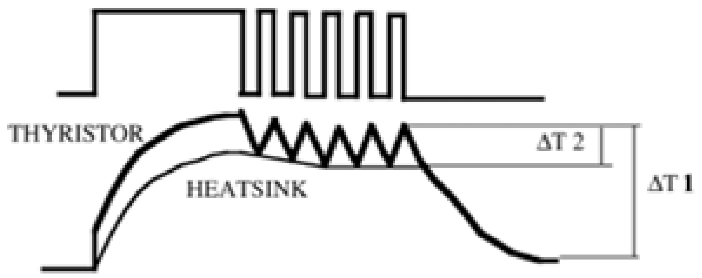


Fig. 30. Variation in temperature on a resistive load with significant amplitudes in the preheating phase (ΔT1), then less in the regulation phase (ΔT2).

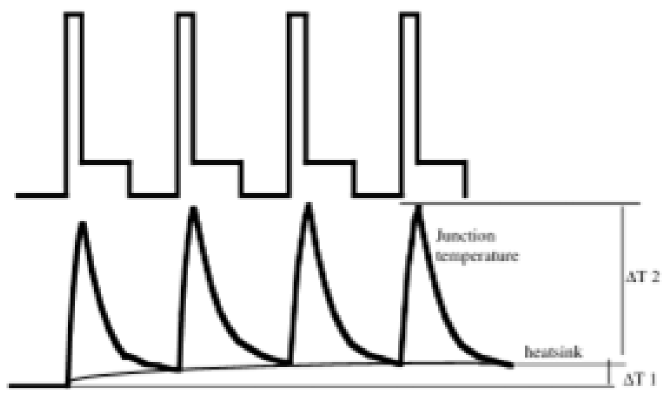


Fig. 31. Variation in temperature on a motor with significant variations (ΔT2) on every start-up due to starting currents capable of reaching 8 x In for 1.6s.

- The amplitude of this variation is also due to the quality of the thermal resistance $R_{thj/c}$ between the junction and the heatsink (or case). Thermal impedance / non-stabilized temperatures, DCB technology ensures a very significant reduction in this $R_{thj/c}$.
  The difference in temperature between the junction and the heatsink (case) is directly related to the thermal impedance and the power dissipated: $\Delta T_{j/c} = R_{thj/c} \times P_D$ (The heatsink stays at a fairly constant temperature during normal operation).

- The size of the silicon chip used determines the surface area of the silicon is of relevant importance. The bigger the chip, the lower power dissipated determined by:

$$P_D = 0.9V_t \times I + rt \times I^2$$

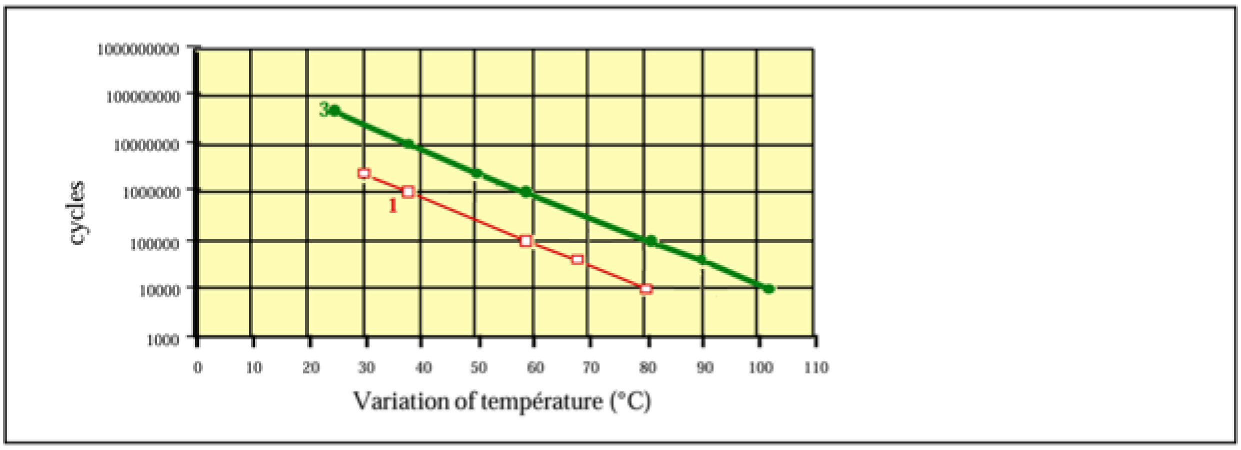
Where the dynamic resistance «rt» drops on a larger chip ;

The junction / case thermal resistance ($R_{thj/c}$) is also inversely proportional to the surface area of silicon chip in contact with DBC ($\Delta T_{j/c} = R_{thj/c} \times P_D$).

This is why **celduc® relais** uses sufficiently-sized chips, for example for a relay of 50A : chip size of a thyristor: 7.2 x 7.2 mm when compared to competitors' chips of 6.3 x 6.3 or 5.8 x 5.8mm, not as expensive but not as efficient either.

- The size of the heatsink is also important. **celduc® relais** complies with European standards related to max ΔT dof the heatsink of 50°C for an ambient temperature of 40°C. These variations in temperature rise to thermal expansion constraints which are all the more severe when the materials used greatly differ. The technology used in the **celduc® relais** relays provides the best connection materials with harmonized expansion characteristics.

It is not easy to verify the life expectancy of power components (mainly due to low variations in temperature) as very long tests are involved. The majority of our tests are performed for ΔT = 80 °C with permanent monitoring. The SSR is mounted on a heatsink with a very low R_{th} < 0,2 K/W, meaning the temperature of the heatsink is practically constant. Current pulses are sent to the SSR to reach: $Rt_{hj/c} \times P_D = \Delta T_{j/c}$ desired. EExample for a relay of 50A: Test was performed with 100A/1s «ON» then 7s «OFF». The results are given in the curve below.



curve N°1 : technology found in the majority of solid state relays on the market.

curve N°3 : **celduc®** technology with DCB + bonding.

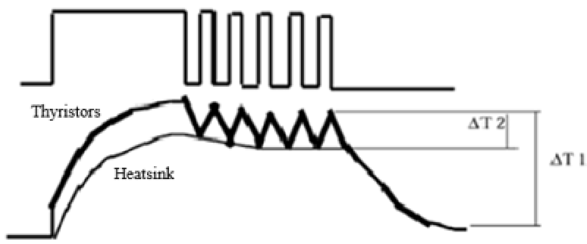
Fig. 32 : Number of cycles in function of ΔT

celduc® relais specifies the curve of the number of switching operations according to the variation in temperature (Fig. 32). For the majority of applications, the variations in temperature (particularly in control mode) are low: ΔT < 15 °C with a high number of switching operations. On loads with repeated surges, an oversized relay rating is preferred to increase life expectancy.

Application Examples

- <u>**Example 1**</u> – Professional cooking oven heating application: I AC-51 = 32A under 400 VAC => **celduc® relais** offers a 50A relay mounted on heatsink of 1.5 K/W in order to comply with the IEC947-4-3 standards which give a rise in temperature of the components that can reach a maximum of 50°C at a ambient temperature of 40°C. => Competition offers a 50A relay mounted on a heatsink of 1.9 K/W (bigger weight and volume) in order to limit the junction temperature to maximum limit of 125°C

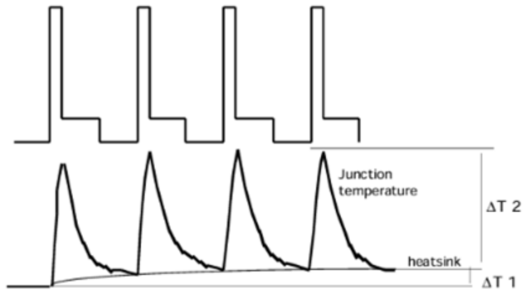
Characteristics	**celduc®** 50Arelay	competitor's 50 A relay
Chip size	7,2x7,2mm	6,3x6,3mm
Technology	«DCB+Bonding»	«standard»
V_{to} (typ. mesured)	0,9V	0,9V
rt (typ. mesured)	7m Ω	8m Ω
P_d@32A=0.9VtxI+rt+I2	33W	34W
Rthj/c (typ)	0,3	0,4
Rthd (Rth heatsink)	1,5	1,9
ΔT1(*)=Rthj/c+Rthd)xPd+2	80°C	98°C
ΔT2=Rthj/cxPd	10°C	13,5°C
** calculation made at initial room T=20 °C, then rise of room temperature up to 40 °C*		



By referring to the thermal stress curves, the latest generation **celduc® relais** SSR could withstand a very high quantity of thermal cycles in regulation mode (ΔT2 = 10 °C) and over 100,000 preheating cycles with ΔT1 = 80 °C. For the competitors' product with ΔT2 = 13,5 °C and especially ΔT1 = 98 °C, the number of cycles is much more limited: less than 2,000 preheating cycles.

- **Example 2** - Motor application I AC-53 = 8,5A under 400 VAC three-phase ==> Adhering to the IEC947-4-2 standards which give a starting current of 8 x In for 1.6 seconds ==> For an I AC-53 current of 8.5A, **celduc® relais** offers a 50A relay.

Characteristics	**celduc®** 50Arelay	competitor's 50 A relay
Chip size	7,2x7,2mm	6,3x6,3mm
Technology	«DCB+Bonding»	«standard»
V_{to} (typ. mesured)	0,9V	0,9V
rt (typ. mesured)	7m Ω	8m Ω
P_d@8x8,5A=0.9VtxI+rt+I2 on starting per channel	87W	92W
P_d@8,5A=0.9VtxI+rt+I2 in operation per channel	7W	7,5W
Rthj/c (typ) (=Zthj/c pour t=1,6s)	0,3	0,4
ΔT1(*)=Pd@8Ax(Rthd+Rthj/c)	low	low
ΔT2=Rthj/cxPd @8x8,5A	26°C	37°C



Referring to the thermal stress curves, the latest generation **celduc® relais** SSR can withstand a very high quantity of starts: ΔT2 = 26 °C, meaning over 40 x 106 switching actions. For the competitors' product with ΔT2 = 37 °C, lthe number of starts would be much more limited, less than 1 x 106 switching actions, so not suitable for high output motor applications. Hence the advantage of using a well-sized semiconductor and DBC + Wire-Bonding technology.

