Crouzet manufactures and sells a complete range of high-performance solid-state relays complying with the new electro-magnetic compatibility standards.

The aim of this manual is to facilitate access to these components by presenting the technological bases for the product and specifying the basic rules for their use.

For further information, refer to the Crouzet “Control” catalogue:

or contact our International Customer Service Centre (ICSC) on 0 823 333 350

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Introduction to Solid-State Relays

**Definition**

A solid-state relay is an electronic component which performs an interface function with electrical isolation between a control circuit, usually at low level, and a power circuit connected to loads which may have high power ratings (motors, pumps, solenoid valves, heaters, etc).

Moreover, this function is performed in an entirely “static” fashion, with no moving parts, thus endowing the component with an almost unlimited lifetime.

**SOLID STATE RELAY**

Based on electronic components

Although the technology was developed many years ago, the first solid-state relays became available as standard components towards the end of the 1960’s, although their structure was much simpler then. In the meantime, miniaturisation of electronic components has both improved the performance of these relays, and also made it possible to add complementary functions, so that today the solid-state relay is particularly well-suited to certain applications: soft start, reversing the direction of rotation, power proportioning.

**Structure of a Solid-State Relay**

The solid-state relay, also termed SSR (Solid-State Relay), consists basically of 5 functions as described below (functions in bold typeface).

![Solid-State Relay Diagram]

1. **input circuit**
2. **optical coupling**
3. **trigger circuit**
4. **switching circuit**
5. **protection**
6. **load**
7. **main AC supply**
8. **solid-state relay**

This structure is technically equivalent to and comparable with that of an electro-mechanical relay (EMR).
The Input Circuit

In an electro-mechanical relay, the input characteristics (voltage, current, ... level) are determined by the coil. Similarly, the solid-state relay has a more or less complex input circuit, which may, at the lower end of the range, consist of a simple serial resistor with its polarisation diode, or, for more complex relays, a circuit generating a constant current for extended input voltage ranges, or an analog-to-digital converter for analog relays.

The Isolation

In an EMR, galvanic isolation is ensured naturally by the electro-magnetic coupling between the moving armature and the coil. In the case of a solid-state relay of the semiconductor type, this isolation is provided by optical coupling (photo-transistor, photo-triac...). On some older versions, isolation may be by magnetic coupling, or even a REED relay.

The Trigger Circuit

This circuit processes the input signal received and switches the output circuit. Where the switching is complex (zero voltage switching, pulses, phase control ...), this circuit guarantees the desired switching mode: in the case, for example, of zero voltage switching, the circuit will ensure that the output will only switch when the voltage next passes zero after application of the control input.

The Switching Circuit

This circuit consists of an element providing for the electrical power to be switched to the load. This component may be either a bipolar transistor or a MOS transistor to switch a DC voltage to the load, or a triac or back-to-back SCRs to switch an AC supply.

As opposed to electro-mechanical relays where the switching element is a simple contact capable of operating either in AC or DC mode, in a solid-state relay, the type of main supply switched is pre-determined by the output.

The Protection Circuit

Electro-mechanical relays usually do not have a protection subassembly. Because of their totally electronic structure, solid-state relays are particularly sensitive to the interference present in the main AC supply; consequently the switching circuit needs to be protected from the surges and interference in low voltage supplies. Although such protection could be installed outside the solid-state relay, it is more and more often integrated in the relay itself.
These Tables show that there is no major disadvantage to solid-state relays as against electro-mechanical relays in normal switching applications and, in this comparison, we have preferred to specify certain restrictions applicable to solid-state relays which need to be known and which may have an impact on the final choice of the type of relay.

Firstly, it has to be accepted that no one type of relay is suitable for use regardless of the application. Relay applications vary enormously and depend on the physical and electrical environment, so that it is impossible to define a precise set of parameters capable of providing the user with a complete guide to the best choice. So the final decision can only be made bearing in mind the parameters specific to each application.

Main Reasons for Using a Solid-State Relay

- **Relay Life**
  Used properly, the most important features of the solid-state relay are its reliability and its lifetime. In practice, the outputs of an SSR last practically forever, while the switching contacts of an EMR would last for 250 hours at a switching frequency of 1 switching operation per second.

- **Cheaper in the Long Run**
  The cost factor is important when choosing a relay. The initial outlay for an EMR is usually lower than that for an SSR with similar technical characteristics. However, in this sort of calculation, the subsequent costs of monitoring, maintenance, and possible replacement of the EMRs are usually forgotten.

- **Control Power**
  The sensitivity of an electro-mechanical relay is around 10 to 20 times less than that of an SSR, i.e. to obtain equivalent output power, an EMR would need 10 to 20 times more power at the control input (200 to 500 mW). This characteristic is vital for compatibility with other electronic equipment, especially digital systems.
Basic Technical Differences between an SSR and an EMR

Operating Mode

Whereas an electro-mechanical relay can only switch a load in asynchronous mode, i.e. the output contact switchover is controlled solely by the control signal without any particular relationship in time with the power signal, in a solid-state relay switching can be synchronised with the output signal. This particularity makes the following switching modes possible in addition to asynchronous switching:

- Asynchronous Mode,
- Synchronous Voltage Zero or Peak Mode,
- Phase Angle Mode,
- Pulse Mode.

The most important of these and their specific uses will be covered in detail later.

Special Precautions and Output Circuit Protection

The all-electronic structure of the solid-state relay usually requires that some special implementation precautions be taken in addition to using protection "systems" on the power output circuit. These measures include in particular:

a) Measures which can be implemented independently of the type of load connected to the relay, and as a result, will often be incorporated directly in the relay housing by the manufacturer. These involve mainly protection against the phenomena which may occur on the main AC supply.

- RC filters to protect against sudden voltage variations including those generated by the switching itself.
- Protection using a varistor or transil diode against high instantaneous or high-energy surges.

b) Measures to be determined depending on the characteristics of the load and of the external circuit, the latter of which can only be fully defined or optimised by the user himself.

- Protection against short circuits on the load using a fuse or in certain cases a circuit breaker.
- Protection against excessive temperature rise by mounting the relay on an appropriate heat sink with heat transfer compound or thermal interface. This protection shall be provided systematically. Special attention shall be paid to the flatness of the contact surface and to the maximum tightening torque of the screws to avoid distorting the base plate. To facilitate the user's task, the

Immunity to the Environment

Immunity to the application environment is a more complex criterion, but SSRs are invariably superior where this parameter is concerned.

The mechanical resistance of an SSR, which has no moving parts, is better than that of an EMR. The resin coating on the SSRs offers complete protection against vibration and shock in addition to providing very good protecting in particular against corrosion.

Moreover, humidity has very little effect on SSRs, only reducing slightly the insulation resistance. An EMR is often more sensitive to humidity, which is likely to cause corrosion in the long term.

Switching Speed

The switching parameters are often the prevailing factors when it comes to choosing an SSR or an EMR. Speed may be extremely important, even critical in certain process control or automatic machine applications.

In certain exceptional cases where very low power factors are involved, the electro-mechanical relay cannot be used, and the same applies if switching without bounce is to be guaranteed.

Electro-magnetic Emission

The possibility offered by the solid-state relay of switching loads when the line voltage passes through zero will limit transient phenomena considerably, as well as current peaks and also electro-magnetic emission as a result.

In certain exceptional cases where very low power factors are involved, the electro-mechanical relay cannot be used. The same applies if switching without bounce is to be guaranteed. So here the AC or DC solid-state relay is inevitable.

Other, more technical factors are obviously also involved in the choice of a relay, all of which will be addressed in detail in the subsequent chapters.
Typical Applications for Solid-State Relays

Solid state relays have been used successfully for 20 years in a wide range of applications, and current experience shows that, although universal, the solid state relay is particularly well-suited to process applications, where machine tools are controlled by PLCs or other microcontroller-based circuits.

Due to their very high input sensitivity (less than 15 mA for controlling up to 120 A) over a wide voltage range, solid state relays are directly compatible with most standards for electronic components such as CMOS, TTL, microprocessors, etc...

Potential uses include (non-exhaustive list):

- **Production equipment:**
  - Printing
  - Textile machines
  - Pumps
  - Conveyors
  - Packing machines
  - Ovens and heat chambers

- **Industrial monitoring equipment:**
  - Temperature monitoring
  - Test machines

- **Service equipment:**
  - Lighting
  - Lifts
  - Automatic doors
  - Computer peripherals
  - Printers

- **Alarm systems**

- **Highway equipment**

- **Medical equipment**

Manufacturers are constantly increasing the offer for solid-state relays with integrated heat sinks defined by the acceptable limit characteristics for current, voltage and temperature.

Special attention shall also be paid to complying with standard industry practices when wiring the power circuit; in particular by adapting the cross-section of the wires to the rated current for the load and to the characteristics of the device protecting against overcurrent.
Examples of Uses for Solid-State Relays

As mentioned earlier, the applications in which solid-state relays are mainly used can be found in all spheres, both industrial and commercial. The few real-life examples given below only provide a very limited glimpse of the potential applications for the SSR.

- **Traffic Light Control**
  Traffic lights are managed by a logic system controlling solid-state relays mounted in a metal cabinet at the roadside. The SSR's resistance to vibration ensure total operating reliability.

- **Automatic Vending Machines**
  Solid-state relays are mounted directly onto the printed circuits controlling these vending machines and command various electro-magnets.

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- **Temperature Control**
  The temperature of injection pipes and nozzles for plastic moulding machines is measured by sensors, and the device heating elements are controlled via solid-state relays by a digital system based on the data acquired.

- **Controlling Motors**
  Solid-state relays are used to control the motors on water pumps used in decorative fountains. These ornamental fountains are installed in both public and private gardens; those with variable, programmable operating cycles are used in entertainment shows.

- **Controlling Re-fusion Ovens**
  Heating elements in re-fusion ovens are powered via solid-state relays, piloted by a micro-controlled logic system. Various output modules (GA8) are used to control electro-magnets which position the PCBs prior to soldering.

- **Lighting Control**
  Automatic lighting control is often used in commercial buildings outside office hours or outdoors in very harsh operating conditions. The use of synchronous relays increases the bulb life.

- **Controlling Electric Hoists**
  The solid-state relay controls the direction in which the 3-phase motor in the hoist operates. This type of hoist is often used extensively in industry, especially in mechanical applications.

- **Regulating a Corrosion Tester**
  The air in the climatic test chamber is heated, cooled and humidified cyclically. Both the heating elements and the motors are controlled by SSRs, which are particularly suitable for corrosive atmospheres.
Complementary Applications using I/O Modules

I/O modules (Input / Output Modules) such as low output power SSRs which are specially adapted to industrial control applications using digital systems, expand the range of potential applications for solid-state relays considerably.

By combining an output module (whose function is identical to that of an SSR with a higher output) and an input module (whose function is the opposite of an SSR since it transforms any AC or DC signal into a logic level compatible with CMOS, TTL ... ) with the inputs of a digital control system, we can satisfy such demands as controlling pushbuttons and indicators in lifts as shown in the Figure below.

Controlling lift pushbuttons and indicators. The I/O modules interface with the control PC.

