

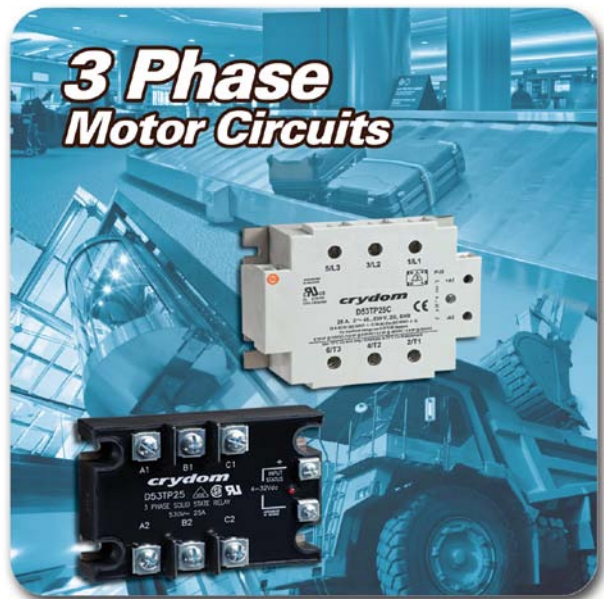
Three Phase Solid State Relays & Their Application in Three Phase Motor Circuits

*By Paul Bachman, Fellow Engineer,
Dr. Oscar Montero, R&D Manager, and
Doug Sherman, FSAE Manager,
Crydom, Inc.*

ABSTRACT

Three phase Solid State Relays (SSRs) have been available since shortly after the introduction of Single Phase SSRs in 1970. The first of these relays were nothing more than 3 individual SSRs with a common input connection packaged in a single housing. This basic design concept remains, for the most part, unchanged today. However, even though the function of single-phase and three phase relays are quite similar, their applications can vary significantly. This is primarily due to the characteristics of three phase power circuits and the attributes/demands of three phase loads, particularly inductive loads.

The proper selection and application of three phase SSRs for Motor control applications depends not only upon a comprehensive understanding of three phase SSRs, but also of the three phase power system and typical loads as well. This paper includes a summary review of three phase power systems, the characteristics of common three phase Motor loads, and a comprehensive discussion of three phase SSRs and their application relative to such loads.



INTRODUCTION

Solid State Relays are used in a wide variety of electrical load-switching applications, including Professional Cooking Equipment, Plastics Machinery, Packaging Machinery, Lighting Systems, Medical Equipment, Laboratory Ovens, Beverage Dispensing Equipment, HVAC&R systems, and many other industrial or commercial applications. However, for the purpose of understanding these applications relative to the use of SSRs for their control, the vast majority of loads can be grouped into two primary categories: heating and motion control. Obviously this is not an all-inclusive grouping as there are other applications outside of the scope of these two categories such as lighting and power distribution systems. However, a majority of Design Engineers specifying SSRs apply them to one of these two general types of three phase loads as shown in **Figure 1** below. The focus here is on Motor loads while a companion paper focuses on Heating loads.