- **Example 3** – HVAC heating application I AC-51 = 37A under 480 VAC three-phase; Ambient temperature: 40°C ==> SSRs are mounted to an aluminum plate and the heat sink is mounted to the same aluminum plate of the opposite side, thermal paste is applied to both ==> Force convection source 500mm below the SSR through a 27 x 222 mm shaft to direct all airflow (approx. 52 CFM or 88m3/hr.) across the full width and fins height of the heatsink.

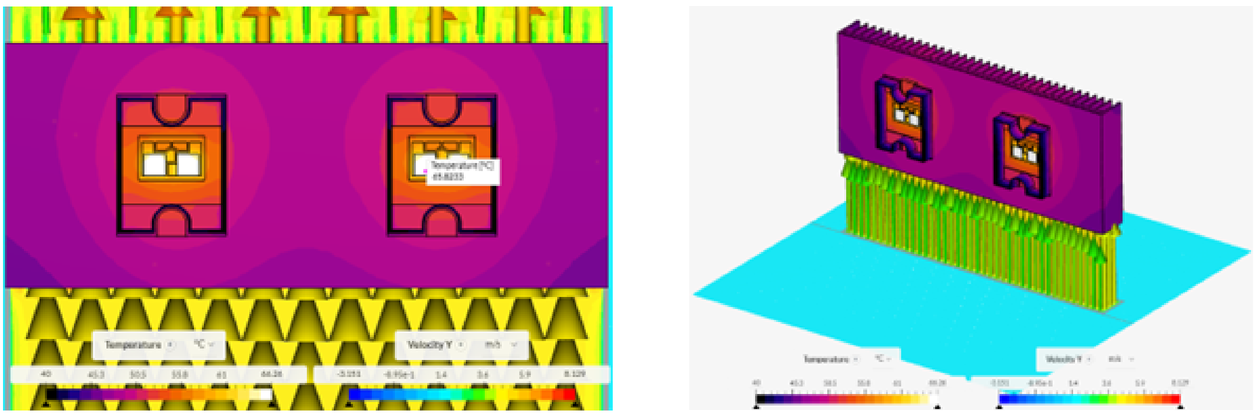
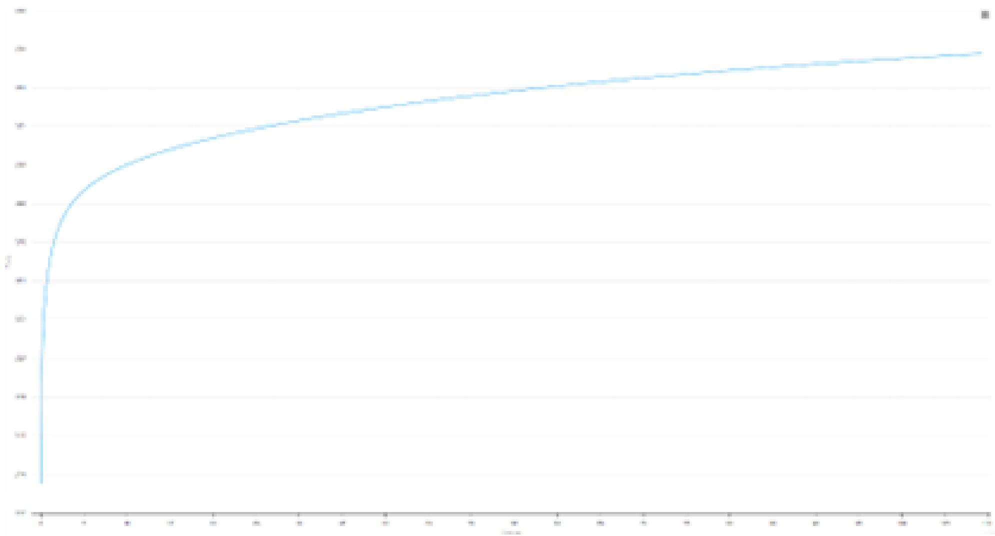


Fig. 33

Existing life expectancy data indicates that number of operational cycles of an SSR is directly related to the max temperature reached by the power element (Fig. 33) so, the bigger ΔT between thyristors and ambient temperature, the larger degradation of the device.
Under forced convection conditions, supplying a powerful airflow induced by the ventilation source (52 CFM), a ΔT de 26 °C is observed, so it is expected that SSR's number of cycles will be in the order of 65 million, but also considering that highest temperature increase happens in a period of 10 seconds (above graph), it means that the maximum cycles of 10 seconds per day possible are 8,640 if the system operates 24/7, so the expected years of service are approximately 20.6 years, this, if there are no external factors to which the SSRs are subjected such as recurrent overcurrent / overvoltage events, excessive inrush current periods or over heating induced from external sources, which will have a negative effect on the life expectancy of the SSR.



Under forced convection conditions, supplying a powerful airflow induced by the ventilation source (52 CFM), a ΔT de 26 °C is observed, so it is expected that SSR's number of cycles will be in the order of 65 million, but also considering that highest temperature increase happens in a period of 10 seconds (above graph), it means that the maximum cycles of 10 seconds per day possible are 8,640 if the system operates 24/7, so the expected years of service are approximately 20.6 years, this, if there are no external factors to which the SSRs are subjected such as recurrent overcurrent / overvoltage events, excessive inrush current periods or over heating induced from external sources, which will have a negative effect on the life expectancy of the SSR.

C/ Safety standards

All industrial devices must comply with certain rules and regulations, and SSRs are not an exception. **Standards and regulations are required to ensure that such devices are safe to use and operate when proper installation and operative procedures are observed.** Next is an overview of which international standards and regulations must be used during the design and assembly of SSRs and related products, so those can be used in worldwide regions:

- Underwriter Laboratories (UL) -USA-
- Canadian Standards Association (CSA) -Canada-
- TÜV -Germany-
- VDE -Germany-
- CCC -China-
- UKCA -UK-
- International Electrotechnical Commission (IEC)

These agencies develop certain sets of rules and standards whose aim is to:

- Ensure that devices designed and built according them regulations will operate reliably and safely
- In complex systems, that the devices will interoperate among themselves
- In case of a device failure, the consequences of the failure will have limited or null impact over other systems and/or the users
- Standardize the quality of the products and systems
- Ensure that devices manufactured in any location can be commercialized and used in other regions/ countries

All **celduc® relais** products are manufactured and designed in compliance with ISO 9001 process regulations to guarantee optimum quality. The «CE» marking is an internal procedure aimed to allow free circulation of products within the European Community. It should be marked on the product, packaging and/or the documents enclosed with the product. In order to show the «CE» mark, the product must be covered by one or more directives. The following directives may apply:

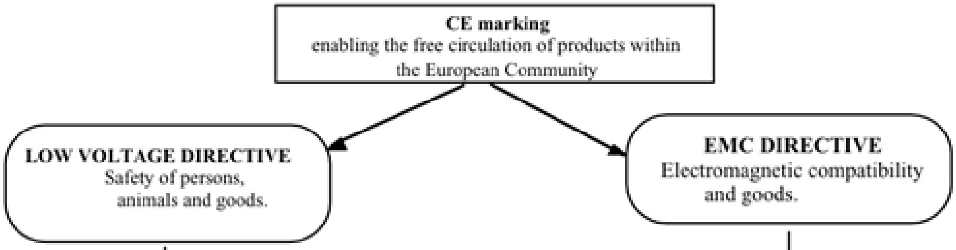
- EMC directive
- Low voltage directive

Electromagnetic compatibility (EMC) rules in effect in the European Community. This implies that electrical

/ electronic devices must be able to withstand certain degree of EM emissions from the environment and they do not emit EM radiation beyond certain levels that could interfere with nearby devices.

CE mark is "self-certified", that is, manufacturers make an statement ("Manufacturer's declaration of Conformity") which must be available to European Authorities should they request it. This is different with respect the previous certification bodies, where the manufacturer must submit documentation and samples for testing, in order to ensure the compliance.

The directive lays down the major requirements making reference to harmonized. The certificate of conformity therefore calls upon a standard reference system. The standard reference system for the **celduc® relais** products is structured as follows:



GENERAL STANDARDS (Low Voltage Directive)

	REQUIREMENTS				
	Materials	Mechanical	Electrical	Thermal	Flame
EN60950 (10102)		*		*	
EN60947-1		*	*	*	
EN60947-4-2			*	*	
EN60947-4-x			*	*	
UL94					*
UL508	*	*	*	*	
CAN/CSA C22.2N°0	*	*	*	*	
CAN/CSA C22.2N°14	*	*	*	*	

GENERAL STANDARDS (EMC Directive)

	REQUIREMENTS			
	Conducted Emission	Radiated Emission	Conducted Immunity	Radiated Immunity
EN50081-1 Residential	*	*		
EN50081-2 Industrial	*	*		
EN50082-1 Residential			*	*
EN50082-2 Industrial			*	*

TEST STANDARDS

	REQUIREMENTS				
	Conducted Emission	Radiated Emission	Conducted Immunity	Radiated Immunity	Electro-static
EN55022 Cl. B EN55011	*	*			
EN61000-4-2					*
EN61000-4-3				*	
EN61000-4-4			*		
EN61000-4-5			*		
EN61000-4-x					

celduc® relais compliance system is not limited to the European standards, but also to all the international standards, including UL and CSA. Regarding to safe handling of products on industrial environments, **celduc® relais** products and specifications account for the requirements of the different standards, particularly concerning to maximum rise in temperature of the parts which can be touched (50ºC) for permanent operation of 8 hours. This data is important when compared to the characteristics given by the different manufacturers.