The Input Circuit

The input circuit, together with the output circuit, is a fundamental element of the solid-state relay. You need to be familiar with its parameters to ensure optimum use and interfacing with the circuit in which the relay will be incorporated.

To satisfy the numerous demands in the industrial field, the solid-state relay input circuit may be designed for direct voltages which will usually be limited to 35 VDC, or for alternating voltages ranging up to 280 VAC. However, some SSRs can be used with either voltage.

DC-Voltage Input Circuit

The diagrams below show two different DC input configurations.

Main Input Circuit Structures
In the version in Figure (A), the control voltage is applied to the terminals of a LED-type diode integrated in an optocoupler which is activated when the voltage applied to its terminals exceeds the threshold of 2 or 3 volts (direct threshold voltage of the LED diode) with a minimum current of the order of 2 mA (i.e., a turn-off power of about 5 mW). The optocoupler will turn off again when the control level falls below approximately 1 volt again.

Simply connecting a resistor in series will enable voltages of up to 35 volts to be applied to the control input, while complying with the optimum operating conditions for the optocoupler without adversely affecting its lifetime (well above 200,000 hours).

Protection against accidental polarity inversion is achieved by adding a diode in parallel to the optocoupler; this will limit the reverse voltage level to 0.6 – 0.7 volts, i.e., less than the reverse flashover voltage of the optocoupler diode (around 2 to 3 volts).

The major drawback of this type of circuit is that it really does not allow optimal use of a status LED indicating the status of the control—the brightness of a LED depends on the current passing through it, and in the case shown in Figure (A), the current varies with the control voltage; so, depending on the circuit calibration, a 5V control voltage may well not provide optimal LED illumination. This is why solid-state relays with status LEDs usually include a circuit of the type shown in Figure (B). This circuit includes a current generator which, whenever the control voltage exceeds a threshold of around 0.6 to 0.8 volts DC, maintains the current in the coupling diodes and the status LED at a predetermined value of around 10 to 15 mA independently of the control voltage level.

A circuit with a current generator has the drawback of a low flashover voltage, which may render the circuit very sensitive to surges. On the other hand, protection against inversions in the control voltage is ensured by installing a diode in series; this significantly increases the resistance to reverse polarity (up to 500 Volts).

**DC Input Circuit Wiring**

![DC Input Connection for a Solid-State Relay](image)

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**Special Precaution for 2-Wire Sensors**

When a solid-state relay is controlled by a 2-wire device or any other device with high leakage current, such as a sensor or other solid-state relay, for example, it is advisable to:

- **Sensor or SSR**
- **Leakage current when open (1 to 8 mA max.)**
- **Shunt resistance is determined such that V < 1 volt**

The solid-state relay with a DC input can be controlled either by its "+" or by its "-" input, as long as the polarities are complied with, and the output current capacities of the control organ are verified and compatible. The main wiring modes for an SSR with DC control are shown in Figure 2.
check that the leakage current of the device alone does not switch the solid-state relay. In this case, a resistor must be mounted in parallel on the SSR input to reduce the voltage level generated by this current to a level below the turn-on threshold (1 Volt).

Additional Precautions

To limit the effects of voltage surges (DC or AC) on the input causing inadvertent switch-off, or even destroying the input circuit, it may be useful to mount a Zener diode in parallel with the input for DC relays.

AC-Voltage Input Circuit

Input Circuit Configuration

Solid-state relays with an alternating control input are generally designed for an input voltage range of 90 VAC to 280 VAC. The alternating control signal is rectified in half or full wave, filtered and sometimes regulated before being applied to the optocoupler diode; and to the status LED.

As a result, a solid-state relay with an AC input can be controlled by a DC voltage. As the input impedance of this type of filter rectification circuit is high, the maximum acceptable input voltage is usually high.

The value of the DC control voltage may be equivalent to the acceptable RMS voltage for alternating control.

AC Input Circuit Wiring

A relay with an AC input circuit can be controlled like a DC-input relay using a dry contact (switch or electro-mechanical relay). A solid-state control can be obtained by inserting the SSR in the anode or the cathode of an SCR or a triac.

It should be noted that an AC/AC solid-state relay can be connected at both the input and the output to two different voltage sources within the limits of the voltage and frequency specifications.

Furthermore, a solid-state relay with a DC input can become an SSR with an AC input by adding an external filter-rectification circuit (Figure 3). This can prove useful if low level AC control is required (24 VAC for example).

The value of resistor R1 can be determined, when R2 is known, given that the input voltage on the relay is defined approximately across the bridge R1 – R2 by the equation:

\[ V_{DC} \cdot (R_2 + R_1) = V_{AC} \cdot R_2 \]

\[ R_1 = \frac{(V_{AC} - V_{DC}) \cdot R_2}{V_{DC}} \]

If \( V_{DC} \ll V_{AC} \)

\[ R_1 = \frac{V_{AC} \cdot R_2}{V_{DC}} \]

and \( C = 4.7 \, \mu F \) (typical value)

As for DC input circuits, it may be helpful to mount MOV (Metal Oxide Varistor) components in the AC control circuit to limit possible effects of line surges. These precautions will be detailed in the following pages.
The Trigger Circuit

The trigger circuit provides the interface between the input circuit and the output circuit to best adapt the switching parameters to the power element. This circuit also determines the switching mode of the solid-state relay. These modes will be detailed later. At this point, it is enough to say that the main, most frequently used modes are:

• Instantaneous Switching
• Zero Voltage Switching

Instantaneous Switching (Asynchronous Switching)

In a solid-state relay with instantaneous switching, the time interval between the application of the control signal and the output closing (turn-on response time) is very short (around 0.1 to 0.2 ms) and is only limited by the response time of the SSR components.

As a result, closing can occur at any point on the sine wave, since the output element (SCR or triac) will always be opened or blocked again the first time the load current next passes through zero once the control signal is no longer applied, i.e., a response time on opening which will always be less than a half period (10 ms max. for 50 Hz).

Zero Voltage Switching (Synchronous Switching)

Synchronous switching is characterised by switching the power to the load only when the main supply voltage first passes through zero following the application of the control signal on the input. As in asynchronous mode, the SSR will open the first time the load current passes through zero following the removal of the control signal.

However, the relay is not turned on when the supply voltage reaches 0 volt precisely, but at a voltage which is close enough to activate all the SSR's internal circuitry. This voltage is known as synchronisation voltage or synchronism, and its value is close to +/- 15 volts, depending on the SSR internal circuits, corresponding to a negligible phase delay of around 2 to 3° for a main supply voltage of 240 VAC.
As a result, any control signal applied to the SSR when the output voltage is above the synchronisation voltage, will only be taken into account at the start of the following half-period, i.e. a response time of up to 10 ms for a 50 Hz supply (8 ms for 60 Hz). This property endows synchronous solid-state relays with very good immunity to electromagnetic interference at the input.

In this switching mode, the voltages switched at turn-on are low, so the power ratings involved during this phase are also low with the result that electromagnetic radiation generated is kept to the minimum.

The voltage at the relay output terminals is shown below.

This type of relay is therefore strongly recommended for switching heating elements, even at high frequencies, while limiting electromagnetic radiation. Similarly, using a synchronous relay will limit the inrush current on igniting tungsten lamps with low resistance when cold, which considerably extends the life of the filaments.
The output circuit of a solid-state relay is nothing more than an element which switches the power to the load; and we will continue to call the solid-state relay by the type of signal it switches - either AC or DC. For economic reasons, the technologies employed do not allow AC or DC switching with the same type of relay as is the case with an EMR. Similarly, for reasons of thermal dissipation and also cost, the electronic structure does not allow multiple outputs either, as is possible with EMRs.

**DC Output (DC SSR)**

In an SSR with a DC output, the power element usually comprises either a bipolar transistor or an FET transistor (Field Effect Transistor) depending on the specifications required.

To obtain rapid response times with limited currents (< 10 A) in an SSR with a DC output, a relay with a bipolar transistor as the output should ideally be used. The FET transistor should be chosen for applications requiring very low leakage current (< 10 μA) with limited temperature rise despite significant load currents (30 to 40 A).

The output element in a DC SSR may be wired as a 2-wire or a 3-wire output. The 2-wire output is mainly used for SSRs in "Hockey Puck" housings with output currents below 10A, while the 3-wire solution is often reserved for I/O modules.

In the 2-wire configuration, the load can be mounted in series with either of the other outputs as long as the power supply voltage polarities are complied with.

Where the output element is a bipolar transistor, the 2-wire connection prevents the transistor from being totally saturated and the voltage drop at its terminals when closed continues to be around 1.2 to 1.5 Volts DC; which is acceptable for most applications, especially where the load power supply voltage is fairly high (> 24 V DC).

Where the operating voltage at the output is lower, as for example in digital interfacing systems, a residual voltage of 1.5 V DC may be too high; in this case a 3-wire connection should be used, allowing total saturation of the output transistor with a residual voltage in this case of 0.2 to 0.3 Volts DC. I/O modules are often used as an isolated interface between 2 low-level digital systems or subassemblies; so they will generally be wired in the 3-wire PNP or NPN mode.
When closed, the MOSFET transistor becomes the equivalent of a low value resistor (50 to 80 mW). The residual voltage to be taken into account depends on the current in the load according to ohmic law. A current of 20A, for example, will result in a residual voltage of 1.2 to 1.5 Volts.

AC Output (AC SSR)

In an AC SSR, the switching element may consist of either SCRs or a triac, selected according to requirements.

It is preferable to use two SCRs mounted back-to-back rather than a triac in AC SSRs with a high nominal output current (> 50 A) or high peak voltage (1200 to 1500 V), while a triac is preferable for versions which are cheaper but do not perform as well in terms of current or dv/dt characteristic.

The SCR

The SCR is most often used as the switching element in an AC SSR, because of its ability to switch currents as high as several thousand amps while limiting the voltage drop at its terminals to low levels (~2 volts max) and to withstand non-repetitive current peaks of 10 or 12 times the nominal current for which it is designed. The SCR also withstands peak reverse voltages as high as several Kv.

The SCR is equivalent to a one-way diode which blocks the current in both directions when its control input (gate) is not active. The SCR is turned on (anode to cathode) either by a short pulse on the gate, or by exceeding the turnaround voltage VBO at its terminals, and can then only be stopped by reversing the voltage or reducing the current between anode and cathode below the minimum holding value IH for a minimum period (~15 μs).

The Triac

Semiconductor technology has made it economically feasible to integrate the equivalent of two opposing SCRs on the same chip, controlled by a single gate: thus the triac was born. However, the triac is much more limited in current (max. = 40/50 A), in voltage (max. = 800 V) and in maximum dv/dt characteristic. This last parameter, which is considered to be of prime importance, can be improved by using filters which may be integrated in the triac; such triacs are commonly known as "snubberless" triacs.
The same phenomenon of uncontrolled SCR turn-on can occur during breaking at current zero on an inductive load. In this instance, when the SCR opens on passing through current zero, the instantaneous value of the main supply voltage will appear at the SCR terminals instantly. The greater the dephasing between the current and voltage, the more abrupt the voltage variation, and a capacitive coupling effect between anode and gate may turn the SCR back on, causing an opening fault. 20V/µs is a typical value for the \(dv/dt\) parameter on switching a triac.

