# Understanding Solid-state relays

Solid-state relays (SSR) are able to perform many of the same tasks as electromechanical relay (EMR)s. The main difference is that SSRs have no moving mechanical parts within it. Essentially, it is an electronic device that relies on the electrical, magnetic, and optical properties of semiconductors and electrical components to achieve its isolation and relay switching function.

**Principle of operation**
Both SSRs and EMRs use a control circuit and a separate circuit for switching the load. When voltage is applied to the input of the SSR, the relay is energized by a light-emitting diode. The light from the diode is beamed into a light-sensitive semiconductor that, in the case of zero-voltage crossover relays, conditions the control circuit to turn on the output solid-state switch at the next zero-voltage crossover. In the case of nonzero-voltage crossover relays, the output solid-state switch is turned on at the precise voltage occurring at the time. Removal of the input power disables the control circuit and the solid-state switch is turned off when the load current passes through the zero point of its cycle.

**Applications**
Since its introduction, the SSR has gained acceptance in many areas that had previously been the sole domain of the EMR or the contactor. The SSR is increasingly employed in industrial process control applications, particularly temperature control, motors, lamps, solenoids, valves and transformers. The list of specific applications for the SSR is broad.

Typical examples of SSR applications include:

- Industrial automation
- Electronic appliances
- Industrial appliances
- Packaging machines
- Tooling machines
- Manufacturing equipment
- Food equipment
- Security systems
- Industrial lighting
- Fire and security systems
- Dispensing machines
- Production equipment
- On-board power control
- Traffic control
- Instrumentation systems
- Vending machines
- Test systems
- Office machines
- Medical equipment
- Display lighting
- Elevator control

- Metrology equipment
- Entertainment lighting

**Advantages**
When used correctly in the intended application, the SSR provides many of the characteristics that are often difficult to find in the EMR; a high degree of reliability, long service life, significantly reduced electromagnetic interference, fast response and high vibration resistance. The SSR has no moving parts to wear out or arcing contacts to deteriorate that are often the primary cause of failure with an EMR.

- Long life (reliability) > 109 operations
- Zero-voltage turn-on, low EMI/RFI
- Shock and vibration resistant
- Random turn-on, proportional control
- No contact bounce
- Arcless switching
- No acoustical noise
- Microprocessor compatible
- Fast response
- No moving parts

**Thermal considerations**
One of the major considerations when using an SSR is properly managing the heat that is generated when switching currents higher than about 5 amperes (A). In this case, the base plate of the SSR should be mounted onto a good heat conductor, like aluminum, and used with a good thermal transfer medium like thermal grease or a heat transfer pad. Using this technique, the SSR case to heat sink thermal resistance is reduced to a negligible value of 0.1°C/W.

**Load considerations**
A leading cause of application issues with SSRs is improper heat sinking. Problems can also arise from operating conditions that specific loads impose upon an SSR. The surge characteristics of the load should be carefully considered when designing in a SSR as a switching solution.

**Resistive loads**
Loads of constant values of resistance are the simplest application of SSRs. Proper thermal consideration, along with attention to the steady state current ratings, will result in trouble-free operation.

**DC loads**
This type of load should be considered inductive, and a diode should be placed across the load to absorb any surges during turn-off.

**Lamp loads**
Incandescent lamp loads, though basically resistive, can present some challenges. Because the resistance of the cold filament is about 5 to 10 percent of the heated value, a large inrush current can occur. It is essential to verify that this inrush current is within the surge specifications of the SSR. One must also check that the lamp rating of the SSR is not exceeded. This is a UL® rating based on the inrush of a typical lamp. Due to the unusually low filament resistance at the time of turn-on, a zero-voltage turn-on

characteristic is particularly desirable with incandescent lamps.

**Capacitive loads**
These types of loads can prove to be problematic because of their initial appearance as short circuits. High surge currents can occur while charging, limited only by circuit resistance. Caution must be used with low-impedance capacitive loads to verify that the di/dt capabilities are not exceeded. Zero-voltage turn-on is a particularly valuable means of limiting di/dt with capacitive loads.

**Motors and solenoids**
Motor and solenoid loads can create challenges for reliable SSR functionality. Solenoids have high initial surge currents because their stationary impedance is very low. Motors also frequently have severe inrush currents during starting and can impose unusually high voltages during turn-off. As a motor's rotor rotates, it creates a back EMF that reduces the flow of current. This back EMF can add to the applied line voltage and create an overvoltage condition during turn-off. Likewise, the inrush currents associated with mechanical loads having high starting torque or inertia, such as fans and flywheels, should be carefully considered to verify that they are within the surge capabilities of the SSR. A current shunt and oscilloscope should be used to examine the duration of the inrush current.

