Output Switching Functions of Solid-State Relays

Arguably, the technical aspect of a solid state relay we discuss most frequently with design engineers and technicians is the manner in which AC output SSRs switch power to a load. In many cases we find that the subject is something most engineers have never even considered, especially those with a background in electromechanical relays. In this case they are simply accustomed to energising a coil and waiting for the arcing & clanking to occur shortly thereafter. The more subtle nature of a solid-state relay is still something of a mystery to them, especially terms such as "zero-cross", "random", and "proportional control" and the benefits therein. Fortunately these switching modes and how they apply to different types of loads are fairly easy to explain.

Zero-Crossing Solid-State Relays

Also known as a "synchronous" solid-state relay, this is the most common type of SSR found in the market today. As the name implies, the switching of the relay from a non-conducting to a conducting state occurs when the AC mains voltage reaches the zero-crossing point of the sine-wave. This minimises the surge current through the load during the first conduction cycle and helps reduce the level of conducted emissions placed on the AC mains.

Figure 1 gives a simplified diagram of the input and output signals on a zero-crossing solid-state relay. At point (1) the control voltage is applied to the input of the relay. However, the relay does not allow load current to flow through the output until point (2), which is the next zero-crossing point of the AC sine-wave. At point (3) the control voltage is removed from the input of the SSR, which then stops conducting load current at point (4).
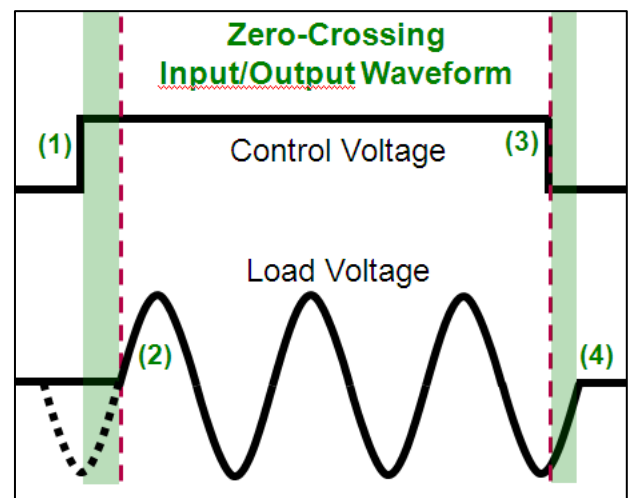

Figure 1; Simplified Zero-Cross Waveform

Note that the output of the SSR does not stop conducting until the load current reaches the next zero-crossing point of the AC sine-wave. However, this is not related to the "zero-crossing" function of the SSR. It is due to the fact that the SCRs in the output circuit cannot turn off until the load current falls below their specified holding current (typically less than 100mA). This is a characteristic of all AC output solid-state relays, regardless of the switching type.

Zero-crossing relays are ideally suited for most commercial and industrial loads, such as resistive heating elements, lamps and ballasts, and any other load

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with low initial impedance or capacitive characteristics.

Random Turn-On Solid-State Relays

Also known as "asynchronous" or "instantaneous" solid-state relays, these relays turn on immediately after the application of the control signal. In most cases the output is fully conducting load current in less than 100µS.

Figure 2 gives a simplified diagram of the input and output signals on a random turn-on solid-state relay. At point (1) the control voltage is applied to the input of the relay. The output of the relay immediately begins to conduct load current (point (2)) as opposed to a zero-crossing relay, which will wait until the next zero-cross point of the AC sine-wave. At point (3) the control voltage is removed from the input of the SSR, which then stops conducting load current at point (4).
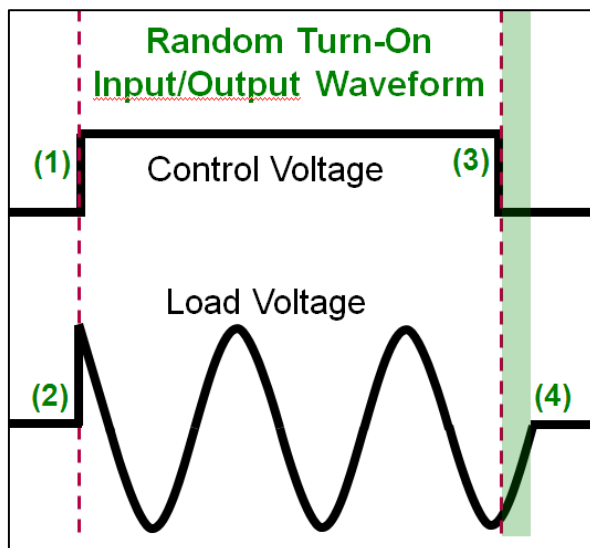

Figure 2; Simplified Random Turn-On Waveform

Random turn-on solid state relays are commonly used in applications where precise control of power to the load is required (phase-control applications). They are also commonly used with inductive loads, where the phase shift between voltage and current can cause problems with zero-crossing relays.

Proportional Control Solid-State Relays

The most common types of proportional solid-state relays on the market today are phase-angle controllers and burst-fire relays. These solid-state relays provide proportional power to the load (from 0% to 100% in most cases) based upon the value of an analogue signal applied to the input. This can be a 0-5V, 0-10V, 4-20mA, resistive value, or other varying signal that translates into a desired load-power level. These relays are often found in heating applications requiring extremely precise temperature levels, and lighting applications requiring the gradual increase and decrease in the brightness of a room or area.