Some of UL standards used in our designs are:

- UL 94 => Flammability of Plastic Materials
- UL 746A => Short term properties of Polymeric Materials
- UL 746B => Long term properties of Polymeric Materials
- UL 746D => Fabricated parts Polymeric Materials
- UL 746E => Laminates and Polymeric Materials used in Printed Circuit Boards
- UL 508 => Industrial Control Equipment
- UL 486E => Equipment Wiring Terminals for use with Aluminum and/or Copper Conductors
- UL 1581 => Reference standard for Electrical Wires, Cables and Flexible cords
- UL 60947-1 => Low-Voltage Switchgear and Control gear - Part 1: General Rules
- UL 60950-1 => Information Technology equipment- Safety - Part 1: General Requirements
- UL 840 => Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment
- UL 969 => Marking and labeling Systems

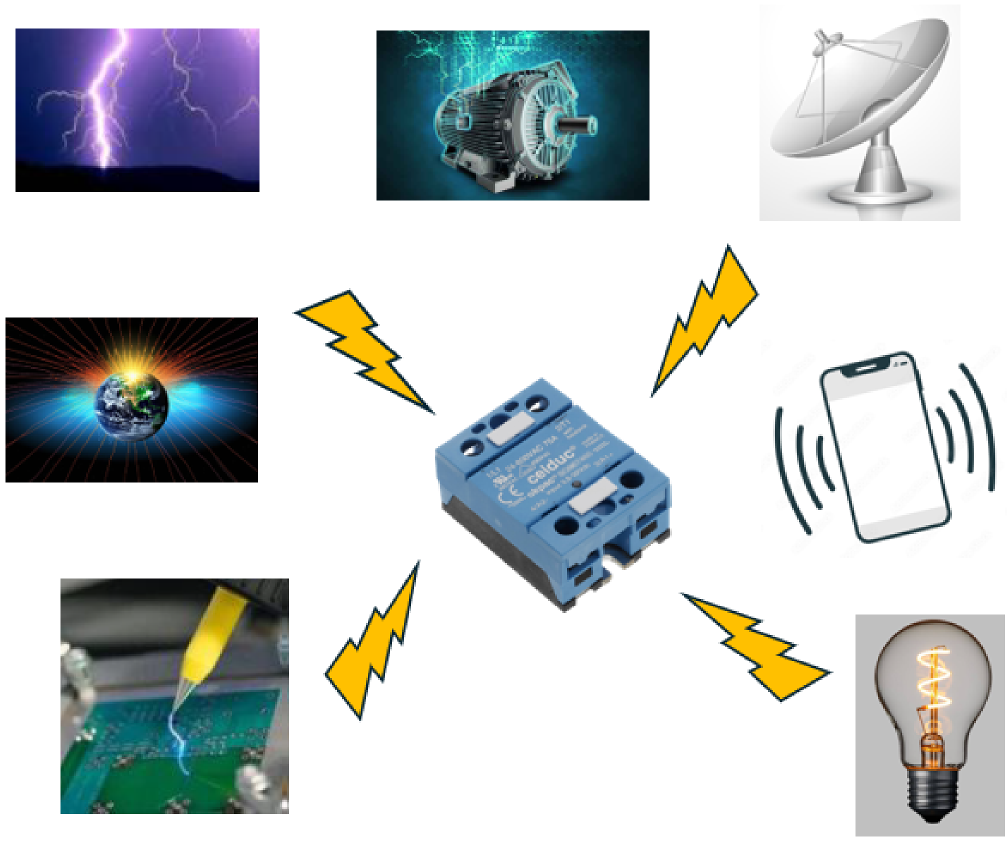
Some of the IEC standards we use and/or test for (related to CE mark and VDE/TUV certification):

- IEC 60335-1 Household and similar electrical appliances - Safety - Part 1: General requirements
- IEC 60664-1 => Insulation Coordination for Equipment within Low Voltage Systems

- IEC 60664-3 => Insulation Coordination for Equipment within Low Voltage Systems
- IEC 60529 => Degrees of protection provided by Enclosures (IP Code)
- IEC 60204-1 => Safety of Machinery - Electrical Equipment of machines
- IEC 60947-4-2 => Low-voltage switchgear and control gear - Part 4-2: Contactors and motor-starters - Semiconductor motor controllers, starters and soft-starters
- IEC 60947-4-3 => Low-voltage switchgear and control gear - Part 4-3: Contactors and motor-starters - AC semiconductor controllers and contactors for non-motor loads
- IEC 61210 => Safety standard for Quick Connect Terminals
- IEC 62314 => Solid-state relays intended for performing electrical operations by single step function changes to the state of electric circuits between the OFF-state and the ON-state and vice versa.
- IEC 61373 => Railway applications - Rolling stock equipment - Shock and vibration tests

D/ EMC Compliance

Electromagnetic Compatibility (EMC) requires that systems / equipment be able to tolerate a specified degree of interference and not generate more than a specified amount f interference towarks other devices (origin might be natural or induced by human activity as shown below):



1. Terms and definitions

- **<u>EMC</u>** – Electromagnetic compatibility. The successful operation of electronic equipment in its intended electromagnetic environment. Encompasses energy generated within or external to the system.

- **<u>EMI</u>** – Electromagnetic Interference. The impairment of operation of electronic equipment from any electrical source, whether natural or man made.

- **<u>Emissions</u>** – Energy emanating from the equipment in question and which may pose a threat to other equipment. May be conducted or radiated.

- **Susceptibility/Immunity** – Energy originating from external sources and interfering with the equipment in question. May be conducted or radiated.

- **RFI** – Radio Frequency Interference. An older, dated term for EMI. At present, refers specifically to radio interference only.

- **Radiated Interference** – interference which propagates through space.

- **Conducted Interference** – Interference which propagates through a conductor.
- **Signal Integrity (SI)** – Maintaining "clean" signals by controlling reflections, crosstalk, ground bounce, and power. SI deals with millivolts and milliamps, while EMI often deals with microvolts and microamps.

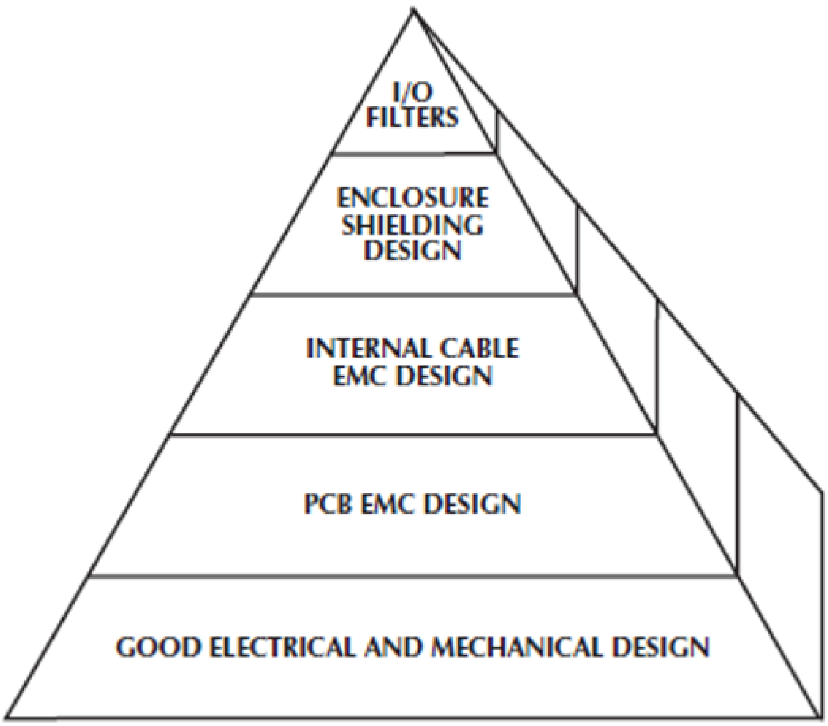
What is required to mitigate such effects:

- Reduce electromagnetic emissions
- Increase immunity to disturbs
- Attenuate the coupling paths with EMC sources

Some enhancements must be implemented on electronic products:

- Anticipate and respect of design rules during circuits design
- Additions of filtering, decoupling, shielding components
- Validation by measurements and simulations
- Get EMC experts advice (researchers, laboratories and agencies)

Good electrical and mechanical design includes reliability considerations like meeting design specifications within acceptable tolerances, good packaging and comprehensive development testing. The engine that drives today's electronic equipment is located on a printed circuit board. The PCB EMC design is the next most important consideration in EMC design. The location of active components, the routing of traces, impedance matching, grounding design, and circuit filtering are driven, in part, by EMC considerations. Certain PCB components may also require shielding.



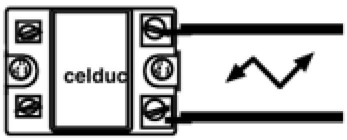
European EMC directive determinates that SSR must not disturb its environment (Emission) and must not be disturbed by the environment (Immunity) where it's installed. EN60947-4-x are reference standards for SSR which describes EMC Tests (Immunity & Emissions). Depending of the applications, specific standards must be in applicable (i.e. EN50121-3-2 for railway applications)..