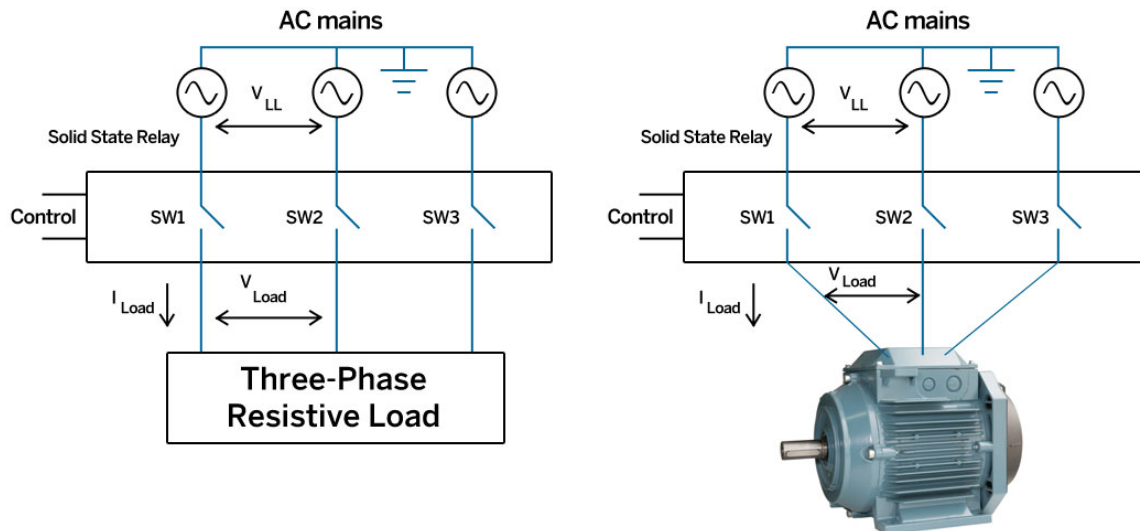


Figure 1 - Block diagram depicting three-phase loads controlled by Three-phase SSRs.

While every application is different and requires its own scrutiny, focusing on these two main categories allows us to generalize about the characteristics of the applications and the subsequent requirements placed upon the SSRs used to perform the switching functions for each. Moreover, limiting the focus to higher-power systems utilizing three phase networks to energize the load(s) covers some of the most demanding commercial and industrial applications where SSRs are used today.



THREE PHASE SSRs DEFINED and DESCRIBED

As previously mentioned above, a three phase SSR is essentially 3 individual single phase SSRs packaged in a single housing with a common input so that each SSR is energized simultaneously. In fact, it is not uncommon for engineers to use 3 individual SSRs to switch power to a three phase load. This is usually done out of preference or where a pre-packaged three phase SSR is not suitable for one reason or another. However, the more common and simplistic approach is to use a three phase SSR to provide the switching function. This simplifies wiring and usually reduces overall space requirements within the panel.

The main attributes of SSRs, whether single or three phase are: contact less turn on and turn off which means no arcing, contact bounce or acoustic noise; high speed switching; long life expectancy; low input control power requirements; zero current turn off which substantially minimizes electrical transients especially when switching inductive loads; and zero voltage turn on which can minimize turn current surges and their resulting transients.

Three phase SSRs are intended to control three phase AC loads, which might otherwise be switched by Electromechanical Relays, Contactors or three phase Mercury Relays or Contactors. For three phase resistive heating applications, zero-crossing three phase SSRs are commonly used. These versions will switch power to the load at the zero-voltage crossing point of each phase in order to minimize inrush currents. Random turn-on SSRs are recommended for switching inductive loads, such as motors, compressors, or transformers where it is desirable to switch on 3 phases on at exactly the same moment. All AC output SSRs (excepting special versions built with FETs or IGBTs) turn off at zero current irrespective of whether they are zero voltage or random turn-on SSRs, and thus reduce transients caused by opening a load with a magnetic field that collapses resulting in transients.

Considerations when incorporating SSRs in three phase applications include: thermal power dissipation in the SSR due to losses in the output power semiconductors which often requires the use of external heat sinks to maintain allowed operating temperature; electrical transients carried on the power lines or created by switching reactive loads that may require additional transient protection for the SSR; and selection of zero voltage or non-zero voltage turn on depending upon load type.

