

May 2010

## Coil Suppression & DC Output Solid State Relays



DC output solid state relays are frequently utilized to switch loads such as electric valves, heating elements, fans, solenoids, electromechanical relay (EMR) coils, etc. They perform the same function as the more commonly used AC output SSRs but, as their name implies, they are designed to only switch DC voltage sources. Accordingly they offer the same advantages as their AC output 'cousins', such as extremely long life, silent operation, no arcing or bouncing of contacts, shock & vibration resistance, and very fast turn on/off times. These benefits, coupled with an increase in battery powered applications such as automotive and renewable energy systems, have led to a continually increasing demand for such products.

Other advantages of DC output solid state relays, specifically those with FET outputs, make them a desirable

switching solution for engineers controlling DC loads. These include a low on-state impedance ( $R_{ds-on}$ ), which can be as low as  $0.005\Omega$  in high current models, and the fact that FET output relays can be wired in parallel to increase the total load current capability of the switching circuit. Therefore, two D1D100 (100Vdc / 100A) SSRs wired in parallel can switch loads up to 100Vdc @ 200 amps.

### Load Types and Characteristics

As with AC output solid state relays, DC relays are used to switch a variety of electric loads. Resistive heating elements are one of the more common types of loads switched with solid state relays. They are also the least troublesome type of load as they are primarily resistive and have little or no reactive characteristics. In other words, surge currents, voltage spikes, and reverse voltage conditions are much less likely with resistive loads than with other types of loads.

Inductive and capacitive loads, on the other hand, can cause a few more headaches for design engineers. Capacitive loads create issues with inrush currents as their initial on-state impedance (when discharged) is close to  $0\Omega$ . If the surge current exceeds the maximum ratings of the relay than the output FET will be destroyed quite quickly. Placing a choke in series with the load reduces the surge current and is a popular method used in the field. However, this is usually the least of our concerns as we rarely encounter

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applications with extremely capacitive loads.

Inductive loads are more common and pose some interesting challenges for DC SSRs. When an inductive load is de-energized quickly the collapsing magnetic field opposes the sudden change and creates an electromagnetic force with the same polarity in order to maintain current flow. If there is no conductive path for this stored energy then the collapse of the field will generate a significant voltage spike on the line. In nearly every case this spike will be sufficient enough to permanently damage the solid state relay performing the switching function.

Therefore, when a customer calls complaining that their DC output SSR has failed after turning on their motor only once or twice, the reason is usually pretty obvious...

### DC Solid State Relay Protection & Coil Suppression

Protecting a solid state relay from voltage spikes generated by the collapsing magnetic field of an inductive load is a fairly straight forward process. The most frequently used method is to simply place a reverse-biased rectifier diode directly across the load as shown in figure 1 below. For most applications a standard recovery diode is perfectly suited to suppress the load. However, if there is a possibility that the SSR will be energized again before the energy in the

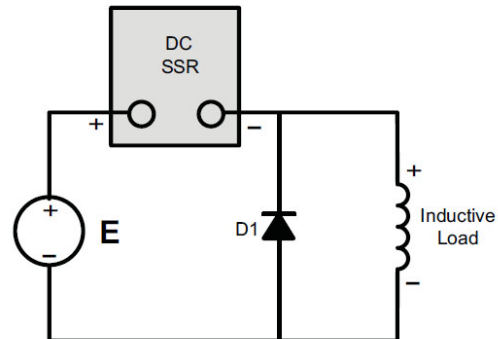


Figure 1: Freewheel diode placed across an inductive load.

load has completely discharged then a fast recovery diode is preferred. This will reduce surge current and duration through the output of the relay. In fact, fast recovery diodes are readily available and inexpensive so it's prudent just to use one in every instance.

As shown in figure 1, the diode is reverse biased when the relay is in the on state. Therefore current will only flow through the load, which has the same polarity as the power source. When the relay is turned off the collapsing magnetic field will attempt to maintain current flow in the "pre off-state" direction. However, as shown in figure 2 below, the freewheel diode will begin to conduct at its specified forward voltage drop (typically ~1.2Vpk). As a result, the collapsing field cannot generate a voltage spike greater than the  $V_f$  rating of the diode, effectively protecting the SSR from damage.

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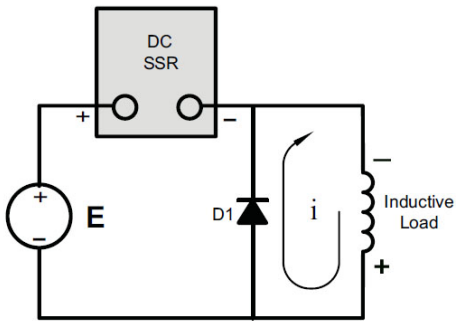


Figure 2: Load polarity and current path through the freewheel diode when the SSR is turned off

### Considerations for Suppressing EMR Coils

The use of DC solid state relays to switch the coils of electromechanical relays is becoming more common in the market. While there are several technical advantages in using SSRs for such applications, the coils of EMRs can be quite inductive and must be adequately suppressed in order to prevent the SSR from being damaged. Unfortunately, electromechanical relays are normally designed without consideration to the effect that suppressors have on the overall reliability of the relay. As a result, suppressing the coil of an EMR with a simple recovery diode will protect the solid state relay performing the switching function but may lead to a premature failure of the EMR itself.