The required levels and the test methods depend on:

The type of the interference

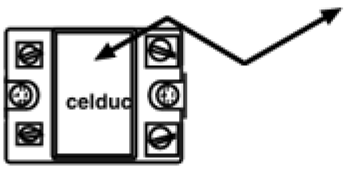
Conducted disturbances

Disturbances are transmitted through the wires



Radiated disturbances

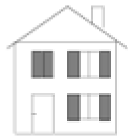
Disturbances are transmitted in the air



Location where the relay will be mounted

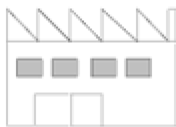
Domestic, commercial light industry

Installation directly connected to the public power network

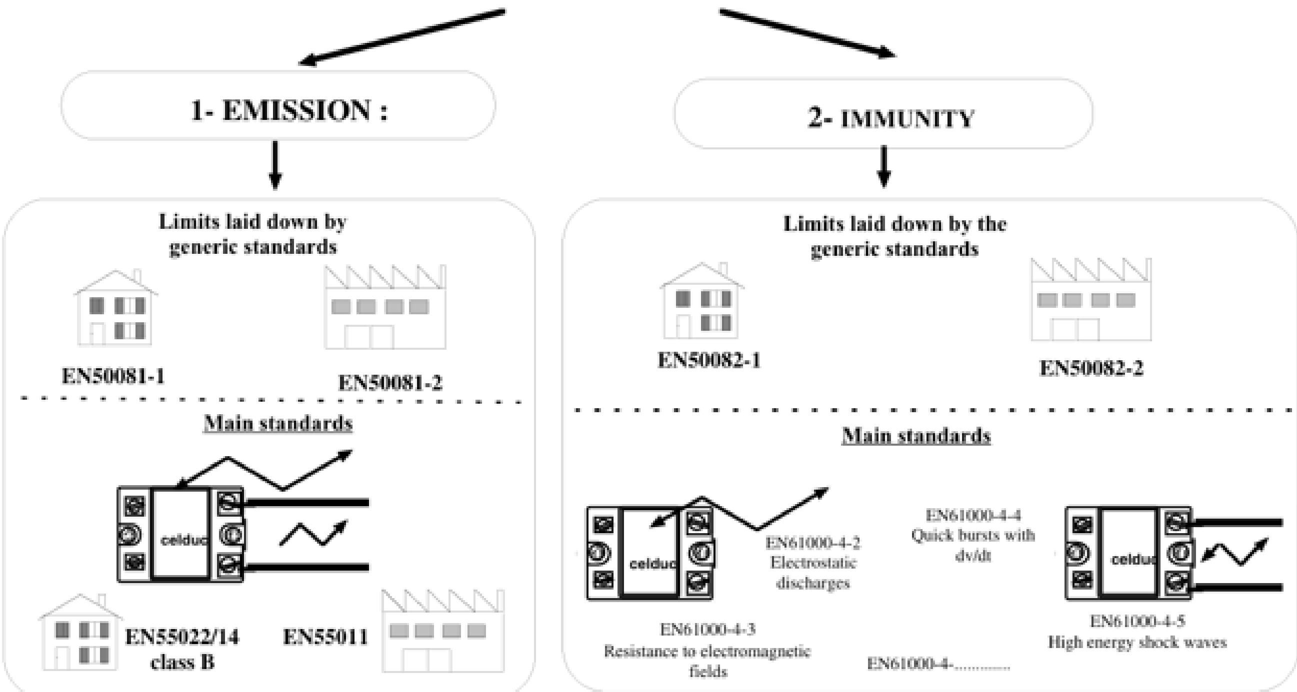


Heavy industry Installation

Installations connected to the public network through a transformer



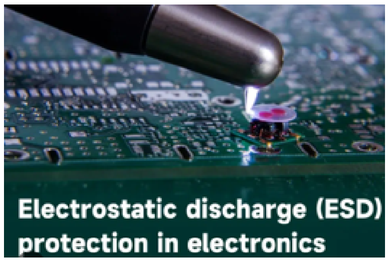
MAIN STANDARDS TO BE ADHERED TO

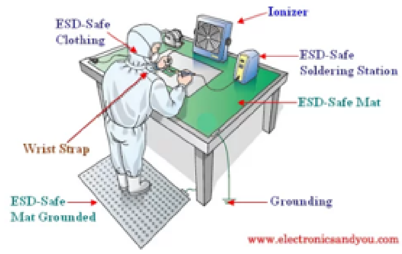


A standard solid state relay might have a conducted emission level greater than the level accepted by the standards. This level is linked to the type of load (mainly resistive) and the current level. **celduc® relais** has proposed conformity solutions and has developed SOFTLIFE technology products, driving an emission level much lower than the levels accepted in the most severe environments such as in domestic and medical applications. It is, however necessary to remark an extract of the standard IEC60947-4-3/ EN60947-4-3, which specifies that it is the responsibility of the system/equipment manufacturer to confirm that subsystems which have installed controllers and contactors meet with the requirements of all levels and regulations applicable. Solid state relays are generally designed for device class A (Industrial). The use of products in domestic environments may produce radio interference. In this case, the user may be called to use additional reduction means, such as external filtering networks.

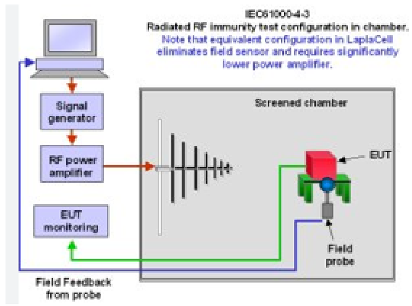
2. Immunity

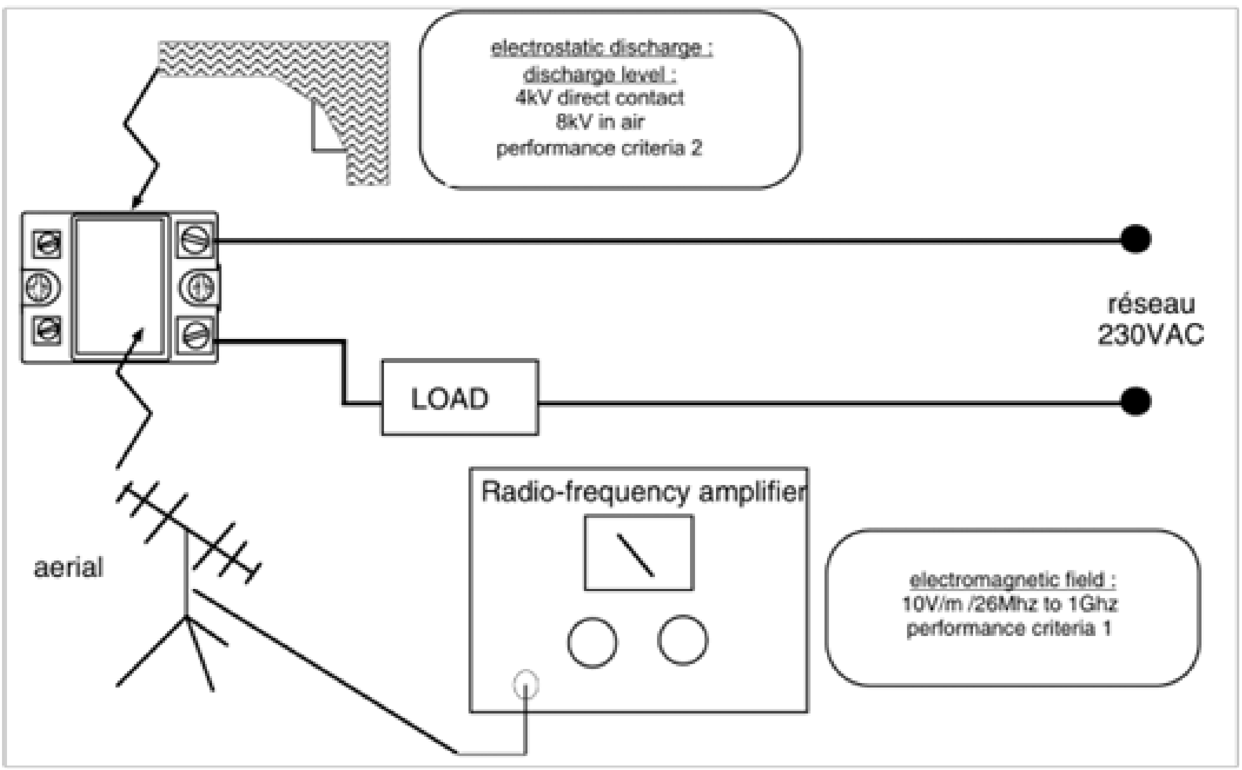
❶ Electrostatic discharge (ESD)
Standard EN/IEC 61000-4-2



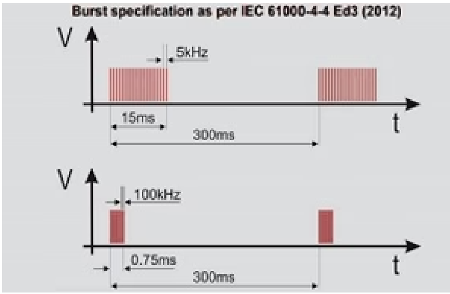


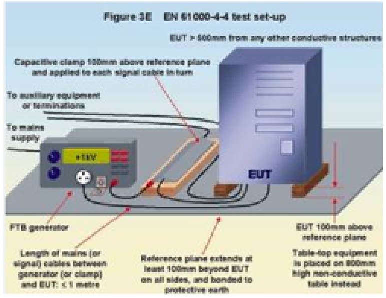
❷ Radiated radio frequency
Sensitivity to electromagnetic
fields Standard EN/IEC 61000-4-3