**Transformers**
In controlling transformers, the characteristics of the secondary load should be considered, because they reflect the effective load on the SSR. Voltage transients from secondary load circuits, similarly, are frequent in transformers and can be imposed on the SSR. Transformers present a problem in that, depending on the state of the transformer flux at the time of turn-off, the transformer may saturate during the first half cycle of subsequently applied voltage. This saturation can impose a very large current (10 to 100 times rated typical) on the SSR that far exceeds its half-cycle surge rating. SSRs having random turn-on may have a better chance of survival than a zero cross turn-on device, for they commonly require the transformer to support only a portion of the first half cycle of the voltage. On the other hand, a random turn-on device will frequently close at the zero cross point, and then the SSR must sustain the worst-case saturation current. A zero cross turn-on device has the advantage that it turns on in a known mode and will immediately demonstrate the worst-case condition. The use of a current shunt and an oscilloscope is recommended to verify that the half-cycle surge capability is not exceeded.

A typical approach in applying a SSR to a transformer load is to select a SSR having a half-cycle current surge rating greater than the maximum applied line voltage divided by the transformer primary resistance. The primary resistance is usually easily measured and can be relied on as minimum impedance, limiting the first half cycle of inrush current. The presence of some residual flux, plus the saturated reactance of the primary, will then further limit, in the worst case, the half-cycle surge safely within the surge rating of the SSR.

**Switching devices**
The thyristor family of semiconductors consists of several very useful devices. The most widely used of this family are metal-oxide semiconductor field effect transistors (MOSFETs), silicon-controlled rectifiers (SCRs), triac, and alternistor triac. In many applications, these devices perform key functions and it is imperative that one

understand their advantages, as well as their shortcomings, to properly specify a reliable system. When applied correctly, thyristors can be an important advantage in meeting environmental, speed and reliability specifications that their electromechanical counterparts could not fulfill.

**MOSFET**
The MOSFET is a semiconductor device that consists of two metaloxide semiconductor field effect transistors (MOSFETs), one N-type and one P-type, integrated on a single silicon chip. The MOSFET is ideal for switching DC loads.

**SCR**
The silicon-controlled rectifier (SCR) is a four-layer solid-state device that controls current flow. The SCR acts as a switch, conducting when its gate receives a current pulse, and it continues to conduct for as long as it is forward biased. The SCR is ideal for switching all types of AC loads.

**Triacs**
A triac is an electronic component approximately equivalent to two silicon-controlled rectifiers joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. This results in a bidirectional electronic switch that can conduct current in either direction. The triac is ideal for switching resistive AC loads.

**Alternistor triac**
Used to switch AC loads, the alternistor has been specifically designed for applications that switch highly inductive loads. A special chip offers similar performance as two SCRs, wired inverse parallel (back-to-back), providing better turn-off behavior than a standard triac. The alternistor triac is an economical solution that is ideal for switching inductive AC loads.

**Thermal considerations and heat sinking**
Thermal management is a fundamental consideration in the design and use of SSRs because of the contact dissipation (typically 1W per amp). Therefore, it is vital that sufficient heat sinking is provided, otherwise the life and switching reliability of the SSR will be compromised. In order to properly size a heat sink, one has to consider what goes into getting the thermal resistance numbers in order to understand what it means. Let's first begin by defining some variables:

P = Power dissipation (W)
EDROP = Voltage drop—maximum on-state (V), can be found in the specification table
ILOAD = Load current (A)
TA = Maximum ambient temperature where the relay will be located (°C)
TJ = Maximum semiconductor junction temperature—generally 100 °CTR = Allowable temperature rise (°C)
REJC = Thermal resistance, junction to case—found in the specification table (°C/W)
RECS = Thermal resistance, case to heat sink—generally 0.1°C/W. This accounts for losses in the thermal grease or thermal transfer pad
RESA = Thermal resistance, heat sink to ambient—this is the required heat sink characteristic based on volume of the heat sink and the design (°C/W)

**The basic formulas are as follows:**
P = EDROP x ILOAD

TR = TJ – TA
TR = P(REJC + RECS + RESA)
Solving for RESA
RESA = (TR / P) – (REJC+ RECS)

Example: What is the required heat sink thermal resistance characteristic for a solid-state relay with a voltage drop of 1.6V and a thermal resistance (junction-to-case) of 1.02°C/W, with a load of 20A and ambient temperature of 25°C?

**Assigning the variables:**
EDROP = 1.6V (from catalog specification table)
ILOAD = 20A
TA = 25°C
TJ = 100°C
REJC = 1.02°C/W (from catalog specification table)
RECS = 0.1°C/W (generally accepted thermal resistance due to grease or thermal transfer pad)

**Solving:**
P = 1.6 x 20 = 32W
TR = 100 – 25 = 75°C
RESA = (75/32) – (1.02 + 0.1)
R ESA = 1.22°C/W

Typically, it is good practice to round down to the nearest tenth to provide additional headroom. This would result in a thermal resistance of 1.2 °C/W.

Using a chart will further assist in selecting a heat sink. There are a variety of charts available from different sources based on fan usage and materials. It is best to contact the heat sink manufacturer for more details.

Source:

http://www.automation.com/library/articles-white-papers/industrial-io/understanding-solid-state-relays