However, this type of fault is only encountered very rarely and when switching highly inductive loads with currents close to the nominal current values. Using "snubberless" components also reduces this phenomenon.

There are other power switching solutions, such as the alternistor (2 SCRs mounted back-to-back and controlled by a triac); their operation is similar to that of back-to-back SCRs.

**Main Limitations of Power Components**

The characteristics of SCRs and triacs, and of any switched component in general, are particularly well-suited to switching high currents at high speeds. In addition to the usual restrictions such as maximum current, voltage, ..., these components have other specific limitations which must be taken into account in optimising their implementation and to avoid certain malfunctions.

### Static \(dv/dt\) Limitation

The positive inverse feedback of SCRs and triacs is the source of the particularly attractive characteristics of these components (max. current and switching speed), but also of the component's \(dv/dt\) limitation. Applying too sudden a variation in the voltage between the anode and cathode can result in uncontrolled SCR closure, owing to a capacitive effect between the anode and gate. If \(C\) is the stray capacity, the current across this capacity, and hence the base of \(V1\) (see "Principle of an SCR" diagram) will be defined by:

\[
I = C \cdot \frac{dv}{dt}
\]

Depending on the value of \(C\) and of \(dv/dt\), the current may rise high enough to cause the SCR to turn on. The maximum voltage variation which can be applied to the SSR terminals without causing uncontrolled closure is generally stipulated in the specifications (static \(dv/dt\)) and is given in volts per micro-second. 500 V/µs is a typical value for an SCR, while the \(dv/dt\) for a triac would be about 200 V/µs. By way of comparison, the maximum \(dv/dt\) of the 230 V 50 Hz main supply on passing through zero is 0.1 V/µs.

These \(dv/dt\) values may be increased significantly by adding RC-type filters internally or externally. However, these filters known as "Snubbers" have the disadvantage of increasing leakage current.

### \(di/dt\) Limitation

Because of their internal semiconductor structure, triacs and SCRs have a limited ability to absorb a \(di/dt\) current variation, at the risk of being destroyed by overheating in the semiconductor junction. The maximum \(di/dt\) value acceptable to an SSR depends on the output element and ranges from 10 to 200 A/µs.
Thermal Characteristics of Solid-State Relays

For a semiconductor to provide nominal performance, it is essential that the operating temperature does not exceed a maximum value specified by the manufacturer.

In most semiconductors, this maximum temperature is never reached in nominal utilisation conditions. Beyond a given utilisation power, it is often necessary to cool the semiconductor using a dissipator.

The SSR is a power element which is prone to temperature rise, and it has to be cooled sufficiently to avoid the junction temperature of the power semiconductor element mounted in the relay exceeding a temperature of around 120, 125°C.

General Theory of Thermal Conduction

The electric power applied to the control input of a solid-state relay is usually very low, so the power dissipation of the relay is basically related to the current in the power element, and consequently in the load, per the formula:

$$ P_d = V_0 I_c $$

where:

- $V_0$ is the voltage drop at the SSR terminals
  - (1.25 to 1.4 V for an SCR - 1.65 to 1.85 V for a triac, on average for $I_{max}$)
- $I_c$ is the current across the relay

Thermal relationships are governed by a law similar to ohmic law and thermal resistance is defined by the equation:

$$ R = \frac{\Delta T}{P_d} $$

where $P_d$ is the power dissipated and $T$ the difference in temperature between the two measurement points.
The equation for the thermal schematic above would be:

\[
R_{\text{th,JA}} = R_{\text{th,JC}} + R_{\text{th,CS}} + R_{\text{th,SA}} = \frac{T_J - T_A}{P_d} \quad (\degree\text{C/W})
\]

\[
R_{\text{th,SA}} = \frac{T_J - T_A}{P_d} - (R_{\text{th,JC}} + R_{\text{th,CS}})
\]

where

- \(R_{\text{th,JC}}\) is the thermal resistance between the semiconductor junction and the SSR housing. This value is given in the SSR technical specifications.
- \(R_{\text{th,CS}}\) is the thermal resistance between the relay housing and the heat sink. If the relay has been mounted correctly using heat transfer compound, this value is close to 0.1 °C/W. Without heat transfer compound, the resistance can be multiplied by a factor of 10 or 20, i.e. 1 to 2°C/W.
- \(R_{\text{th,SA}}\) is the thermal resistance of the heat sink. Given by the manufacturer, the resistance values are generally between 0.5 and 3°C/W depending on the model.

**Simplified Calculation / Use of Graphs**

While the above calculation is very accurate, in practice it entails a tedious process involving measuring temperatures using thermocouples or other such devices. To make this calculation easier and assist in selecting a heat sink, CROUZET has devised graphs which are easy to use to select the optimum heat sink for its entire range of solid-state relays.

Knowing the load current \((A)\) and the ambient temperature \((T)\), the minimum thermal characteristic of the heat sink to be used can be determined from the graph below. To guarantee that the operating margin is sufficient, always select a heat sink with a thermal coefficient above that passing through point \((T - A)\).

**Special Utilisation Conditions**

- **Forced-Air Cooling**
  
  Forced-air cooling around the solid-state relay and the heat sink ensures better thermal dissipation for a given size.
  
  The thermal resistance of any profile in forced-air cooling conditions is described by the equation:

\[
R_{\text{th, forced air}} = \alpha \cdot R_{\text{th, natural convection}}
\]
and \( h = 1.42 \, k \) in vertical position
\( h = 1.21 \, k \) in horizontal position, facing upwards
\( h = 0.63 \, k \) in horizontal position, facing downwards

values in which \( K \) is a coefficient dependant on the temperature and the geometry of the heat sink

The full calculation shows that there is an increase of the order of 7 to 10% in thermal resistance between the vertical and horizontal/upwards positions.

A similar calculation leads to an increase of the order of 100% in thermal resistance between the horizontal/upwards and horizontal/downwards positions.

The thermal resistance values of heat sinks are generally expressed by the manufacturers based on the position providing the best thermal dissipation (vertical position). To simplify, the following correction coefficients can be applied depending on the mounting position:

<table>
<thead>
<tr>
<th>Mounting</th>
<th>Correction Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>1</td>
</tr>
<tr>
<td>Horizontal, upwards</td>
<td>1.1</td>
</tr>
<tr>
<td>Horizontal, downwards</td>
<td>2.1</td>
</tr>
</tbody>
</table>

**Effect of the Temperature Difference \( T \)**

The thermal resistance of a heat sink is defined by the formula \( R_\theta = \frac{T}{P} \),

where \( T \) is the difference in temperature between the ambient air and that of the heat sink.

The values given by the heat sink manufacturers are defined for the given \( \Delta T \) conditions (usually 50°C). Consequently, it has to be corrected to take account of the real \( \Delta T \) value and to define precisely the optimum heat sink for the application under consideration. The following rule applies without exception:

“The higher the temperature difference \( T \), the higher the thermal dissipation capacity and conversely”.

**Effect of Forced-Air Cooling on Heat Sink Performance**

**Dissipator Orientation**

In general, the thermal resistance of dissipators are always given for optimal natural convection and in vertical position.

The thermal performance of a heat sink is seriously downgraded when its orientation is changed from vertical to horizontal, facing down, or horizontal facing upwards.

<table>
<thead>
<tr>
<th>Air Speed in m/s</th>
<th>( \alpha ) Coef.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td>0.64</td>
</tr>
<tr>
<td>1.5</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Dissipator Orientation**

In general, the thermal resistance of dissipators are always given for optimal natural convection and in vertical position.

The thermal performance of a heat sink is seriously downgraded when its orientation is changed from vertical to horizontal, facing down, or horizontal facing upwards.

Globally, thermal resistance can be described by the simplified equation below:

\[
R_\theta = \frac{I}{h_c \cdot \text{(total surface of the heat sink)}} \, m^2
\]

where \( R_\theta \) is expressed in °C/W

\( h_c \) = thermal transfer coefficient expressed in W/m² °C

A similar calculation leads to an increase of the order of 100% in thermal resistance between the horizontal/upwards and horizontal/downwards positions.

The thermal resistance values of heat sinks are generally expressed by the manufacturers based on the position providing the best thermal dissipation (vertical position). To simplify, the following correction coefficients can be applied depending on the mounting position:
Effect of the Dissipator’s Surface Condition

The total thermal emissivity of a material is a complex function of the dissipator profile (fin shape, position, etc.), of the material used, but also, and for a large part, of the surface condition.

Today, most standard dissipators for solid-state relays are either made of extruded aluminium either untreated, chromium-plated (alodine) or anodised; and each of these surface treatments produces a different appearance and emissivity.

It is important firstly to note that most thermal radiation in a material occurs mainly outside the spectrum of visible frequencies; it can easily be deduced therefore, that the colour of the material will be of little significance in its total thermal emissivity. So a heat sink made of anodised aluminium will perform in the same way whatever the colour of the anodising (black, green, blue).

The variations in performance related to the heat sink’s surface treatment also depend on the shape of the fins. However, the following averages can be considered:

<table>
<thead>
<tr>
<th></th>
<th>Anodised</th>
<th>Chromium-plated (Alodine)</th>
<th>Untreated Aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Performance</td>
<td>100 %</td>
<td>92 %</td>
<td>87 %</td>
</tr>
</tbody>
</table>

It should be noted that with forced-air cooling, the thermal transfer between heat sinks and the environment take place mainly by convection rather than by radiation; so the effect of the surface condition is negligible, and anodising will not provide any additional advantage in terms of performance.

Utilisation with a Baseplate

Solid-state relays are often mounted on metal plates in cabinets for reasons of simplicity as much as cost, the mounting plate serving in this case as a dissipator. The thermal resistance of the baseplate can be calculated from the graphs below, provided for aluminium and steel.

As an example, an aluminium plate 5 mm thick and 18 cm square will have a thermal resistance of around 3°C/W, while a plate of the same size, but made of steel, will have a higher thermal resistance of around 4°C/W under identical conditions.

It should be noted that the rules presented above regarding the correction applicable in the event of a change in orientation also apply here, despite some corrections which we consider to be minor.

N.B.: Frequently in industry, there is a sheet-metal mounting plate at the back of the control unit which can be used as a dissipator, or even the rear plate of the cabinet itself may be used. In this case, to increase thermal performance, special care must be taken to remove entirely all traces of the paint which is usually applied to the unit elements.
**Using One Dissipator for Several Power Sources**

The characteristics of dissipators are generally given considering that a single heat source is situated in the centre of the cooling device.

Where several SSRs are mounted on one dissipator, it is easier to define the dissipator by dividing it into sections of equal size for each SSR. As an initial approach, each section can be considered to be independent.

However, this method is only valid if the relays are sufficiently far apart. For single-phase relays, this method can only be considered valid where the spacing between two SSRs is at least 10 cm.

For a multiple-source application with increments of less than 10 cm/SSR, the thermal resistance is calculated using the equivalent thermal diagram for the assembly. The example below presents three relays mounted on one dissipator. The thermal diagram can be represented as shown in the Figure below:

![Thermal Circuit with Several Heat Sources on One Heat Sink](image)

Where several SSRs are mounted on one dissipator, it is easier to define the dissipator by dividing it into sections of equal size for each SSR. As an initial approach, each section can be considered to be independent.