Figure 3 gives a simplified diagram of the output waveform on a phase-angle controller / SSR. In this example we have a 5V analogue signal applied to the input of a 0-10V SSR (50%). The corresponding output waveform shows the SSR turning on at the peak of each AC half-cycle, effectively applying 50% power to the load. If we gradually increased the analogue input from 5V to 10V, then we would see the shaded areas in the waveform diagram slowly disappear until we reached 100% power to the load.
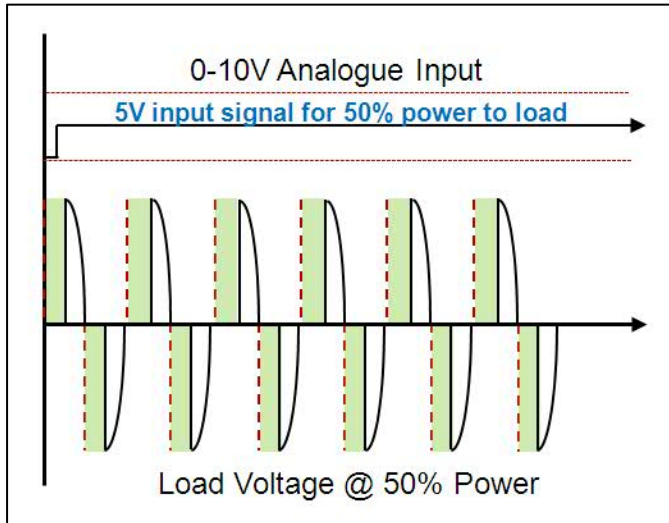
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Figure 3; Simplified Phase-Angle Waveform at 50% Power

Burst-fire controllers are similar to phase-angle SSRs in that they provide proportional power to the load. However, instead of conducting partial load current during each half-cycle, burst-fire controllers provide a continuous train of full AC cycles to the load. The number of "on" and "off" cycles determines the percentage of power applied to the load over a fixed time period, which is controlled by the value of the analogue signal applied to the input. The advantage of this is that it reduces the level of conducted emissions placed upon the AC mains as the relay is turning on and off at the zero-crossing point of the sine-wave. The disadvantage is that burst-fire SSRs are typically not suitable for lighting applications, as the variance between on and off times can create an unwanted flicker effect.

Figure 4 gives a simplified diagram of the output waveform on a burst-fire controller / SSR. In this example we have a 5V analogue signal applied to the input of a 0-10V SSR (50%). The corresponding output waveform shows the SSR providing five full AC cycles to the load, then turning off for five full AC cycles (50% power, effectively). If we gradually increased the analogue input from 5V to 10V, then we would see the shaded area in the waveform diagram slowly disappear until we reached 100% power to the load.
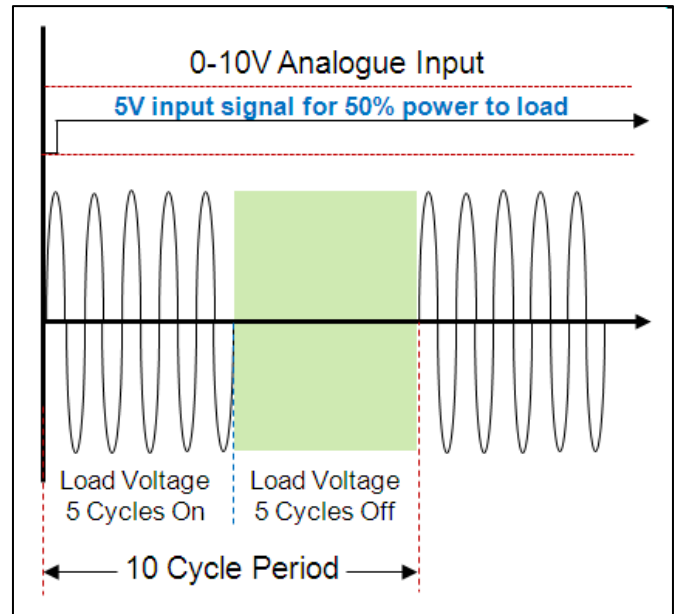

Figure 4; Simplified Burst-Fire Waveform at 50% Power

Conclusions

Understanding what type of solid-state relay to use within a given application allows for a level of precision and reliability not even remotely possible with equivalent rated electromechanical relays. The trick is ensuring that the correct relay is selected based upon the characteristics of the load. However, as we said at the beginning, this is a fairly easy process and only requires a few small guidelines to remember when selecting a solid-state relay;

Resistive Loads (heating elements) and loads with some capacitance – pf >0.75;

Zero-crossing relays are perfectly suited for nearly all loads with a power factor of greater than 0.7, which is why they are the most common type of relay found today in resistive heating applications. They are also preferred in applications with some level of capacitance as they can minimise surge currents during the first conduction cycle.

Phase-angle and burst-fire relays are also perfectly suited for resistive loads, especially where precise temperature control is required. However, if there is capacitance in the load then we only recommend burst-fire relays.

Inductive Loads (motors, contactor coils, transformers) – pf <0.75;

Random turn-on relays are usually recommended for these types of loads as the phase shift between voltage and current may cause problems with some zero-crossing relays. However, most Crydom zero-crossing SSRs today work well with motor loads, but historically we have always recommended random turn-on relays.

Phase-angle and burst-fire relays are not suitable for inductive loads.

Lighting Applications;

Depending upon the application, zero-crossing, random turn-on, and phase-angle SSRs are all suitable for lighting applications. Zero-crossing relays are commonly used when a simple on/off function is required for the lamps. However, random turn-on and phase-angle relays are primarily used for dimming applications.

Burst-fire relays are not recommended for lighting applications as the on / off period may cause unwanted flicker in the lamps.

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