THREE PHASE POWER SYSTEMS

Three phase electric power is the most common method for distributing electric power worldwide. **Figure 2** depicts three phase power as provided by three voltage waveforms for three conductors carrying alternating current at the same frequency but with a shift of 120° between any two of the three phases (instantaneous peak values at different times). Three phase power is typically used to power large motors or other high-power loads and offers several advantages over equivalent single-phase or two-phase systems including:

- Three phase power provides the most consistent supply of current and therefore power. There is always at least 2 phases delivering power to the load where as single phase systems have zero power delivered for a short time each half cycle.
- Three phase systems tend to be more economical as they use less conductor material to transmit power than single or two-phase systems providing the same power level.
- Neutral conductors can use less material or be eliminated completely as the phase currents cancel out one another in a balanced load. In this circumstance where the neutral is eliminated it is also possible to control the load by switching only 2 of the 3 phases which offers further advantages by reducing the number of relays or contacts required.
- Power transfer is constant into a linear and balanced load, which helps reduce vibration in three phase motors compared to single phase motors of equivalent HP.
- Three phase systems produce a magnetic field rotating in one direction, which helps simplify motor design and offers the ability to easily reverse a motor's direction of rotation by swapping two of the three phases.

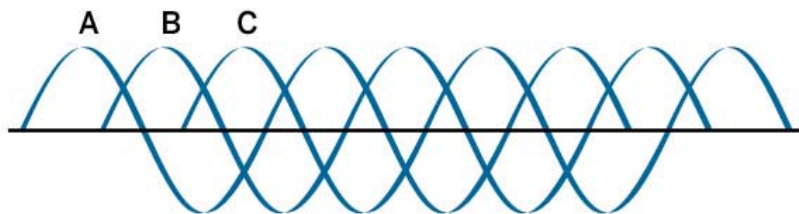


Figure 2 – Three-phase power systems

THREE PHASE INDUCTION MOTOR LOADS

Three phase induction motors have 3 individual coils and while they may be wired in either a wye or delta configuration much like three phase heaters, the wye configuration is the more common and preferred configuration (**Figure 3**). The design and placement of the coils is such that for each revolution of the motor, the three interspersed magnetic fields generate rotational torque on the rotor, causing it to turn. This design creates more mechanical force with less current per phase than for equivalent rated single phase motors. Due to the 120° separation between the coils, there is significantly greater starting torque and less vibration than for single phase motors, and often no need for start capacitors to provide additional current to overcome high inertial or compressor loads.

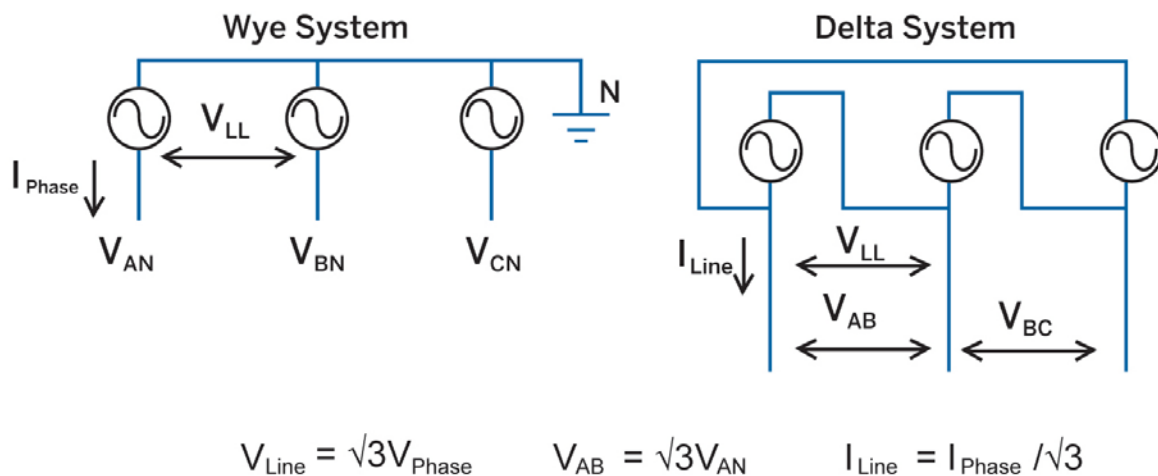


Figure 3 – Wye and Delta connection of Three-phase motors

Consequently, three phase induction motors are used in many industrial applications to operate loads such as pumps, compressors, valves, conveyors, and many other motor-driven devices. They are relatively simple in design, efficient, smaller, less expensive and generally more durable than single-phase motors with comparable ratings.