The velocity of the armature in an EMR as it returns to its “rest” position plays a significant role in the relay’s ability to avoid severe arcing across the

contacts or “tack welding”. When the coil is de-energized, the greater the voltage spike the faster the magnetic field decays and the faster the armature returns to its “rest” position. Placing a suppression diode across the coil slows the decay of the magnetic field when the relay turns off, which in turn slows the return of the armature to its resting position. Therefore, it is more difficult for the relay to break the flow of load current and the additional arcing on the contacts may seriously degrade the overall reliability of the relay. With heavy inductive loads, the arcing may generate enough heat to weld the contacts together and prevent the relay from being able to break the flow of current to the load.

In such applications it is therefore necessary to incorporate a suppression circuit that allows for the dissipation of the voltage before it reaches a level capable of damaging the SSR, but high enough to allow the armature to quickly return to its rest position. This is commonly done by adding a zener diode in series with the suppression diode. As seen in figure 3 below, the voltage across the coil when the relay is de-energized still has a conductive path through the suppression diode, similar to what is shown in figure 2. However, the magnetic field will not discharge until the reverse voltage reaches the avalanche voltage of the series zener diode. This allows for a rapid decay of the magnetic field and subsequent quick return of the armature to its resting position.

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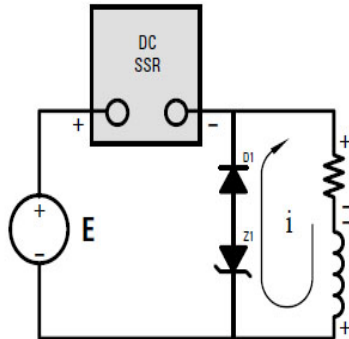


Figure 3: Freewheel diode with series zener diode for EMR coil suppression

One important note with regards to using a zener diode for coil suppression; the sum of the zener diode voltage,  $V_f$  of the freewheel diode, and DC supply voltage must not exceed the maximum voltage rating of the SSR. For example, if we use a 100Vdc SSR with a 48Vdc supply, then the voltage across the freewheel diode circuit must never exceed 52Vdc. Otherwise the combined voltages will exceed the maximum rating of the solid state relay. In this example a 48V zener diode would allow for sufficient head room to adequately protect the SSR from damage.

### Other Suppression Techniques

While fast recovery and zener diodes are effective and the most common suppression techniques used in the field to protect DC SSRs, there are other methods that may also be considered. In some cases a simple resistor placed across the coil is sufficient to suppress reverse voltage spikes and protect SSRs. However, consideration must also be given to power dissipation as some level of load current will flow through the resistor while the SSR is in

the on state. RC “snubber” networks have also been used in the past but are not very economical. MOVs are another possible solution but not commonly used as their inherent design characteristics make them less reliable as a long-term solution.

Also, as we just discussed, the response time must also be considered if the load is an EMR coil. Table 1 below shows the drop-out time of an EMR and the theoretical and measured voltages across the coil for various suppression methods. As can be seen in the test data, the armatures of an unsuppressed coil returned to their resting position in 1.5ms. Adding a diode decreased the response time by more than a factor of six. Alternatively, placing a 24V zener in series with the diode only caused an additional delay of 400uS and still provided adequate suppression of the voltage spike.

Suppression Technique	Drop-out Time (ms)	Theoretical Transient	Recorded Transient
Unsuppressed	1.5		-750
Diode & 24V Zener	1.9	-24.8	-25
680Ω Resistor	2.3	-167	-120
470Ω Resistor	2.8	-115	-74
330Ω Resistor	3.2	-81	-61
220Ω Resistor	3.7	-54	-41
100Ω Resistor	5.5	-24.6	-22
82Ω Resistor	6.1	-20.1	-17
Diode	9.8	-0.8	-0.7

Table 1: Response time and voltage across a 55 Ohm coil with a 13.5Vdc supply. Courtesy of www.kilovac.com

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[D06D Series to 100A @ 60Vdc](#)

[D1D Series to 100A @ 100Vdc](#)

[SSC Series to 25A @ 1000Vdc](#)

**PCB Mount SSRs**

[CMX Series to 20A @ 60Vdc](#)

[MCMX Series to 10A @ 100Vdc](#)

[Mini-SIP DC SSRs](#)

**DIN Rail Mount SSRs**

[CKM Series to 30A @ 60Vdc](#)

[DRA1 Series to 10A @ 100Vdc](#)

[DRA4 Series to 8A @ 100Vdc](#)

[DRACN Series to 2.5A @ 24Vdc](#)

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