However, this method is only valid if the relays are sufficiently far apart. For single-phase relays, this method can only be considered valid where the spacing between two SSRs is at least 10 cm.

For a multiple-source application with increments of less than 10 cm/SSR, the thermal resistance is calculated using the equivalent thermal diagram for the assembly. The example below presents three relays mounted on one dissipator. The thermal diagram can be represented as shown in the Figure below:

\[
R_{\theta \text{SA}} = \frac{T_{J(1)} - (R_{\theta \text{JC}(1)} + R_{\theta \text{CS}(1)}) P_1 - T_A}{P_1 + P_2 + P_3}
\]

To account for the fact that the sources are distributed at different points of the heat sink, thus ensuring better thermal dissipation, the following may be used:

\[
R_{\text{ISA}} = \frac{R_{\text{ISA}}}{0.7}
\]

**Examples**

<table>
<thead>
<tr>
<th>SSR</th>
<th>Power Dissipated</th>
<th>Max Tj (°C)</th>
<th>R__JC</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>10 W</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>#2</td>
<td>20 W</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>#3</td>
<td>10 W</td>
<td>120</td>
<td>1.2</td>
</tr>
</tbody>
</table>

\[
R_{\text{ISA1}} = \frac{120 - (1 + 0.1) 10 - 40}{40} = 1.725 \, ^{\circ}\text{C}/\text{W}
\]

\[
R_{\text{ISA2}} = \frac{120 - (1 + 0.1) 20 - 40}{40} = 1.45 \, ^{\circ}\text{C}/\text{W}
\]

\[
R_{\text{ISA3}} = \frac{120 - (1.2 + 0.1) 10 - 40}{40} = 1.675 \, ^{\circ}\text{C}/\text{W}
\]

\[
R_{\text{ISA}} = \frac{1.45}{0.7} = 2.07 \, ^{\circ}\text{C}/\text{W}
\]
The ability of an SSR - dissipator assembly to dissipate best the heat generated by Joule's law when a current passes through the junctions of a semiconductor, plays a critical role in the operating reliability of the relay.

This ability to dissipate heat depends of course on the size of the dissipator, on the ambient temperature, on the quality of the SSR - dissipator assembly ... all of which were addressed in chapter "Thermal Characteristics of Solid-State Relays" above.

The equation for the thermal diagram relating to this type of assembly is:

\[ R_{\theta JA} = R_{\theta JC} + R_{\theta CS} + R_{\theta SA} \]

and \( R_{\theta JA} \) consists of two elements, one of which defines the ability of the relay to transfer to the base plate the heat given off as a result of the Joule effect at the junctions. From the user's viewpoint, for a given assembly, this equation results in the need for an external heat sink whose size and performance increase with \( R_{\theta JC} \) thermal resistance. So manufacturers have tried to reduce this resistance as far as possible to improve the dissipation of Joule-effect heat in relay power elements. This is why CROUZET has introduced the latest generation of “DCB” technology (Direct Copper Bonding) into its solid-state relays.

**DCB Technology**

Assembling a chip on an electric circuit support of the ceramic type (B$_2$O$_3$ or Al$_2$O$_3$) usually involves sandwiching several different layers of material, depending on the need and the performance required.

Traditional assembling usually used for low and medium power chips, consists of a series of layers held together either simply by glue, soldering or vacuum evaporation.

The number of interfaces in the assembly can increase rapidly, with limited thermal characteristics.

In DCB technology, the sandwich is achieved using a hot compression technique, which causes the copper to diffuse into the upper layers of the ceramic; this renders the assembly thermally uniform and virtually insensitive to differential thermal expansion between the various materials.
To optimise still further the thermal characteristics of our relays, while guaranteeing a minimum electric isolation of 4 KV between the load circuit and the SSR housing, CROUZET has elected to reduce the thickness of \( \text{Al}_2\text{O}_3 \) ceramic - a material which, contrary to \( \text{BeO} \) (Beryllium oxide), is not poisonous - to 0.380 mm instead of 0.63 mm.

For high-power SSRs, inserting a thick copper plate in the base of the housing, in particular the 75, 100 et 125 A versions, improves heat diffusion to the heat sink.

Among the major advantages of this technology, the following deserve special mention:

- Improved thermal resistance,
- Higher electric load capacity,
- Operating temperature up to 800°C (excluding the electronic chip),
- Improved reliability since there are fewer interfaces,
- Lower assembly cost and material savings.

Diffusing copper into the upper layers of the ceramic also endows the assembly with a mechanical resistance which is much better than that of the traditional, soldered assembly. So the relay output terminals can be connected directly to the chip, thus significantly improving the electrical capabilities and thermal dissipation.

This technology enables Crouzet to lay claim to having the best \( R_{\theta} \) thermal performance of all the solid-state relays currently available on the market.

### Load Switching on Solid-State Relays

If, as a general rule, using an EMR relay does not cause particular problems in the majority of cases, the difficulties with installation which are often encountered in solid state relay applications basically arise from lack of familiarity with the operating conditions for the SSR when connected to the various types of load.

#### Resistive loads

In an electrical circuit with purely resistive load, the instantaneous current in the load is always proportional to the instantaneous voltage at its terminals. In this case, current and voltage are in phase and are linked by the equation:

\[
V = R \cdot I
\]

where \( R \) is the resistance of the circuit.

If the switching of such a load occurs by means of an SSR, use of a relay with synchronous switching is strongly recommended.

When the current is in phase with the voltage, the relay will open and close when voltage and current pass through zero. In these conditions, relay operation will be such that:

- \( \frac{dv}{dt} \) will be limited by the power supply (105,000 v/s for a 50 Hz 230 V supply, ie 0.1 v/µs),
- \( \frac{di}{dt} \) will be limited by the impedance of the load and of the output circuit.

Electro-magnetic emission is then limited both on closing and on opening because of the low power which is present during switching.

<table>
<thead>
<tr>
<th>Technology</th>
<th>10 Amp</th>
<th>25 Amp</th>
<th>50 Amp</th>
<th>75 Amp</th>
<th>100 Amp</th>
<th>125 Amp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>1.48</td>
<td>1.02</td>
<td>0.63</td>
<td>0.31</td>
<td>0.28**</td>
<td>0.22</td>
</tr>
<tr>
<td>Crouzet GN DCB</td>
<td>0.40</td>
<td>0.40</td>
<td>0.25</td>
<td>0.155</td>
<td>0.155</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Synchronous switching on resistive load
This peculiarity of operation in synchronous SSRs on resistive loads makes them particularly suitable for convector heater type applications where the switching frequency can be very high.

In the case of a resistive load, the simple acceptance of maximum current and voltage parameters results in trouble-free SSR operation in the majority of applications.

**Exception concerning incandescent lamps**

Incandescent lamps represent the worst example of resistive loads due to the low resistance, particularly of the tungsten filaments in cold state. This may cause overloads on ignition of up to 10 or 20 times the current in steady state.

If $I_{RMS}$ is the rms load current in steady state, the max current on ignition will be:

$$I_{MAX} = 20 \cdot \sqrt{2} \cdot I_{RMS}$$

If a synchronous SSR is used, the $di/dt$ ratio can then be limited and the lifetime of the lamp will be greatly prolonged. To avoid possible destruction of the SSR, it is a good idea to place a fuse in series with the lamp, which will not only protect the SSR at the moment of ignition, but also in the event of the power supply wires accidentally short-circuiting, if the filament breaks.

---

**Connection to a 3-phase supply**

The same connection rules as for the single phase supply apply to each phase of the 3-phase supply.

In the case of a balanced 3-phase supply without neutral (star or delta connection), switching can occur on 2 phases instead of 3.

Attention should still be paid to the maximum voltages which can arise following a short-circuit or supply imbalance at the SSR terminals. As one phase is then permanently connected to the device, it is important to check that measures have been taken to ensure the safety of personnel.

These wiring methods apply to resistive loads, and also inductive loads.
Inductive loads

The principal effect of an inductive load on an AC circuit is that dephasing occurs between the voltage and the current. This delay is expressed as a phase angle of between 0 and 90° or even as a power factor $P_f$ of between 1 and 0 respectively. This power factor is also equivalent to the equation:

$$P_f = \frac{R}{Z} = \cos \phi$$

where $R$ is the resistance of the circuit

$Z$ its impedance

$\phi$ phase angle

For a purely resistive load $P_f = 1$

Synchronous solid state relays are designed for operation in normal conditions with loads which have a power factor between 1 and 0.5 (phase angle = 60°). This range of power factors, with just a few exceptions, encompasses practically all inductive loads found in actual applications. Nonetheless, it is advisable to limit the use of synchronous SSRs to applications with a $\cos \phi \geq 0.7$ (resistive load with low inductive impedance).

Take care to avoid saturation of inductive loads, as impedance may then become extremely low (residual ohmic value) and lead to overloads or even to the destruction of the solid state relay.

The problem most commonly encountered with an inductive load concerns the dv/dt parameter at the time of breaking. At this moment the load voltage is applied to the SSR terminals for an instant. Dephasing may lead to the dv/dt gradient then being very high, which would turn the relay back on (see Figures 3.16 and 5.5). The use of filters mounted in parallel on the SSR output can limit or even eliminate this phenomenon.

This problem is particularly important in SSRs with Triac outputs, as their dv/dt characteristics are more critical than those obtained with SCR outputs.

As with resistive loads, the use of an SSR with synchronous switching is recommended in the case of a load with a power factor $P_f$ between 0.7 and 1.

Example of loads with $P_f < 0.7$

Where the power factor < 0.7, a synchronous relay may not turn on in spite of a control signal being applied at the gate. If the impedance of the load is too inductive, the load will strongly oppose the establishment of a current in the load. If the minimum holding current has been unable to establish itself during the active switching zone, the output element cannot switch, or only switches partially for half a period. This phenomenon often occurs in systems with low load currents.
This problem can be resolved by placing a "snubber" type filter or shunt resistances in parallel with the load to allow faster establishment of a minimum current in the SSR.

In this case, an SSR with asynchronous switching is preferable so as to allow the current the time to establish itself correctly. In addition, as with a higher power factor, attention must be paid to the dv/dt parameter.

Example of switching on a transformer

The transformer is a special, extreme case of inductive loads which can become saturated with residual magnetism.

The magnetic characteristic of a transformer can be described by its B/H curve (Induction / magnetic field) as illustrated below. H is the magnetic field with the same sign as the voltage applied to the transformer terminals and B is the induction present in the transformer.

In steady state AC, the magnetic cycle of the transformer describes the M contour. If the voltage at the transformer terminals is broken following a final positive half-wave, the residual magnetic state of the transformer will be fixed at point BR.

If the first half-wave is positive at the next power-up, the magnetic cycle of the transformer will follow on the first half-wave of the S curve leading to high saturation and a drop in the impedance of the primary coil, resulting in a high voltage surge. This saturation will tend to diminish during subsequent cycles until normal operation is resumed (in line with the M curve) in steady state, as described earlier.

During saturation, and depending on its intensity, the circuit impedance may be equal to just the ohmic impedance, which is generally very low, of the transformer primary with additional external resistors on the circuit.