For three phase motors, the following formula applies:

$$HP = \frac{\sqrt{3} \times I_L \times V_L \times Eff \times pf}{746} \quad (1)$$

Where HP is horsepower, V_L is line voltage, I_L is line current, Eff is the motor's efficiency as a decimal value, and pf is power factor.



Therefore the line current per phase or “FLA” (full load amperes) in a three phase motor operating at its maximum specified horse power would be calculated as:

$$FLA = I_L = \frac{HP \times 746}{\sqrt{3} \times V_L \times Eff \times pf} \quad (2)$$

Similarly, when the motor’s Kilowatt rating is known, the line current per phase or FLA would be calculated as follows:

$$FLA = I_L = \frac{KW \times 1000}{\sqrt{3} \times V_L \times Eff \times pf} \quad (3)$$

Therefore, when the motor’s Kva rating is known, the line current per phase or FLA would be calculated as follows:

$$FLA = I_L = \frac{KVA \times 1000}{\sqrt{3} \times V_L} \quad (4)$$

Locked rotor current (I_{LRA}) is calculated as follows:

$$I_{LRA} = \frac{577 \times HP \times KVA/HP}{V_R} \quad (5)$$

Where KVA/HP is motor slip calculated as a % reduction in RPM from the synchronous RPM to actual RPM (see **Table 1** below), and V_R is the motor’s rated nominal AC operating voltage. If the actual operating line voltage is different, then the locked rotor current will vary directly as the line voltage varies ($I_{LRA} \times (V_L/V_R)$).

| Code | KVA/HP | Code | KVA/HP | Code | KVA/HP | Code | KVA/HP |
|------|-----------|------|-----------|------|------------|------|------------|
| A | 0-3.14 | F | 5.0 -5.59 | L | 9.0-9.99 | S | 16.0-17.99 |
| B | 3.15-3.54 | G | 5.6 -6.29 | M | 10.0-11.19 | T | 18.0-19.99 |
| C | 3.55-3.99 | H | 6.3 -7.09 | N | 11.2-12.49 | U | 20.0-22.39 |
| D | 4.0 -4.49 | I | 7.1 -7.99 | P | 12.5-13.99 | V | 22.4 & Up |
| E | 4.5 -4.99 | K | 8.0 -8.99 | R | 14.0-15.99 | | |

Table 1 - Motor slip value codes

Note: formulas (1), (2), (3), (4), (5) & Table 1 courtesy of Baldor Electric Company.

It is evident that the actual HP delivered by the motor depends on the line voltage (V_L) applied to its terminals. Furthermore, the line current (I_L) drawn by the motor also depends on V_L as well as the actual mechanical load attached to the motor's shaft. It is important to recognize the following points regarding I_L :

- *During motor starting operation:* I_L reaches its highest value as the motor tries to overcome the mechanical inertia imposed mainly by the mechanical load. As shown in **Figure 4**, this is a transitory condition that may last from several cycles to seconds depending on the nature of the mechanical load. This current is also known as Locked Rotor Current, I_{LRA} , and is calculated using equation (5).
- *During motor steady state operation:* As the motor speeds up, the current I_L decreases until it settles at an operational value that matches the HP delivered to the load. The highest value for I_L corresponds to the motor rated current or Full Load Current, FLA.