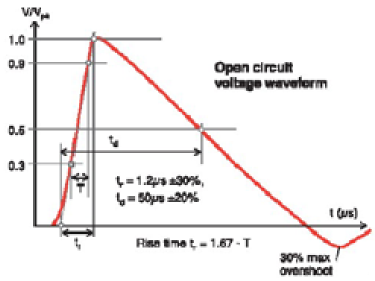


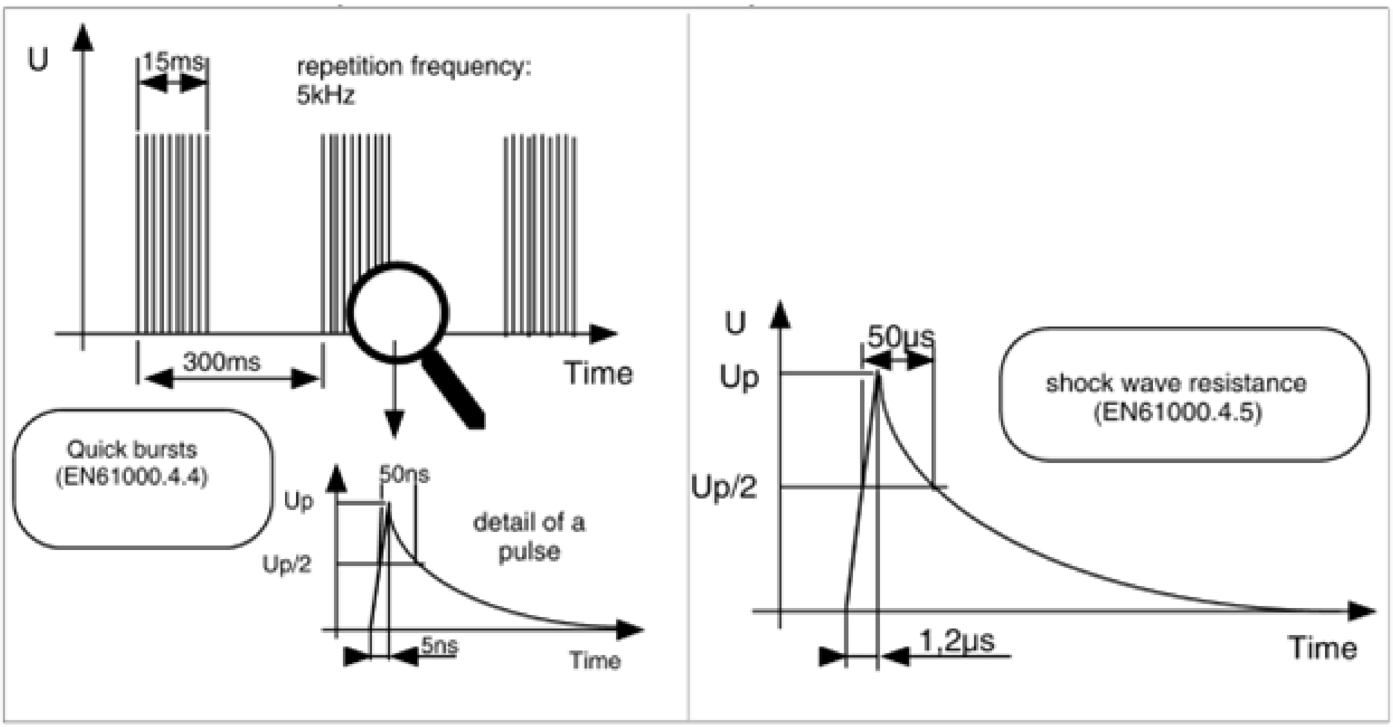
❸ Electrical fast transient (burst)
Standard EN/IEC 61000-4-4





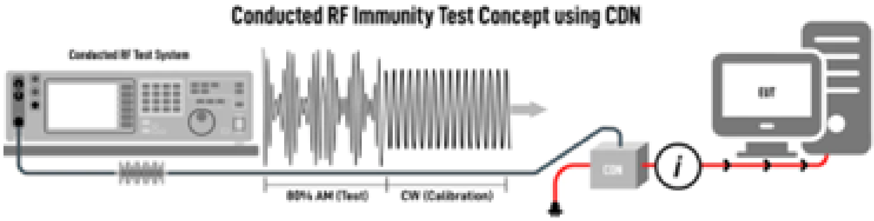
❹ Electrical surge, shock waves
Standard EN/IEC 61000-4-5



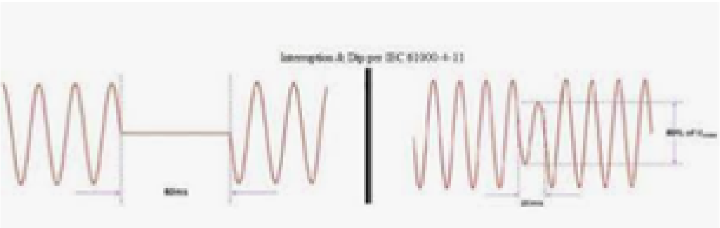


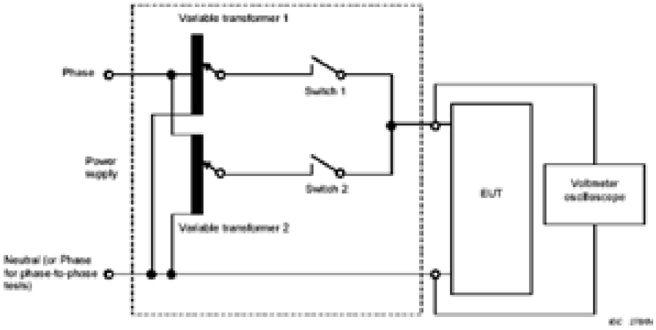
EN61000-4-4 test corresponds to a high dv/dt test. **celduc® relais** relays have a very high immunity level under this conditions. EN61000-4-5 test corresponds to a high energy voltage surge. It's highly recommended the use of varistors to enhance immunity.

❺ Conducted radio frequency
Standard EN/IEC 61000-4-6



❻ Interruption & Voltage dips
Standard EN/IEC 61000-4-11

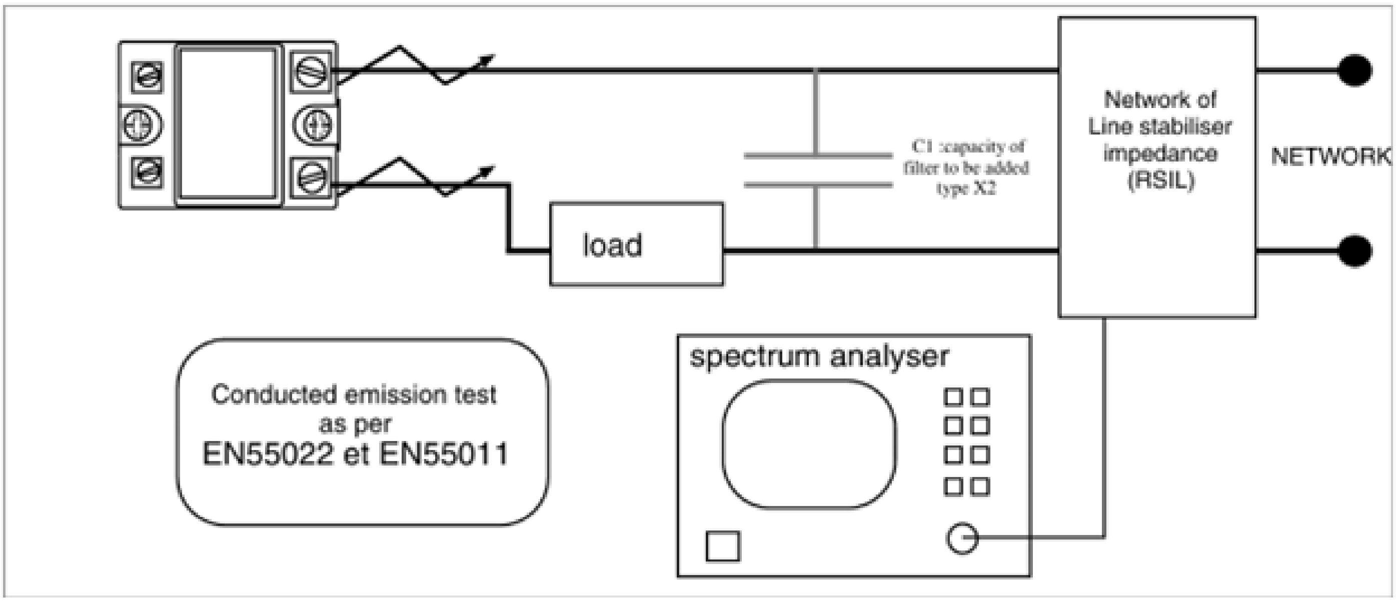




3. Emissions

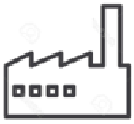
All **celduc® relais** solid state relays have been tested in accordance with related standards: Electromagnetic noise conducted or radiated:

- EN55022 for residential applications: class B
- EN55011 for industrial and residential applications

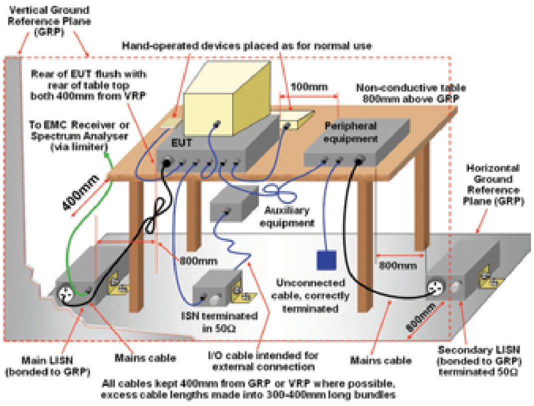


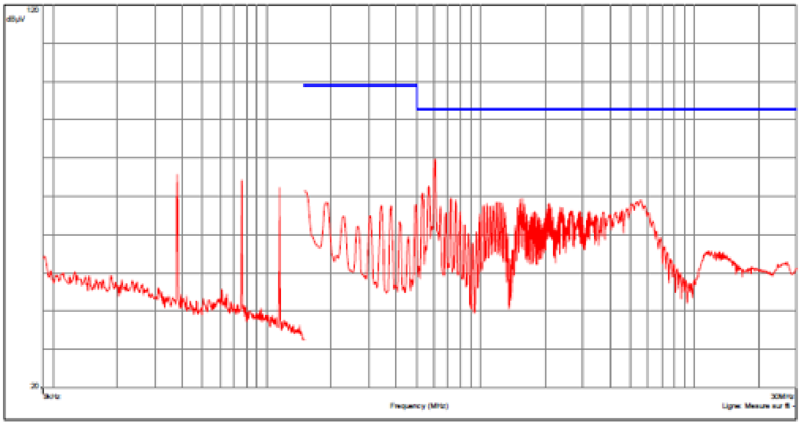
❶ Radio interference field emission (Conducted)