Example:

Supply voltage : 230 VAC
Coil resistance : 1 Ω
External resistance (wire + connection) : 0.5 Ω
Overload peak current:

\[ I_S = \frac{230 \cdot \sqrt{2}}{1.5} = 216 \text{ Amps} \]

Placing a low-level resistor in series with the transformer will limit the overload. This resistor should be chosen on the basis of not disturbing normal transformer operation.
In this example, the preferred option is an SSR which can at least tolerate a current surge during 1 cycle of at least 200 A.

If a synchronous relay is chosen, there is a 50-50 chance of transformer saturation occurring, resulting in an overload on the first half-waves.

When a transformer is not charged, it constitutes a pure inductance. The current across it is then the magnetising current which is in quadrature with the voltage. In these conditions maximum voltage switching then limits the overload of the magnetising current by starting at current zero. But this option can be varied according to the load on the secondary, which will impose zero switching if it is capacitive.

In these conditions, instantaneous switching, although not ideally suited to all situations, is the solution which suits most transformer applications.

### Switching motors

A motor is an inductive load with its own laws, which is a function of the mechanical load with which it is associated. On starting, a 3-phase motor can therefore have a current across it of 6 or 8 times the nominal current in steady state. For some single phase motors, this overload may be as high as 10 \( I_N \).

The current absorbed by a motor is defined by:

\[
I = \frac{P_{\text{USABLE}}}{U \cdot \eta \cdot \cos \phi}
\]

for a single phase motor.

or:

\[
I = \frac{P_{\text{USABLE}}}{\sqrt{3} \cdot U \cdot \eta \cdot \cos \phi}
\]

for a three-phase motor.

### Starting state

When determining which relay to use, both the size of this starting overload and that of the heatsink associated with the relay should be taken into account, especially if the overload occurs repeatedly following numerous stops and starts (repetitive cycles).

Approximating the current to square root signals, the rms current can be defined by:

\[
I_{\text{RMS}} = \sqrt{\frac{I^2(\text{load}) \cdot t_1 + I^2(\text{nominal}) \cdot t_2 + \ldots}{\sqrt{t_1 + t_2 + t_3 + \ldots}}}
\]

- \( I_{\text{RMS}} \): rms current
- \( I_1 \): starting time
- \( I_2 \): nominal operating time
- \( I_3 \): pause time

Besides, the power factor for an asynchronous motor is a function of the mechanical load and may be considerably less than 0.4 or 0.5 during no-load operation.

Consequently, the use of asynchronous relays is recommended for switching motors.
The voltages at the terminals of L1 and L2 are in quadrature and the voltage VSSR at the terminals of the open relay is the same as the voltage at the terminals of the capacitor C, i.e. as in the corresponding phase diagram:

\[ V_{SSR} = \frac{1}{2} V_{SUPPLY} \]

If L1 and L2 are not totally in quadrature, as when stopping, this voltage may be even higher. For a 230 V motor, choose an SSR with a nominal voltage of 400 V.

3-phase motor

Whereas a 3-phase load with neutral will require a control on each phase, a load without neutral can be switched with only 2 relays.

In cases where control occurs on three phases, once the supply voltage has been disconnected but before stopping completely, the motor generates slightly less EMF than the supply voltage, decreasing to zero. If the mechanical load is high on rapid stopping, the voltage surge may be as high as:

\[ V_{RMS} = \sqrt{\frac{2}{3}} \cdot \frac{V_{AC}}{\cos\varphi} = V_{AC} \cdot 1.5 \]

When two motor phases are disconnected, the EMF voltage generated by the motor, with the phase which has not been disconnected, can create a voltage at the SSR terminals which is slightly less than twice the supply voltage.
Examples of motor applications

3-phase motor with 2 poles, 3000 rpm, Δ 400 V AC, starting time ≤ 3 s.

<table>
<thead>
<tr>
<th>Pn (Kw)</th>
<th>Ig (A) 400 V</th>
<th>Cos η</th>
<th>Efficiency η</th>
<th>Ig/IN (D.O.L. starting)</th>
<th>Relay calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>0.50</td>
<td>0.90</td>
<td>67</td>
<td>5.5</td>
<td>10 A</td>
</tr>
<tr>
<td>0.25</td>
<td>0.66</td>
<td>0.78</td>
<td>71</td>
<td>6.8</td>
<td>4.48</td>
</tr>
<tr>
<td>0.37</td>
<td>0.95</td>
<td>0.83</td>
<td>71</td>
<td>4.8</td>
<td>4.60</td>
</tr>
<tr>
<td>0.55</td>
<td>1.35</td>
<td>0.85</td>
<td>75</td>
<td>4.9</td>
<td>6.60</td>
</tr>
<tr>
<td>0.75</td>
<td>1.90</td>
<td>0.83</td>
<td>71</td>
<td>5.8</td>
<td>11.00</td>
</tr>
<tr>
<td>1.10</td>
<td>2.60</td>
<td>0.82</td>
<td>76</td>
<td>6.4</td>
<td>16.60</td>
</tr>
<tr>
<td>1.50</td>
<td>3.30</td>
<td>0.82</td>
<td>79</td>
<td>7.7</td>
<td>25.40</td>
</tr>
<tr>
<td>2.20</td>
<td>4.40</td>
<td>0.89</td>
<td>82</td>
<td>6.8</td>
<td>29.90</td>
</tr>
<tr>
<td>3.00</td>
<td>6.30</td>
<td>0.83</td>
<td>80</td>
<td>7.6</td>
<td>47.80</td>
</tr>
<tr>
<td>5.50</td>
<td>10.90</td>
<td>0.88</td>
<td>83</td>
<td>8.6</td>
<td>93.70</td>
</tr>
<tr>
<td>7.50</td>
<td>15.50</td>
<td>0.85</td>
<td>82</td>
<td>8.3</td>
<td>128.00</td>
</tr>
</tbody>
</table>

3-phase asynchronous motor, Δ 400 V AC, D.O.L. starting, starting time ≤ 3 s.

Capacitive loads

Loads which are purely capacitive are not very common, but they can nonetheless exist in combination with other loads (inductive or resistive) in some electrical installations. With high value capacities (low impedance), it will then be necessary to pay particular attention to the dl/dt parameter.

Switching of this type of load is always performed by a synchronous relay.

On a 230V AC supply, it is possible to estimate a maximum value for the dl/dt parameter by considering the following calculation:

\[ I = C \cdot \frac{dv}{dt} \]

\[ I = (\text{amp}) = C \cdot (\text{Farad}) \cdot 10^6 \]

\[ I = 0.1 \frac{\text{A}}{\mu\text{F}} \]

Corresponding to the max dl/dt which can appear in this type of circuit.

We recommend placing shock inductances in series in a highly capacitive circuit.

Various SSR connections

- **Parallel / series connection**

The SSR inputs can be connected either in parallel or in series, whereas the outputs can only be combined in a serial arrangement, apart from DC outputs with an FET transistor. When the outputs of 2 relays are connected in series, the maximum output current will correspond to the most limited characteristic of the two SSRs, while the maximum applicable voltage will equal the sum of the voltages applicable to each of the SSRs taken individually.
Increasing the output current on a DC SSR

The output current of DC SSRs can seem limited, especially in the versions with transistor output. It is possible to minimise this drawback by adding an external power circuit.

Summary

<table>
<thead>
<tr>
<th>TYPE OF LOAD</th>
<th>SWITCHING TO BE CHOSEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistive load</td>
<td>Synchronous switching</td>
</tr>
<tr>
<td>Motor load</td>
<td>Asynchronous switching</td>
</tr>
<tr>
<td>Inductive load 0.7 ≤ P_f ≤ 1</td>
<td>Synchronous switching</td>
</tr>
<tr>
<td>Inductive load P_f &lt; 0.7 and transformer</td>
<td>Asynchronous switching</td>
</tr>
<tr>
<td>Capacitive load</td>
<td>Synchronous switching</td>
</tr>
</tbody>
</table>

Protecting SSRs against transient phenomena

The weakest point of solid state relays, compared with EMR relays, is probably their sensitivity to electrical interference and transients as well as voltage and current surges.

Transient phenomena can have two origins:
- an electro-magnetic radiated origin whose interference mainly affects the low-voltage structure of the SSR, such as the input circuit comprising the optocoupler.
- an electrical origin conducted by the power supply wires. As the I/O capacitive coupling is weak, these transients mainly affect the power output circuit.

However, whatever the phenomenon may be, it is often caused by lightning, switching on inductive loads (motors, etc), distribution equipment placed on the electrical supply (micro power cut, etc). These phenomena exist on all industrial electrical supplies, and their incidence can in many cases be reduced by simply being aware of them and taking elementary precautions.

A vital basic safeguard against all these phenomena is to select the correct size of SSR in relation to its application in order to take advantage of all the SSR characteristics with an adequate safety margin.

Transient phenomena on input / protection

The main problems encountered on an SSR input come from radiated or conducted voltage surges. If such a voltage surge exceeds the minimum turn-on voltage (1 to 3 volts) the SSR output circuit will open at least until the output current next passes to zero. A voltage surge that is too high could destroy the optocoupler if this is not adequately protected.

Input protection method

The input SSR can be protected against possible voltage surges by adding an RC supply or a zener diode mounted in parallel on the input. These components, often integrated directly within the SSR, delay the relay switching for several micro-seconds (which will not have serious consequences, particularly with AC) and reduces the effects of a radiated or conducted stray impulse.

Furthermore, a synchronous relay is "naturally" protected against the effects of a stray impulse on the input as long as the stray impulse occurs outside the valid switching window.
Transient voltage phenomena on the output

- **Voltage surge on output**

  If, following a voltage surge, the voltage at the output terminals of an AC SSR exceeds the maximum permissible direct voltage or turnaround voltage, the SCR or the triac will switch on until the current next passes to zero.

  Because of the high switching speeds of SCRs or triacs, switching can be triggered by a very short pulse of only a few µs.

- **Increase in dv/dt direct voltage**

  This characteristic is linked to the physical structure of the output element and in particular to the coupling capacities between anode and cathode in an SCR or triac. If the variation of the voltage at the relay terminals is too rapid, this can result in an uncontrolled turn-on.

  The severity of the consequences of such a stray trip will obviously depend on the application, but these can, in certain specific circumstances, lead indirectly to the solid state relay being destroyed:

  - Very high energy impulse,
  - Unexpected turn-on with short-circuiting of a relay acting as a reversing motor.

Output protection method (voltage)

- **RC supply - “Snubber”**

  Mounting an RC supply in parallel on the output both reduces the dv/dt gradient generated by a stray impulse and reduces the amplitude of this impulse by filtering, as long as the impulses do not recur.

  Any variation in the voltage at the terminals of an RC supply results in a current in the C capacitor, causing a voltage drop in the load such that:

  \[ V_d = V + L \cdot \frac{di}{dt} - U \]

  This voltage drop will protect the output SCR.

  The main disadvantage of this type of filter is the significant increase in the SSR leakage current. Using a “snubber” can in fact, depending on the values of the filter components, double the amount of leakage current.

  All SSRs usually have “snubber” filters, which improve their performance. However, some SSRs use special SCRs which accept significant dv/dt variations. These relays are known as “Snubberless”.