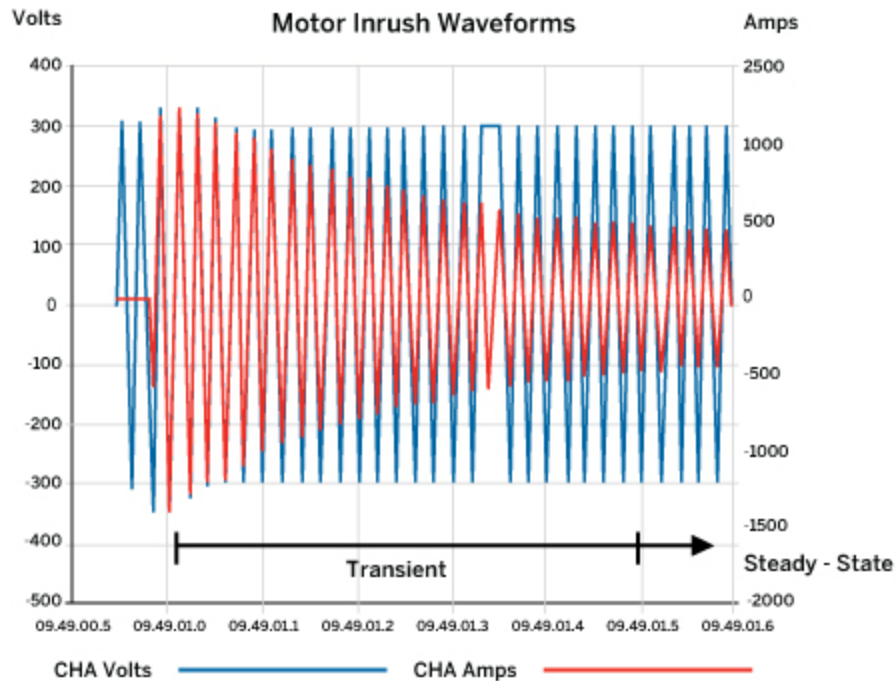


Figure 4 - Typical LRA and FLA waveforms for an AC motor.



The current through a motor load can then be said to have two main components:

$$I_{\text{Load}} = I_{\text{transient}} + I_{\text{steady-state}} \quad (6)$$

Where I_{Load} is the per phase current flowing through both the load and consequently the switch or relay.

In particular, $I_{\text{transient}}$ is negligible for Resistive loads hence I_{Load} can be approximated to $I_{\text{steady-state}}$. However, for Motor loads, $I_{\text{transient}}$ can be considered equivalent to Locked Rotor Amps (LRA), while $I_{\text{steady-state}}$ can be considered equivalent to Full Load Amps (FLA). LRA values can be 5 to 7 times FLA values for several seconds depending on the type of motor and application.

Example Line Current Calculation for a three phase Induction Motor

Calculate the full load and locked rotor line currents per phase for a 5 HP, 440 VAC, 85% efficient, 0.7 power factor three phase induction motor with slip code E operating in a 40°C ambient:

$$I_L = \frac{\text{HP} \times 746}{\sqrt{3} \times V_L \times \text{Eff} \times \text{pf}}$$

$$I_L = \frac{5 \times 746}{1.73 \times 440 \times .85 \times .7}$$

$$I_L = 8.2 \text{ amps per phase}$$

For locked rotor rating, the range of lower to higher values is calculated as follows:

$$I_{\text{LRA}} = \frac{577 \times \text{HP} \times \text{KVA/HP}}{V_R}$$

$$I_{\text{LRA}} = \frac{577 \times 5 \times 4.5 \text{ (lower limit)}}{440}$$

$$I_{\text{LRA}} = 29.5 \text{ amps}$$

$$\text{Using the upper limit of slip (5.0), } I_{\text{LRA}} = 32.8 \text{ amps}$$

For this example, locked rotor currents would fall between 29.5 and 32.8 amps per phase.