Class A for industrial

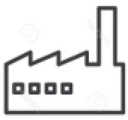


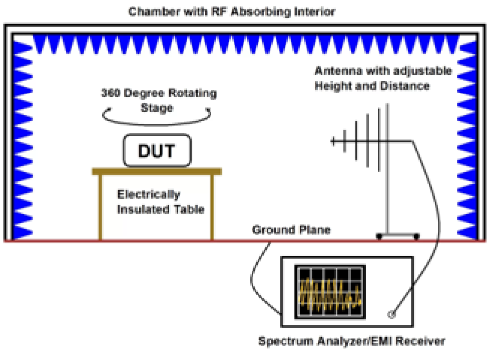
Class B for residential

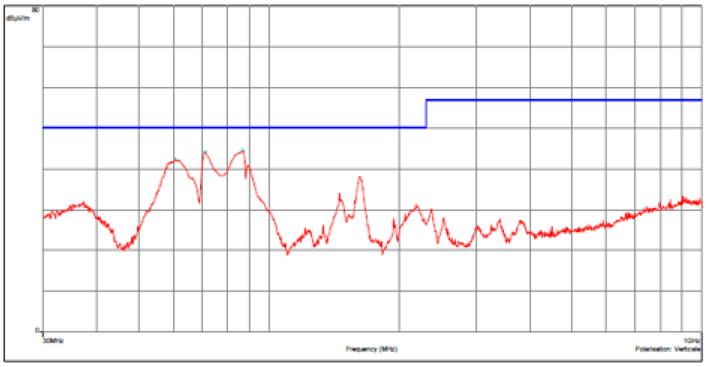




❷ Radio interference field emission (Radiated)





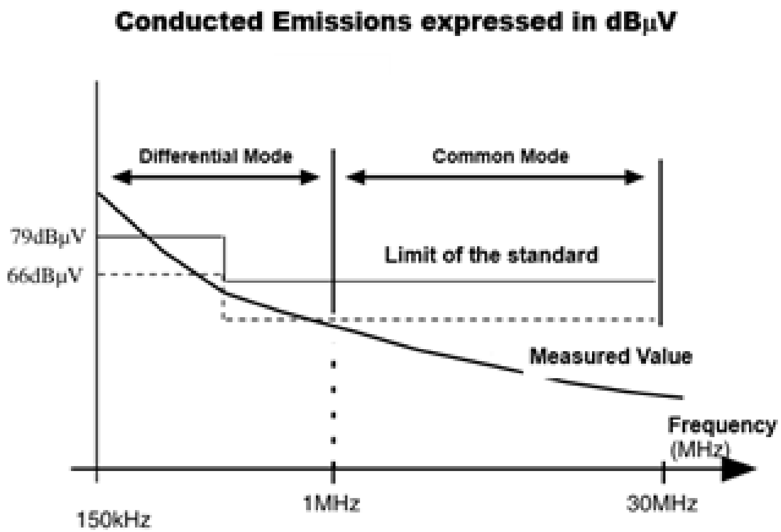


For a solid state relay, the level of radiation must be lower than the levels accepted by the standards

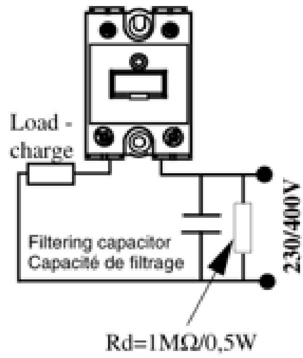
According to limits of the standard, the test must be performed over the frequency range of 150khz to 30Mhz (value measured is expressed in dB V). The limit @150khz for domestic applications is 66dB V and the limit @150khz for industrial applications is 100dB V.

The conducted interference of a solid state relay is evaluated at minimum operating voltages. These arcing voltages are low at **celduc® relais**, solid state relays, however, the levels measured depend on the load and, in some cases, those might exceed the levels permitted by the standard. For such cases **celduc® relais** recommends for domestic applications to add a filter at the mains for resistive loads, a simple X2 type capacitor (see diagram) is required to solve the problem. A parallel mounted discharge resistor is required on this capacity (rd).

The use of low noise SGL family which is built in «SOFT-LIFE» technology, which is recommended particularly for «domestic» applications» when the level accepted is lower, and where the addition of a filter is problematic.



Relay specifications	Filtering capacitor values Class A Industrial: EN50081-2	Filtering capacitor values Class B Domestic: EN50081-1
12A/230V/Charge-load:12AAC1	None @ 100dBµV	1µF / 275V / X2
25A/230V/Charge-load:25AAC1	None @ 100dBµV	2,2µF / 275V / X2
40-50A/230V/Charge-load:40-50AAC1	None @ 100dBµV	3,3µF / 275V / X2
12A/400V/Charge-load:12AAC1	None @ 100dBµV	1,5µF / 440V / X2
25A/400V/Charge-load:25AAC1	None @ 100dBµV	2,2µF / 440V / X2
40-50A/400V/Charge-load:40-50AAC1	None @ 100dBµV	4,7µF / 440V / X2
75A/400V/Charge-load:75AAC1	None @ 100dBµV	Consult Celduc
125A/400V/Charge-load:125AAC1	None @ 100dBµV	Consult Celduc



The best solution is to review and confirm the overall level of the machine or equipment where SSR will be installed. In general, motor type loads remain at a level which is lower than the standard in industrial applications.

E/ RoHS Directive

During last decades there has been a growing concern about the harmful effects of cumulative waste of natural resources and use of toxic substances used in common household and industrial electronic equipment.

RoHS: The Restriction of Hazardous Substances or RoHS was released as Directive 2002/95/EC. This directive aims to protect human health and the environment by restricting the use of certain hazardous substances in new equipment, as well as a complement to the WEEE Directive. It banned after July-2006 the usage of Lead (Pb), Mercury (Hg), Hexavalent Chromium (Cr6), and flame retardants based on Polybrominated Biphenyls (PBE) and Polybrominated Diphenyl (PBDE) Ethers in new Electronic and Electrical equipment, except in certain specific applications where no suitable substitute exists so far. All exceptions considered in this directive are reevaluated every 4 years.

Note: Lead is still allowed only in very low quantities for specific exceptions, but exposure to it must be limited or restricted. The maximum allowed concentration of lead in homogeneous materials is 0.1% (1000 ppm) by weight. However, there are exemptions, particularly for certain applications like lead in solders or lead in glass and ceramics, where higher concentrations are temporarily permitted. Therefore, it's expected to be fully prohibited in the coming years revisions.

RoHS directive was last updated in 2011 and is currently undergoing an evaluation process to assess its effectiveness and identify potential improvements.

F/ WEEE Directives

Waste Electrical and Electronic Equipment or WEEE was released as Directive 2002/96/EC. This Directive aims to reduce the waste arising from electrical and electronic equipment and improve the environmental performance of all those involved in the life cycle of electrical and electronic products. Private householders will be able to return their WEEE to collection facilities free of charge.

Producers (manufacturers, sellers, distributors) will be responsible for financing the collection, treatment, recovery and disposal of WEEE from private households deposited at these collection facilities

Producers will be responsible for financing the collection, treatment, recovery and disposal of WEEE from users other than private householders from products placed on the market after 13 August 2005

Producers will also be responsible for financing the management of WEEE from products placed on the market before 13 August 2005. However, it may be possible for all or part of these costs to be recovered from users other than private householders.

WEEE directive was last updated in 2012 and is currently undergoing an evaluation process to assess its effectiveness and identify potential improvements.

VII/ Testing Solid State Relays

Tests required to verify SSR performance are dangerous and caution actions must be taken, using adequate safety equipment for the personnel conducting such tests. In field testing it should be noted that safety standards controlling power wiring, ducting, etc., are based on local electrical codes that can vary from one location to the next. Possibly the simplest of all field tests that can be made to determine proper function of an AC SSR is by using of a 3-volt battery, a light bulb and a line wire. For precise measurements of specific parameters, such as those made to verify specification limits, more sophisticated test equipment is needed, however, the battery-bulb arrangement is useful for a quick failure analysis.

A more complete performance verification might include to operate the SSR with the intended load, while exercising the system installation functionally through all specified environmental and power combinations. Where this is not possible to conduct an "on-site" test and SSR specification limits need to be confirmed, a general performance test must be conducted by a qualified laboratory. When connecting test equipment directly to the power circuit of an SSR output, protective fusing would be a recommended precaution. Also, with some equipment such as an oscilloscope, the case must be «floated» (ungrounded) and may be at line potential. In some test circuits, an isolated current probe or an isolation transformer can be used to avoid this hazard. The test methods described below are mostly set up for typical DC controlled AC output SSRs using thyristors. DC output or AC inputs SSRs, require slightly different treatment, nevertheless, same general steps might be followed.

By utilizing standard commonly available test equipment, avoid the need for assembling special test circuits. The accuracy of standard laboratory equipment is generally adequate for most SSR testing. Precision equipment may occasionally be required to meet specific user specifications. Test conditions are considered to be at normal room temperature and environment, close to 25°C (77°F), however, sometimes it's required to conduct some tests at lower of higher temperatures, in such case the use of a thermal chamber might be necessary. For special investigative testing of parameters not defined in SSR or user specifications, such as endurance, life, temperature, moisture resistance, noise sensitivity, transient capability, EMI (emissions & susceptibility), more specialized equipment and technical personnel will be required.

A/ Turn On and Turn Off parameters

These parameters define the SSR input drive requirements in terms of must operate, must release, and input power. The turn-on voltage is equal to or greater than 3 VDC and the turn-off voltage is typically equal to or less than 1 VDC, with the band between these two values as an threshold state. For a normally closed SSR the on-off conditions would be reversed. SSR data sheets specifies input control voltage range, which is usually the same as the turn-on voltage, while the maximum value limited by power dissipation in the input circuit. The maximum current drain on the driving source is usually specified at two points-a low point and a high point within the control voltage range. This defines the input power requirements which may also be given in terms of input impedance at a given voltage.

Turn-On and Turn-Off Times are defined as the maximum time between the application or the removal of the specified control signal and the transition of the output device to its appropriate fully conducting (on) or blocking (off) state. Response times usually include both propagation and rise or fall transition times, unless otherwise specified.

Off-State Leakage is defined as the RMS current that flows in the SSR output circuit while it is in the off-state (no control signal applied). About half of the leakage current results from drive circuit bias and leakage in the output power device, and the other half is reactive (AC) leakage from the snubber capacitor. Usually specified at nominal line voltage over the temperature range.

B/ Output (Load) Parameters

- **Peak Repetitive Turn-On Voltage and On-State Voltage Drop:** These measurements can be tested at the same time as those are on the same order of magnitude. Peak repetitive turn-on voltage is the maximum (peak) off-state voltage that appears across the SSR output immediately prior to turn-on at the beginning of each half cycle, while the SSR is in the on state. On-state voltage drop is the maximum (peak repetitive) voltage that appears across the SSR output after turn-on for the balance of each half cycle, at full rated load current. This is the turn-on period of time where the SSR and is responsible for most of its power dissipation. An appropriate heatsink must be used accordingly. Both of the above parameters apply to SSRs with or without the zero turn-on circuitry.