  Typical value of a “Snubber”:

  - Resistance : \( 33 \, \Omega < R < 100 \, \Omega \)
  - Capacity : \( 0.1 \, \mu F < C < 0.47 \, \mu F \)
Protection using “Transil” (Surge-Suppressor) Diodes

A “Snubber” filter alone is not usually sufficient to protect an SSR effectively, particularly against high-energy stray pulses. Using a “Transil” (surge suppression) diode improves this protection reliably.

Surge-suppression diodes are intended to protect electrical equipment which is sensitive to fast transients of low or medium energy levels. They are designed to have very good performance where the needs of this type of equipment are concerned, i.e. for overloads lasting close to one millisecond or less. This type of component can also provide good protection against electrostatic discharges (ESD).

**How to Select a Surge-Suppression Diode**

On its ability to drain and on the two voltage characteristics: $V_{BR}$ and $V_{RM}$.

$V_{BR} = \text{reverse avalanche voltage or elbow voltage.}$ This is the value above which the current in the diode rises very rapidly with a slight increase in voltage.

$V_{RM} = \text{standby voltage.}$ This is the voltage which the diode can withstand with constant load.

For applications requiring higher voltages, the diodes can be mounted in series. It is not even necessary to balance them using RC supplies. However, it is preferable to mount in series only diodes of the same type to distribute the energy evenly.

**Nota**: Mounting in parallel is not usually possible.

**N.B.**: With an alternating current, use a bi-directional version or two “Transils” mounted head to tail.

Protection via Varistors

To protect the SSR against high energy stray pulses, it is also possible to use varistors.

The drawback with these is that they lose their characteristics over time as a result of the stray pulses received. They must be replaced after each incident.

The characteristic of a varistor is that with a voltage at its terminals less than its nominal value, the impedance of the MOV is very great (several Mohms). However, once that value is exceeded the impedance very quickly drops to less than 1 Ohm, with the response time for the MOV being approximately 20 to 50 ns.

The basic parameters of a varistor are:

- the voltage which the varistor must be able to tolerate permanently (usually: $V_{varistor} = V_{supply} \times 1.15$),
- the peak voltage at which the phenomenon must be suppressed,
- the energy (expressed in Joules) freed by the source of the transient phenomenon (to be defined for each application).

Although the first two parameters can be found easily, choosing the correct varistor requires, in addition, a minimum of knowledge about the source impedance and the power of the stray pulse, as well as an approximate idea of the supply quality, as the lifetime of an MOV is largely influenced by the number of stray pulses and the power of each pulse received.

Dans le domaine industriel, l’utilisation de varistances de moyenne puissance pouvant absorber des impulsions d’énergie entre 50 et 130 Joules devraient convenir.

**Varistor selection guide**

Three-phase supply without neutral (load + SSRs connected between phases)

<table>
<thead>
<tr>
<th>Voltage between phases (V)</th>
<th>Peak limiting voltage (V) at 100 A</th>
<th>Energy (J) (10-100µs)</th>
<th>Manufacturer references</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>HARRIS</td>
</tr>
<tr>
<td>3 x 230 / 3 x 240</td>
<td>710</td>
<td>140</td>
<td>V275LA40A</td>
</tr>
<tr>
<td>3 x 400 / 3 x 415</td>
<td>1 100</td>
<td>160</td>
<td>V420LA40B</td>
</tr>
</tbody>
</table>
Three-phase and single phase supply with neutral connected (load + SSRs connected between phases and neutral)

<table>
<thead>
<tr>
<th>Single phase 3-phase</th>
<th>3-phase supply voltage, neutral connected (V)</th>
<th>Peak limiting voltage (V) at 100 A</th>
<th>Energy (J) (10-100µs)</th>
<th>Manufacturer references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single phase supply voltage (V)</td>
<td>3-phase voltage, neutral connected (V)</td>
<td>120</td>
<td>3 x 240</td>
<td>710</td>
</tr>
<tr>
<td>230 - 240</td>
<td>3x400 / 3x415</td>
<td>270</td>
<td>3 x 480</td>
<td>710</td>
</tr>
<tr>
<td>277</td>
<td>3 x 690</td>
<td>1100</td>
<td>160</td>
<td>26</td>
</tr>
<tr>
<td>380 - 415</td>
<td>277</td>
<td>3 x 690</td>
<td>1100</td>
<td>26</td>
</tr>
</tbody>
</table>

**Varistor connection mode**

For optimum protection, a varistor is usually mounted in parallel with the component it is to protect. However, in the case of a motor reverser, MOVs should be mounted as described below to protect both directions of rotation adequately.

---

**Protecting DC SSRs**

A diode mounted in parallel with an inductance and linked to a zener diode in parallel on the SSR is the most efficient means of quickly eliminating high voltage surges which can occur in an inductive DC circuit on breaking. These voltage surges are the result of the energy \( \frac{1}{2} LI^2 \) accumulated in the inductance at the moment of breaking. This is the energy that must be discharged via the diode. All these products in the CROUZET DC SSR have an integrated protection diode which is suitable for most applications.

---

**Transient current phenomena**

As with the voltage characteristics, it is essential to allow a sufficient safety margin with regard to the current characteristics of the SSR. However, some specific physical phenomena inherent in certain loads (inductances, motors, etc), and also certain accidents, can lead to instantaneous or permanent current overloads in the circuit.

The special characteristics of the main electrical loads are generally very well known and it is possible to select an SSR on the basis of these characteristics. A motor can have a starting current for a limited time of 10 times its nominal current. Similarly an inductance will have an impedance equal to its ohmic impedance, therefore very low, in saturation phase.

Such overloads are acceptable for an SSR if this has been taken into account when selecting the SSR. In contrast, the same motor accidentally blocked by a mechanical overload will result in a permanent overload; this will initially cause overheating of the output SCR, then its destruction possibly by short-circuiting, which will destroy the motor if no preventive measures have been taken.

An efficient protection system against overloads should, as a priority:
- Restrict the duration of overloads.
- Restrict the frequency of overloads.

**Current limitation by fast-blowing fuse**

Rather than use an unnecessarily large SSR, which will only protect the SSR itself against current overloads, it is advisable to protect the whole installation against accidental overloads by fitting fuses in the circuit which will protect both the relay and the electrical systems connected to it. Such fuses should be chosen from the range of fast-blowing fuses.

A fuse is equivalent to a low-level resistor which is capable of absorbing a defined amount of energy in a given time. Once this has been exceeded, the fuse blows.

The power dissipated by a current I in an electrical resistor R is shown as:

\[ P = RI^2 \]

and the corresponding energy during that time is shown as:

\[ E = RI^2t \]
For a fuse, R is constant and therefore the energy going through the fuse is simply defined by the coefficient I²t.

For a relay, a coefficient I²t is calculated from the maximum peak current on a half-period (10 ms) ie:

\[ I^2t_{(10\,\text{ms})} = \frac{I_{\text{max, peak}}^2}{2} \times 0.010 \, (\text{seconds}) \]

To protect an SSR a fuse with an I²t coefficient lower than that of the relay should be selected.

The I²t coefficient can be better adapted to the SSR to define the I²t coefficient whatever the measurement time with the equation:

\[ I^2t \, (\text{in time } t_x) = I^2t \times \sqrt{t_x} \]

\[ t_x \] fuse reference time

**Example:**

GA3 25 A

Overcurrent during a cycle: 270 A

\[ I^2t_{(10\,\text{ms})} = \frac{270^2 \times 0.01}{2} \, = \, 364.5 \, \text{A}^2\text{s} \]

(Typical catalogue value = 365 A²s at 10 ms)

For example, a fuse could be selected with the value:

\[ I^2t_{(10\,\text{ms})} = 300 \, \text{A}^2\text{s} \]

The fuse corresponding to 1 ms will be:

\[ I^2t_{(1\,\text{ms})} = \frac{365 \times \sqrt{0.001}}{0.01} \, = \, 1154 \, \text{A}^2\text{s} \]

This calculation can be used, if necessary, to correlate the I²t values given by some supplier catalogues at different times with those normally used for solid state relays (10 ms).

In some cases the I²t value indicated by the fuse manufacturer should be corrected to take account of the actual operating voltage, which may differ from the manufacturer’s reference value.

The following should be taken into account when making the final selection of a fuse:

- the operating voltage of the fuse which should be at least equal to the supply voltage,
- the nominal current of the fuse which should be greater than the load current in steady state,
- the maximum current in the system,
- the maximum permissible peak current for the fuse.

For the whole of its SSR range, CROUZET offer a selection of fuses from the FERRAZ fuse range (see the section on “Accessories for solid state relays” in the CROUZET catalogue).
Special precautions and help with circuit diagnostics for SSRs

A solid state relay is an active electronic component which it is wise to choose carefully and avoid any chance of the SSR not being suitable for the application. Detailed analysis of requirements must be performed before choosing the SSR in order to define the essential characteristics which it should meet.

Once the application parameters have been defined, an accurate choice can then be made by using, if necessary, the guide drawn up in the form of a flowchart which appears at the beginning of this manual. Particular attention should also be paid to the selection of the heatsink, which is required when the anticipated output current exceeds 5 amps.

Once installed, if the SSR malfunctions, two troubleshooting methods are possible:

- Replacement, pure and simple, of the SSR.
  This method, although self-evidently the quickest troubleshooting method, will not actually produce a positive result if the malfunction is due to a phenomenon external to the solid state relay.
- Preliminary analysis of the origin of the malfunction before replacement, if necessary.

It should be remembered that generally, the reliability of a solid-state relay is such that, if an solid-state relay fails after being installed according to standard industry practices, it is highly probable that the cause of the failure is external. Replacing the relay without first analysing the origin of the malfunction or taking action to improve the external circuit is likely to solve the problem only temporarily. Until the underlying reason for the fault is eliminated, the fault is likely to recur. It is therefore essential to perform a fault analysis.

The most common malfunctions noted in circuits with SSRs are of 2 types: malfunctions on closing, or, malfunctions on opening.

These malfunctions may occur randomly in certain conditions and not recur. They are then very difficult to correct; but by taking a minimum of precautions and following a minimum of rules when wiring up the installation, such malfunctions, including some total malfunctions, can very easily be avoided. Take care, therefore:

- to wire up the inputs and outputs separately to avoid the risk of interference.
- to tighten the connection screws correctly.
- to fit the recommended type of filters on the relay, so as to avoid transient phenomena as far as possible.
- to limit interference caused by the supply by fitting appropriate filters on all the equipment (supply filter etc)..
- to ensure correct ventilation in the control unit.
- to mount an appropriate heat sink (+ heat transfer compound).

Fault on closing

If the output circuit is not activated by a control pulse on the input, the first thing to check is the output circuit wiring:

1 - When no control pulse has been applied to the input, the output voltage should be the same as the load voltage.
   - If this voltage is zero, check that the load circuit is not open, and that the power supply is correctly connected to the circuit (watch out for intermediate switches which may not have been closed).
   - If the output voltage is the same as the power supply voltage, check that the load has not short-circuited, which might have damaged the SSR output in the open position.