Safety Agency Standards Relative to Solid State Relays

SSRs may be rated by their manufacturer for operation in certain types of applications. The most common rating categories pertain to applications for resistive loads and motor loads. The main difference between these two ratings is that SSRs for motor applications must be rated to handle both LRA and FLA. The following table (**Table 2**) summarizes the three most common standards for Solid State Relays in motor applications.

| Standard | Classification |
|-----------------|---------------------------|
| UL508 | Motor Controller |
| IEC62314 | Motor Load, LC B |
| IEC60947-4-2 | Motor Controllers, AC-53a |

Table 2 – SSR Motor Load Ratings per Relevant Standards

Standards mentioned in **Table 2** require that switches intended for controlling Motor loads be able to handle load currents that resemble LRA conditions. As a result, a given SSR would have different Load current ratings for Resistive loads or Motor loads. Essentially, the SSRs Resistive load rating is derated when applied to Motor loads. For instance, an SSR capable of carrying 50A resistive current could be rated as a 17A SSR when placed in motor control applications.

SSRs for three phase Induction Motor Applications

Historically the most common devices used for switching power to induction motors are electromechanical relays and contactors. However, as demand for improved performance and reliability increases, solid state relays are being applied in growing numbers. As with resistive load controls, this can be accomplished with 3 individual SSRs, one three phase SSR, or with 2 SSRs (or 1 dual SSR) where codes permit.

The major advantages of SSRs for three phase induction motor control are as follows:

- All solid state construction eliminates mechanical fatigue within the relay
- Contact less, arc free silent operation
- High speed switching allowing very precise control
- Logic compatible low input control power
- Electronic “AC and DC coils” which eliminate transients created when EMR Contactor coils are operated
- Zero current load turn off eliminating transients
- Extremely long life when compared to mechanical relays or contactors
- 4000 VAC isolation input to output
- RoHS compliant

Start/Stop Motor Applications

Most applications utilizing three phase motors simply require the motor to turn on and off as depicted on **Figure 5**. For example, an industrial fan would typically run in only one direction to circulate air and would therefore only need to be switched on and off. A compressor is another example of a three phase load where the motor simply needs a connection to a three phase AC supply circuit for proper operation. These applications typically use a simple three phase solid state relay, contactor or motor starter switch to apply power simultaneously to all 3 of the motor's windings in response to a single input control signal to the contactor.

The power factor for induction motor loads can be quite low ($<.6$) so there can be a significant shift between the voltage and current of each phase (phase current lags behind the phase voltage). Zero-crossing solid state relays are typically not suitable for such applications as the relay will only turn on when the AC sine wave is close to the zero-crossing point. With three phase AC systems each phase is shifted 120° from the other 2 phases which means that zero voltage SSRs in each phase will turn on sequentially, not simultaneously as needed. Also due to the phase shifts associated with induction motors, the relay may fail to turn on due to insufficient latching current through the output SCRs before the line voltage exceeds the zero-cross window. In some cases, the relay may operate erratically and half-wave or only provide power to one or two phases of the motor.

Therefore, random turn-on (sometimes called "instantaneous" or "asynchronous" turn-on) solid state relays are recommended. The output of a random turn-on relay will switch power to its load within 100us of the input signal being applied, regardless of the voltage amplitude of the AC sine wave. Thus all three phases will be supplied to the motor simultaneously and phase shifts between current and voltage no longer affect the turn on performance of the solid state relay.