- **Zero voltage turn-on:** Maximum (peak) off-state voltage which can appear across the SSR output immediately prior to initial turn-on in the first half cycle and defines the limits of the allowed turn-on window. Most available SSRs include this characteristic as opposed to random turn-on model, used for phase control mostly.

- **Operating Voltage and Load Current Ranges:** most complete performance test, where the SSR is taken to the extremes of its performance capabilities. The output waveform is generally viewed across the load to verify the applied line voltage under minimum and maximum load current conditions including resistive, capacitive or inductive loads. For nominal loads over 3 amperes, an appropriate heatsink must be matched with the SSR to allow continuous SSR operation at corresponding ambient temperature.

C/ Insolation (dielectric strength)

Dielectric strength test must be conducted to confirm isolation capability. Test voltage is applied between input and output, and input/output to case if the case is conductive (metallic). The test duration is usually specified as 1 minute, with a maximum allowable leakage current of 1 mAmp along the test duration.

D/ Surge Current

This parameter corresponds to maximum allowable transitory output current flow, normally specified as a peak value. If not specified as a separate parameter, it may be taken from time versus current curves in corresponding data sheets.

E/ Peak Transient Voltage

Transient overvoltage is also known as blocking voltage and its defined as the maximum permissible peak off-state voltage that an SSR can withstand without a breakdown event. This value is defined by the SSR circuitry, potentially causing damage if sustained, however, for test purposes it might be taken long enough to be read during a laboratory test.

F/ Failure Modes

Systems reliability studies require to capture the probability of failure of an SSR under certain operational conditions, to predict system effects and consequences. Assuming the SSR incorporates commonly used discrete circuitry, a random internal component failure, open or closed, will lead a greater than 50% probability of the output failing in open mode. Failure due to a recurring component defect will obviously slant the failure mode in a predictable direction until the problem is eliminated. Based on records of SSR field returns where operate the devices out of specified parameters was the cause of failure (overvoltage, current, or temperature), failure in the closed state is a 90% probability. The 10% open failure mode is most frequently due to a secondary effect such as a shorted load that leads a shorted SSR output, which will cause burns internally through current path due to insufficient fusing, showing evidence of overheating and burning on circuitry components or PCB / Power platforms surfaces.

SSRs lifetime predictions are not commonly found commercial SSR datasheets, but when, those are available are based on statistical methodology and models. Predictions made by this method provide a theorical mean time to failure (MTTF) which is little more than a supposition, unless the SSR is built with components and processes that have been evaluated through High Accelerated Life Tests (HALT). In some cases, curves specifying SSR lifetime/cycles versus current surge events are not always related to actual steady-state lifetime.

celduc® relais for instance, provides lifetime data (cycles of operation) based on actual accumulated operating hours for a given number of SSRs and HALT tests conducted to different SSR models, so this type of data is much more reliable for a wider number of applications or user specifications and it's considered the most valuable. Also, robotic assembly production lines implemented by **celduc® relais** considerably improves the quality and reliability of the SSR.

In the absence of suitable reliability data, another source of confidence about reliability if the devices hold VDE, TUV or UL certification, which means that such SSRs families have been submitted to overload and endurance testing with successful results. SSR unsteady performance might be caused by a defective internal component, but also due to certain characteristic(s) of the application related. A quick to identify the fault can be made by replacing the intermittent SSR with a new one. If the replacement don't solve the problem, the application must be analyzed. Non-permanent failures are most likely application related.

Failure Analysis Process:

1. Visual Inspection: Check for any signs of physical damage, such as burn marks, cracks, or melted components.

2. Input Check: Verify the control voltage and signal at the input terminals. Ensure the LED indicator (if present) is functioning correctly.

3. Output Check : Confirm that the SSR is switching the load on and off as expected when the input signal is applied.

4. Load Compatibility : Ensure the SSR is compatible with the load type (resistive, inductive, or capacitive) and that the load current is within the SSR's ratings.

5. Environmental Considerations: Assess the operating environment for factors like temperature, humidity, and potential sources of electrical noise.

6. MTTF Analysis: If available, review the Mean Time Between Failures (MTBF) data for the specific SSR model to assess its expected reliability.

Systematically analysing the SSR's behaviour, its operating environment and its interaction with the load and equipment in which it is installed makes it more feasible to identify the cause of failure and implement appropriate solutions.. For further reference, a **celduc® relais** video called « Procedure for testing the operation of a Solid State Relay » is available on their YouTube channel.

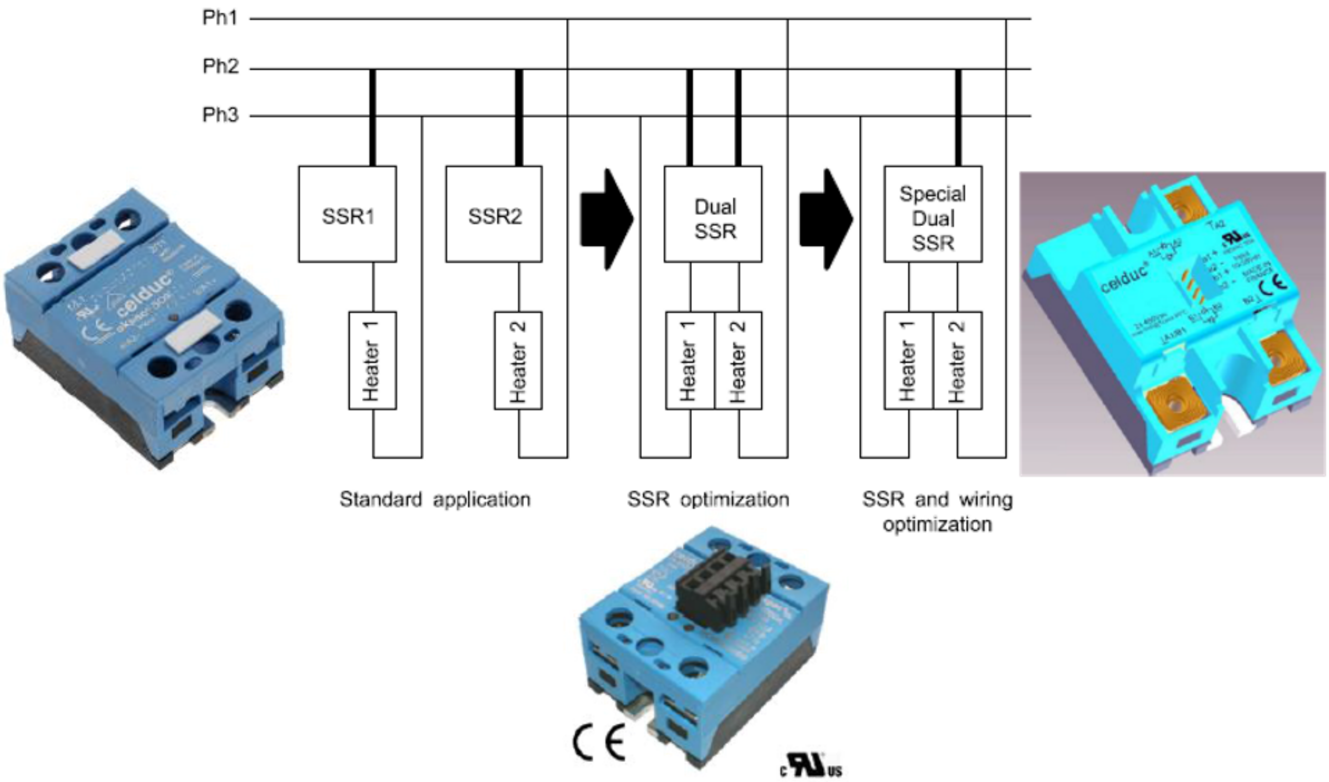
VIII/ Applications

DIn some cases, SSRs cannot operate exactly in the same way as EMRs, it is considered that SSR user has an adequate knowledge of electronics and can fill in the gaps, where necessary, for specific applications. Where fusing is suggested as preventive add-on against shorts or to protect the wiring, other circuits may also benefit from fusing, even though its use may be less relevant. When the faster but more expensive semiconductor fuses are suggested to preserve the SSRs, other circuits may be similarly protected wherever the additional cost is justified or applications where SSRs are difficult to replace.

A/ Temperature Controller

SSRs are ideal for use in temperature control systems or to replace mechanical contacts in existing systems. The zero switching characteristics virtually eliminate contact noise and wear, improving reliability. A very simple temperature controller can be implemented with a thermostat controlling an SSR or a thermistor bridge at the input of a sensitive SSR such as a buffered AC output (I/O) module.

However, greater precision can be achieved with a standard SSR driven by a differential comparator. For instance, some companies use solid state relays to control the heating elements in the barrels of their injection molding machines. The load current per relay varies from 5 Amps to 50 Amps, depending upon the requirements of the heating zone. Solid-state relays are preferred due to their silent operation and life-expectancy, but some challenges are found related to over cost and thermal issues, for this reason precise requirements must be evaluated related to equipment different load requirements and ambient conditions to determine most optimal SSR / heat sink assemblies.



B/ Phase-controller Dimmer

A solid state relay may be used with a non-zero switching to provide isolated lamp dimming. The system is operating as a one-shot, triggered by a negative pulse from the output of the zero detector circuit. Once triggered, the timing interval begins and the SSR is off. Upon time out, dependent on the time constant, system controller turns on the SSR for the balance of the half cycle. The phase angle firing point is independent of DC control voltage. However, at the higher DC voltages and shorter firing angles (full-on), the heat to be dissipated might increase driving the need of additional heatsinking capacity. In other hand, theatrical dimmers are used to gradually increase or decrease the light level to create a dramatic lighting effect. Random turn-on SSRs are commonly used and phase-angle controlled by the control system to provide the desired lighting level. In many cases, chokes are used in series with the load to prevent surge currents from damaging the relay and/or lamp. Almost all theatrical dimming accounts utilize custom solid state relays to meet their specific electrical and mechanical requirements I^2t ratings suitable for use with circuit breakers.