2 - When a control pulse has been applied to the input, the output voltage should be approximately 1.5 V depending on the SSR. If this is not the case, check the input.
   - Check the connections and polarity (DC SSR) of the control signal.
   - Measure the control voltages at states 0 and 1, and the corresponding currents (ammeter or voltage measurement at the series resistor terminals if this exists). If the current is zero, whatever voltage is applied, the input circuit is faulty. If the voltage is outside the limits, check the external circuit.
   - Check that adequate protective devices against transient phenomena are present.
   - The load current must not exceed the maximum limits, as this will cause overheating. Check the SSR load and output, which may have short-circuited. If so, replace the relay.

Fault on opening

This malfunction can be confirmed by disconnecting the control wires:

1 - If the SSR opens, first check the switching thresholds on the input which may be too low, meaning the SSR is faulty.
   - If the threshold voltages are correct, the external control circuit may be suspect.

2 - If the SSR does not open after disconnecting the wires, check that the power supply voltage does not exceed the maximum output voltage (see: turnaround voltage on SCR or triac).
   - Check that adequate protective devices against transient phenomena are present.
   - The load current must not exceed the maximum limits, as this will cause overheating. Check the SSR load and output, which may have short-circuited. If so, replace the relay.

This troubleshooting guide should help to resolve the majority of problems encountered when using solid state relays. However, it should not need to be used very often, given the reliability and long life of solid state relays. Nevertheless, should you have particular difficulties when using an SSR, do not hesitate to contact Crouzet Ltd for help and advice, Nr 0 825 333 350.
Solid-State Relay Characteristics and Terms

A solid-state relay is obviously defined by a certain number of electric parameters and characteristics, but also by its “packaging”. The manufacturers have developed several type of housing some of which are to be considered to be standard.

The most wide-spread housing type is commonly known as the "Hockey Puck" housing because of its shape. This housing is particularly well-suited to medium and high-power applications, but nonetheless requires the user to define the heat sink appropriate for the application. This type of housing associated with an optimised heat sink, often represents the most cost-effective alternative in applications involving large-scale production quantities.

To facilitate the implementation of solid-state relays, several years ago, the manufacturers developed relays with integrated heat sinks corresponding to the main relay characteristics in standard utilisation conditions. As a result, the user no longer needs to select the heat sink, the mounting, the attachment inside the control unit or electric cabinet. Moreover, this type of relay also complies with the main size standards in industry, 22.5, 45 and 90 mm wide and capable of being mounted directly on DIN rails.

This document would not be complete without mentioning the I/O-type housings or input / output modules, which are simply low level AC or DC solid-state relays which represent a simple automation solution often used to interface different voltage levels. These modules exist in several formats, the most common of which are the industrial format and the modular format.

- **Input Voltage**
  Voltage range which can be applied to the input and or which relay switching is guaranteed. The upper value corresponds to the maximum voltage which may be applied to the input without destroying the circuit. The lower value in the range is defined based on the turn-on voltage (voltage at which the relay switches from OFF to ON) and is usually 0.3 to 0.5 V (for DC) above this value.

- **Turn-Off Voltage**
  Value of the input voltage below which the OFF state of the relay is guaranteed by the manufacturer. This value is usually very low (1 to 1.5 V for DC, a few volts for AC). This characteristic is especially important where the solid-state relay is to be controlled by a 2-wire element, with a high leakage current. This case is dealt with in detail later.

- **Maximum Input Current**
  This value is usually specified at maximum control voltage and provides for sizing the control circuit.

- **Input Impedance**
  This characteristic which is in principle given for SSRs with a passive input circuit, provides for sizing the control circuit. The characteristic is useless for input circuits with integrated current generators.

- **Turn-On Response Time**
  Maximum time between the moment the control signal is applied to the input and the moment the output switches. For an instantaneous relay, this time is very short (< 0.1 ms). For a synchronous relay, depending on the control (AC or DC) and the angular position of the control in relation to the load voltage, this time may range up to 20 ms maximum (at 50 Hz).

- **Turn-Off Response Time**
  Maximum time between the end of the control signal and the moment the relay switches to OFF state. As for turn-on/making response time, turn-off response time can vary (up to 30 ms) depending on the type of relay, and its control voltage. The fastest response times are provided by relays with DC control voltage (10 ms 50 Hz).
Typical Electric Specifications for Solid-State Relays / Manufacturer Data
**Output Characteristics**

- **Output Voltage (max. V RMS)**
  Voltage range which may be applicable continuously at the output and at which the SSR will operate in accordance with the specifications.

- **Peak Voltage (1 min) or Peak Voltage When Open**
  This value corresponds to the turnaround voltage VBO of the relay SCRs. This is the minimum voltage which can be applied to the relay terminals without causing the SSR to turn-on by itself as a result of exceeding the VBO value. This value is only significant for those SSRs without transil-type protection.

- **Voltage Drop When Closed**
  Voltage drop appearing at the relay terminals when a given current (I \text{MAX}) passes through it. This value provides for calculating the power dissipation of the relay.

- **Load Current / Maximum Current**
  Maximum current which can be switched by a relay in given conditions. This value may be corrected as a function of external operating conditions (temperature, heat sink...).

- **Leakage Current When Open**
  Leakage current passing through the relay and therefore through the load when the relay is open. This value must be taken into account especially where the relay load is another relay or any other electric device with high input impedance (e.g. I/O module).

- **Holding Current**
  Minimum current necessary for the SSR output SCRs to remain closed when a control signal is applied to the input.

- **Overcurrent: 1 Cycle / for 1 Minute**
  Maximum acceptable peak current over one cycle (10 ms for 50 Hz) for 1 minute. This non-repetitive current value decreases the longer the overcurrent lasts. For 1 cycle this value is of the order of 10 times the nominal current. For one second, the overcurrent may be 3 times the nominal current at the most.

- **I^2t**
  This parameter represents the maximum energy that the solid-state relay can withstand without damage during a short circuit or non-repetitive overcurrent. This value is expressed in square amps for a given duration (usually 10 ms), and is one of the main characteristics involved in selecting the protection fuse.

- **Dv/dt**
  This characteristic is generally given when open (static / stable) and on switching. The static dv/dt value defines the maximum voltage variation rate on the SCR terminals when the SCR is open. A higher voltage variation than this causes the output element to switch. The dv/dt value on switching characterises the maximum voltage variation rate on the SCR terminals when the relay opens. This characteristic may be exceeded when highly inductive loads are switched, preventing the relay from closing.

- **Di/dt**
  This parameter characterises the ability of the solid-state relay to absorb a current variation. Exceeding the limit value usually destroys the relay, as a result of short-circuiting the SCR.

- **Utilisation Frequency**
  Operating frequency range. It should be noted that the leakage current on the output is directly proportional to the operating frequency value.

- **Junction/ Housing Thermal Resistance**
  Expressed in degrees Celsius (or Kelvin) per Watt, this parameter characterises the temperature gradient (whatever the power applied) between the SCR power junction and the relay housing. This parameter is extremely important in determining the optimal heat sink for a given application.

- **Dielectric Strength**
  Maximum voltage which may be applied between the relay terminals and the base plate without causing a breakdown.

- **Input / Output Isolation**
  Maximum potential which may be applied between the SSR inputs and its outputs. An isolation fault may lead to serious damage in the electrical installation in which the relay is installed.

- **Input / Output Capacity**
  The value of the coupling capacity between the input and output terminals.

- **Switching Mode**
  The solid-state relay may be switched in various ways depending on the type of load. However, the mode most frequently used is the synchronous mode which is suitable for many applications and generates the least interference.
For electric components and more generally, for automation components, solid-state relays included, the following Directives are to be applied:

• Low Voltage Directive (LV) (73/23/CEE) applies to all electrical equipment intended for use with voltages from 50 to 1000 VAC and 75 to 1500 VDC.

• EMC Directive (Electro-Magnetic Compatibility) (89/336/CEE) applies to all product likely to generate electro-magnetic interference… but also likely to be susceptible to electro-magnetic radiation.

These two Directives are filled out by the Machine Directive (98/37/CE) which applies to machinery or equipment incorporating moving elements (which may represent a danger for the user) and to safety components.

N.B.: Where an automation component such as a solid-state relay is intended to be mounted in a machine, the component itself is not subject to the Machine Directive - it is the responsibility of the manufacturer of the machine to ensure that the equipment complies in its entirety with the Directive under which it falls.

Each of these Directives is based on general or generic standards or where they exist, on product- / application-specific standards (specifying for example the maximum acceptable levels for the various parameters) and which refer to various test standards.

Overall, the manufacturer is solely responsible for ensuring compliance with these Directives. The manufacturer demonstrates that he fulfils the requirements by applying the corresponding standards, which are published by the European bodies (official gazette).

CE Marking (93/68/CEE)

CE marking on products (and machines) was initiated by European Law based on the application of the European Directives issued to this end. This marking is mandatory and guarantees the product concerned freedom to circulate throughout the European Community.

Electric components and automation components whose main purpose is to be mounted in equipment are principally subject to the Low Voltage Directive guaranteeing that the component does not represent a danger, consequently CE marking on these components is required per this Directive alone.

Throughout this reference document, the solid-state relay is considered to be a component (and not a saleable end product as such) intended to be connected to a low voltage electric supply. In this light, the solid-state relay is only subject to compliance with the LV Directive for CE marking, which ensures that it may circulate freely throughout the EC.
Beyond the strictly “standard” and regulatory aspect, the solid-state relay remains first and foremost an electronic component, for rapid switching of currents which may be high (up to 90 / 120 Amps), capable of causing severe interference in its environment, and which can also be disturbed by its electro-magnetic environment. To answer this need for reliability in a disturbed electro-magnetic environment, Crouzet offers, over and above the CE marking on relays per the LV Directive, a characterisation in relation to the main standards on which the EMC Directive is founded.

Additionally, for those countries outside the EEC, all the Crouzet solid-state relays comply with and are certified to various American and Canadian standards, in particular UL 508 and CSA C22.2.

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>EN 60947-4-2 and -4-3</td>
<td>EN 60947-4-2 and -4-3</td>
<td>EN 60204-1</td>
</tr>
<tr>
<td>Commercial Light Industry</td>
<td>EN 60335-1</td>
<td>EN 50081-1 (Emission)</td>
<td>EN 60204-1</td>
</tr>
<tr>
<td>Information processing</td>
<td>EN 60950</td>
<td>EN 50081-1 (Emission)</td>
<td>EN 60204-1</td>
</tr>
<tr>
<td>Electro-medical</td>
<td>EN 60601-1</td>
<td>EN 50081-1-2</td>
<td>EN 60204-1</td>
</tr>
</tbody>
</table>

**Table of Standards Applicable to Solid-State Relays**

- **Type of Test Standards**
  - **Protection category**: IEC 60529
  - **Inflammability category for plastic materials**: IEC 60952-2-1, UL 94V0
  - **Insulation voltage and surge voltage**: IEC 60664-1
  - **Dielectric strength leakage current to ground**: EN 60950

- **EMC Test Standards**
  - **Immunity**
    - Electro-static discharges: EN/IEC 61000-4-2
    - Electro-magnetic field Amplitude modulation: EN/IEC 61000-4-3
    - Electro-magnetic field Pulse modulation: ENV 50204
    - Fast transients: EN/IEC 61000-4-4
    - Radio Frequency surge voltages in common mode: EN/IEC 61000-4-5
    - Magnetic Field: EN/IEC 61000-4-8
    - Voltage drops and interruptions: EN/IEC 61000-4-11
  - **Emission**
    - Conducted Emission (Mains/Line): EN55022/EN 55011
    - Radiated: EN55022/EN 55011

**Comments**

- **EN 60947-4-2**: Low Voltage Devices. Semiconductor-based and starters for AC motors.
- **EN 60947-4-3**: Low Voltage Devices. Semiconductor-based and starters for loads other than AC motors.

This standards is a specific standard applicable to solid-state relays in the industrial field, and defining the "LV and EMC" limits for the products concerned. Consequently, this standard replaces the following generic standards as far as EMC requirements are concerned:

- **EN 50081-2**: Emission in an Industrial Environment
- **EN 50082-2**: Immunity in an Industrial Environment

**Immunity**: The level required for industrial applications is tougher than that for applications in the “domestic”, “commercial”, “light industry”, and “electro-medical” fields.

**Emission**: The maximum emission level accepted for industrial applications (Class A) is lower than that allowed for the other application fields (Class B).

The Crouzet solid-state relays fulfil all the provisions specified in these reference standard.

- **EN 60204-1**: Safety of Machines. Electric Equipment for Machines.
- **EN 60335-1**: Safety in domestic electric and analogous equipment.
- **EN 60950**: Safety in information processing equipment, including electric office equipment.
- **EN 60601-1**: Safety in electro-medical equipment.
- **EN 50081-1**: EMC/ Generic Emission Standards. Domestic Commercial and Light Industry.
- **EN 50082-1**: EMC/ Generic Immunity Standards. Domestic Commercial and Light Industry.
- **EN 60601-1-2**: Electro-medical equipment. EMC Requirements and Tests.
Applications

Although by their principle, solid-state relays are often compared to electro-mechanical relays, their implementation is nonetheless frequently more complex and requires a minimum of precautions.

As a result, solid-state relays cannot replace electro-mechanical relays easily and directly, except for some specific relatively simple cases.

Consequently, the examples presented below are to be considered as a directory and application guide for the more complex cases and to orient the designer in the circuit design, and in any precautions for use.

Temperature Regulators

Temperature regulation is a typical application for solid-state relays. The technical advantages of SSRs such as absence of noise when operating, rapidity, longevity and lifetime are shown off to the full in this application.

Controlling a Power Component by a Solid-State Relay (AC Circuit)

Recent technological progress has led to the availability today of solid-state relays capable of controlling currents up to 120 amps; which is ample to control most loads directly. However, it may be useful to control high loads from I/O-type modules and power elements (SCRs or triacs).

Resistor R1 protects the solid-state relay in the event of a short-circuit in the load. The resistor must be selected so as to limit the current to the nominal SSR value. In the same way, resistor R2 prevents external triacs or SCRs from switching, which could be caused by excess leakage current from the control solid-state relay, and I/O module.

\[ R_1 = \frac{V_{AC}}{SSR \text{ nominal I}} \]
\[ R_2 = \frac{0.7}{SSR \text{ leakage current}} \]

The diodes mounted between Gate and Cathode provide for limiting their reverse voltage which could damage the SCRs if it were to rise too high.

Reverser Mounting

A solid-state relay cannot be compared directly to an electro-mechanical relay, but the combination of several relays enables very similar functions to be achieved. A NO/NC reverser can be made (see diagram a) below) by using four solid-state relays and a logic circuit. In diagram (b) below, we have simply added an output buffer to control the solid-state relay inputs more reliably.
To fulfill this need, relay B can be triggered by a signal provided from the voltage on the terminals at load A and slightly offset in time by an RC filter. In this case, relay B can only be activated when load A is switched to the main supply.

**Sequential Load Switching**

In some applications, it may be necessary to switch several power loads using a single control signal and in a specific order. This function can be achieved in two different ways:

- **Time-delay Switching**

  Here, solid-state relays A and B are switched by one and the same control signal. When a control input is applied to points $C - C'$ (Figure 8) in the circuit, this signal will be applied immediately to the inputs on relay A, while being offset by the RC filter for relay B.

- **Controlled Time-Delay Switching**

  In the case described in the previous Figure, should the circuit to load A be interrupted, the $A - B$ switching sequence will not be complied with. Depending on the circumstances, this may lead for example to erratic or even dangerous machine operating cycles.

**Time-delay Switching**

Using two solid-state relays, two separate loads can be controlled in a similar manner; the state of load 1 controls the solid-state relay connected to load 2, per the diagram below:

Special attention must be paid to the characteristics of the source which must be capable of withstanding the power of both loads because of the slight overlap in simultaneous operation of the loads during phase changes. Inserting time-delay circuits between relays 1 and 2 may provide for special trigger functions and sequences.
Increasing the Output Current on a DC SSR

The output current on DC solid-state relays may appear limited for some versions with a transistor output. This drawback can be alleviated by adding an external power circuit per the diagram below.

As before, resistor $R_2$ will be calculated to avoid the SSR leakage current causing the external power transistor to start to conduct / become conductive. Resistor $R_3$ defines the base current of the external transistor. This current should provide for saturating the transistor and thus limiting thermal dissipation (0.4 w/amps or even less).

Controlling a Solid-State Relay by a Pulse

In some cases, it may be necessary to control solid-state relays using pulses of very short duration, or even on a rising or falling edge. This control pulse can be memorised using a D, the control signal being provided by a pulse on the clock input.

Where two control signals or two pulse buttons respectively and OFF are available, this function can be achieved using two NAND gates wired as a rocker switch with - in this case - anti-bounce protection. Remember that anti-bounce protection on the input is only really necessary for DC solid-state relays, since AC solid-state relays incorporate this protection by design.

Where a D rocker switch§, is used anti-bounce protection can be provided by adding an RC supply on the control input.

Installing Solid-State Relays in Parallel

Installing solid-state relays in parallel can be of interest where load currents greater than the relay characteristics are encountered. This possibility can be used with DC relays and in particular with relays fitted with a MOSFET transistor output, and which have the particularity of having a positive temperature coefficient, resulting in the currents on the two relays being automatically balanced.
Inserting Function A-type timers in the control circuit between the relays’ simultaneous switching to ON and if necessary introducing a motor stop delay before changing the direction of rotation.

Reversing the Direction of Rotation on a Single-Phase Motor

1. reverse contact
2. time delay on Direction 1
3. time delay on Direction 2

This "speed" monitoring function can also be achieved, but with less safety using a Crouzet FRL-type control block.

Reversing the Direction of Rotation on a Three-Phase Motor

The direction of rotation of a three-phase motor can be reversed simply by inverting two phases. This function can be achieved using four solid-state relays in the case of a motor with no neutral. An additional relay will be necessary for a motor with the neutral connected.

To avoid short circuits between phases when the direction of rotation is reversed, FWD/BCKWD relays must not be closed simultaneously, and a time delay of 100 to 150 ms is recommended. Complementary protection using a resistor as calculated above and a fuse is strongly recommended. When defining solid-state relay specifications, it may be of use to refer to the Chapter "Switching motors" (see page 50).

Reversing the Direction of Rotation of a Motor

Reversing the rotation direction on a motor is one of the most common applications for solid-state relays whether for DC or AC motors:

**Single-Phase, AC Motor**

This type of motor can be controlled by two relays as long as care is taken not to short-circuit the de-phasing capacitors C should both SSRs switch simultaneously or inadvertently. If this condition cannot be totally guaranteed, a resistor R shall be defined to limit the discharge current on C such that:

\[
R \geq \frac{V_{\text{ALIM}}}{I_{\text{TSM}}} = \frac{\sqrt{2} V_{\text{supply}}}{I_{\text{TSM}}}
\]

With \( I_{\text{TSM}} \) the maximum overload current of the relay and the power of the resistor will be defined by \( P = RI^2 \). The resistor thus defined can be distributed across the two solid-state relays such that \( RI' = R/2 \).

In these conditions, the solid-state relay shall be defined as a function of the voltage which may appear on the motor terminals. The voltages on terminals L1 and L2 (motor windings) are theoretically in quadrature and the voltage on the terminals of the unswitched relay will be equal to the voltage on the capacitor terminals, i.e. per the phase diagram below:

\[ V_{\text{ALIM}} = \sqrt{2} V_{\text{supply}} \]

if L1 and L2 are not totally in quadrature, or when the motor is stopped, the voltage on the relay terminals may be greater than this value. For a 230V motor, a relay with a nominal voltage of 400V at the least, or even more, should consequently be selected.
Braking Control for a DC Motor with Permanent Magnet

When the inertia on a motor is high with low friction, it may be necessary to brake the motor during stop phases, when the motor will behave like a generator (per Figure 10). Braking can be achieved by short-circuiting the motor terminals. Where a reverser is used for ON-OFF/braking control, special attention shall be paid to ensure that both relays are not conductive simultaneously, since this could destroy them. An offset of 5 to 10 ms between the switching of the two relays will guarantee that the first relay is totally non-conductive before triggering the second relay.

This type of relatively brusque braking can be attenuated by installing a resistor in series in the braking relay.

During the braking phase, the motor will behave like a generator and the corresponding current may be as high as the start current. Consequently, relays of similar characteristics should be selected for both the ON-OFF/braking functions.

Reversing the Direction of Rotation of a DC Motor

Reversing the direction of rotation of a DC motor requires 4 solid-state relays. In particular, care must be taken when defining the control circuit which must prohibit any attempt to switch to both directions simultaneously; this is likely to create a short circuit which would destroy the solid-state relay.

Introducing a delay of a few milliseconds (depending on the motor) between the orders to change direction, will allow the motor current to cancel out and will avoid random overloads on the solid-state relays.

Care shall also be taken to protect the transistor or FET type outputs of the SSRs, by locating “free wheel” diodes on the output terminals. While this diode is often mounted as standard equipment by manufacturer on solid-state relays, it is less often found on I/O modules which may be used to control smaller motors.

If additionally, the mechanical inertia of the motor is low, changing the motor direction may lead to currents of up to twice the start current during the braking phase.

N.B.: The direction reversing function with a time delay is directly incorporated in the GAO-type relays. Where reversing the direction of rotation is achieved using single-phase solid-state relays, the control system must include an inter-lock prohibiting giving the command for one direction while the other is still active. Each relay shall be fitted with a varistor to absorb the surges on the main supply.

Connecting a Direction Rotation Reverser using a GAO-Type Relay

Rotation Direction Reverser for a DC Motor
Fast Switching for an AC Load

Switching an AC load using SCRs does not provide for fast switching, in particular when stopping conduction which may require up to 8.3 ms (at 60 Hz), 10 ms (50 Hz). A DC solid-state relay can switch an AC load via a diode bridge thus avoiding the constraints specific to SCRs and triacs, in particular the interruption at current zero and triggering with a high dv/dt.

This function can be achieved either with a DC solid-state relay and a diode bridge (complete with the voltage drops which relate to it), or with two DC solid-state relays and two diodes mounted in series on each SSR, reducing voltage drops.