SKL used in DIMMER application for scenic lamps, RANDOM 50A Thyristors SKL for control power lamps and inrush currents (3U x 19» plug-in modules for 12 x 3 kW, 6 x 5 kW or 3 x 12 kW)

C/ Hazardous Environments Applications

While using SSRs in some high power switch applications, there must be considered all SSR and system characteristics which might in combination, produce a hazardous conditions for human safety or an equipment. For instance natural SSR sensitivity to overvoltage transients and fast rising voltages (dv/dt) might lead a brief "on" condition that, together with the tendency to make before break, might be dangerous when switching between power lines or supplies. However, with appropriate circuitry and protective measures, an acceptable setup can usually be achieved, assuming that properly rated SSRs are available.

For applications with a high risk, motor reverser on three-phase systems probably are on the top high. Limited lifetime and electrical noise produced by contactors has always been a problem in this type of application, making the excellent lifetime properties of SSRs particularly convenient. One very effective configuration is composed by line reversal accomplished by mechanical switches or EMRs with the power off and the motor stationary, while the start/stop operation is performed by SSRs, in such a configuration, the SSRs would provide arc-free on/off switching. Where only solid-state relay circuit are used, there is a possibility of two relays turning on simultaneously causing a line to line short, in such case, the device must be capable of supporting such event without failure. Precautions are mandatory in order to avoid potentially dangerous conditions of a high energy short circuit. Effectiveness of the circuit will be limited by the availability of SSRs with sufficiently high ratings to meet the suggested criteria, while permitting normal operation of the motor.

A major difficulty occurs with the paralleling of thyristors where parameters over which the user has no control can prevent tum-on of one SSR causing destruction of the other. In the field, if a combination of two or more SSRs is found to operate properly under all combinations of input, output, and temperature variations, the opportunity to reach an adequate setup is good. However, due to the serious consequences if an SSR fail, a thermal shutdown system must also be installed as a redundant measure.

Control positioning of electro valves in Nuclear Plant using a SW961230 with new control voltage 48V is a good example of an hazardous applications due to the criticality of an adequate operation of all the electrical system including the SSR which is preferred over EMR sue to allowable faster cycle time and reliability aspects (repairing and replacement cost).

D/ Renewable Energies and Electrification Applications

The conversion of electricity into heat (power-to-heat) plays an important role in daily life, in addition to operating various consumers such as heat pumps, e-charging stations, infrared heaters, storage systems, the photovoltaic surplus is ideally suited for controlling electric heating elements for hot water production. Due to the high efficiency, there is hardly any energy loss in the hot water tank (1kWh solar power in the heating element = 1kWh heat (efficiency 100%)).

SSR SVTA4654 for 3-phase and SO445420 for single phase are used to heat water (6 kW heaters for energy storage), max. temperature of 60°C.An electronic thermostat drives on/off the relay as water flows through the system and there is a variation of the preset water temperature. Due to their size and ease of installation, tank-less water heaters are ideal for indoor use.

This type of applications, originally used electromechanical relays but have been switching switched to SSRs technology in the last years, so by incorporating **celduc® relais**, SSR, the "click" noise associated with EMRs was eliminated and life expectancy was increased avoiding to replace EMRs. Efficiency was also increased as the heater is turned on/off faster than with an EMR. The SSR is mounted over the water outlet. This increases the efficiency of the heat sink and allows for higher current ratings in a smaller space than with a conventional convection heat sink. Load is more resistive (heating element) than inductive, and proportional controlling is not necessary to accurately control the temperature in the application.

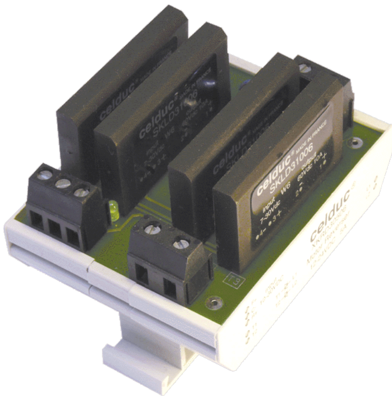
E/ Reversing Motor Control

DC motors are often used in gate and door controls, including low voltage systems powered from 24Vdc. The advantages of using 24VDC is that the door / gate systems can be powered through battery systems, charged from normal AC lines or solar cells, so those can provide operation during AC line power interruptions. Reversing three phase induction motors is often used to change rotation of the load on the shaft or sometimes only to break the motor. To take care of the mechanical part as well as the electrical, it is necessary to add a device in the circuit to limit the transient torque and the inrush current.

A reverser DC SSRs (XKRD30506) might be used for motor reversal from a single power supply, time delay before enabling the drive in either direction must be greater than the SSR turn-off time to preclude the possibility of a hazardous make before break condition. Internal reverse diodes or Zeners installed in the SSRs will suppress inductive transients across the low impedance of the power supply. If no internal suppressors exist, a reverse diode should be installed across each SSR output or alternatively, SSRs with blocking ratings at least twice that of the supply voltage may be used. The circuit should be current limited or fused to protect the wiring in the event of a short circuit.

The XKRD30506 utilizes 4 power MOSFET solid state relays to accomplish switching, but includes all the related features of integrating the interconnections, logic control for interlocking, integrated clamping voltage, Control visualization by LED. The power handling capacity of the XKRD30506 extends to 5 amp at 60VDC to control reverser to motors below 100W @ 24 VDC on a single din-rail mountable assembly without need for additional heatsinking.

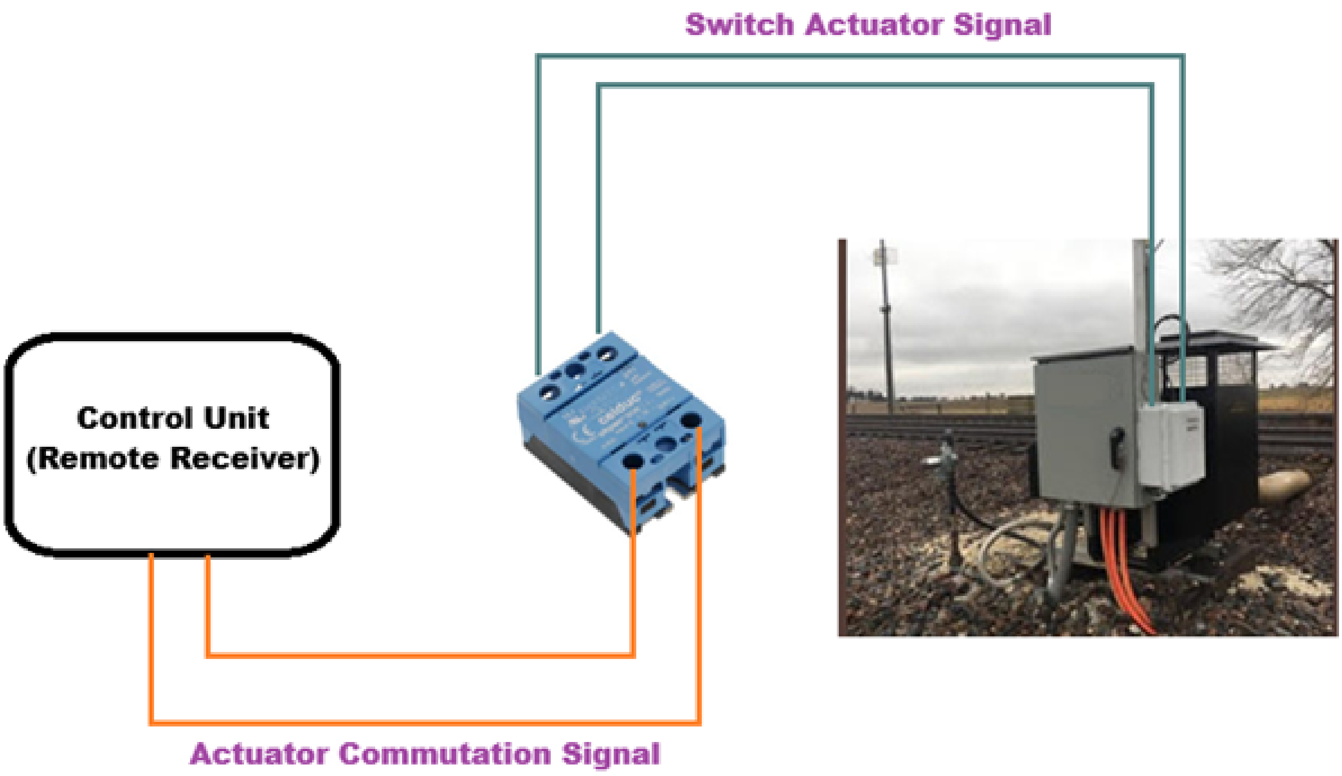
In addition, other benefits of using **celduc® relais** solid state relays are substantial, such as high immunity level, stable operation on harsh environments (high humidity, dust, dirt), as these conditions will not affect the XKRD30506 performance. Finally, contact wear through arcing present on EMRs is no longer an issue.



F/ IoT Applications

Railways companies are often renewing and automating the electric cabinets for railways environment, so there are some needs related to safety electrical power switch inside these cabinets with remote control version, especially for cabinets located in remote places or difficult to access. By implementing a remote control (IoT) solution, the load can be disconnected by activating a small motor which allows to commutate the status of the actuated power switch.

These kind of actuated switch uses AC motors (i.e. 230VAC, 75W) which is activated by 1 second, changing the position of the switch. Inside the cabinet, it is installed a control unit which receives the remote command from central station.



For the first versions of this system an electro-mechanical solution was implemented. However, most recent systems use solid state relays due to reliability, excellent resistance to hazardous conditions such as high humidity, shock and vibration resistance. For this application **celduc® relais** reference SO745090, is more than capable to control such motor rating, as it's capable to manage AC-53 motor loads of 5 Amps (1KW @230VAC).

Thank you for your attention

celduc®
relais

www.celduc-relais.com