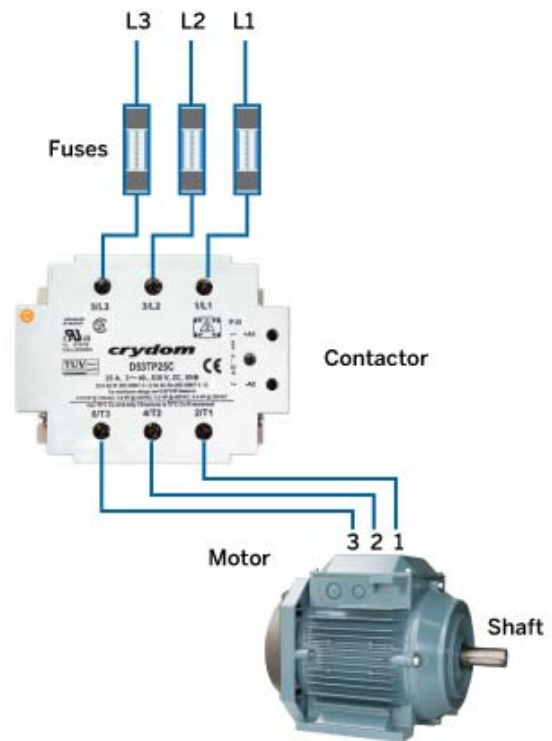


Figure 5 - Simple three phase motor



Load Current Transient conditions must also be considered when specifying solid state relays for use with motor loads. Depending upon the size of the motor and the load placed upon the motor itself, the inrush current when it is first energized can be 5 to 7 times its normal operating current. This overload which can potentially be as high as the motor's Locked Rotor Amps (LRA) will gradually decrease to its Full Load Amps (FLA) rating over several AC cycles as the motor begins to rotate (see **Figure 4** above), but the relay and associated connections must be sized properly to prevent them from being damaged during start-up. Consideration must also be given to the possibility that a motor may stall under certain conditions which would result in line current equal to or greater than the motor's LRA value. In this circumstance, over current protection must be employed to protect both the relay and the motor.

Voltage Transient protection is also another consideration for SSRs. Nearly all AC mains carry transients to one degree or another created when loads wired to the same or adjacent circuits are switched. These transients can easily be several thousand volts in amplitude and result in damage to SSRs wired to these lines. For both reliability and safety, it is advisable to provide transient protection for all SSRs controlling 3 phase induction motors. Such protection may be available internal to the SSR, or applied external to the SSR. The most commonly applied devices are MOVs which have very good power dissipation ratings, but are somewhat slow to react to fast transients. However, bi-directional TVS diodes provide very good performance for fast transients although their dissipation ratings are somewhat lower than MOVs.

Motor Reversing Applications

Some loads such as sun-tracking solar panel systems utilize motors to reposition solar panels throughout the day to follow the path of the sun across the sky. In this application, not only does the motor have to start and stop repeatedly, it must also reverse its direction of rotation to return the panels to their original position in order to greet the sun the following morning. This requires a motor control that not only energizes the motor, but also reverses its direction of rotation when needed.

Figure 5 above illustrates a simple wiring diagram for controlling a three phase motor with a contactor. When the contactor is energized it switches the three phases of the AC mains to the motor which then begins to rotate accordingly. It will continue to rotate at a constant speed and direction for as long as the contacts remain closed. However, if the connection of any two phases of the AC mains to the contactor are interchanged (connect L1 to terminal #2 and L2 to terminal #1, for example), the direction of the motor rotation will reverse when it is re-energized.

Of course, physically changing the wiring connections on the contactor every time there is a need to change the direction of the motor is impractical. Therefore, a means is needed to do this automatically when a "direction" command is provided by a controller. Traditionally this was accomplished by using discrete components, multiple mechanical relays or, more conveniently, a three phase motor-reversing contactor. However, mechanical solutions have the same drawbacks associated with any electromechanical device. The most significant of these drawbacks is life expectancy, especially in applications where the motor is repeatedly "bumped" or "inched" in order to achieve a specific position.

One possible motor-reversing solution that addresses the problems associated with mechanical contacts is the utilization of multiple single-phase solid state relays. As seen in **Figure 6**, L1 of the AC mains is connected directly to the motor. SSR #1 and SSR #3 connect either L2 or L3 to the second leg of the motor, and SSR #2 and SSR #4 connect either L2 or L3 to the third leg of the motor. When SSRs #1 & #2 are energized, the motor will rotate in one direction. To reverse the direction, SSRs #1 & #2 are de-energized, and SSRs #3 & #4 are energized, effectively swapping the connection of L2 and L3 to the motor leads.

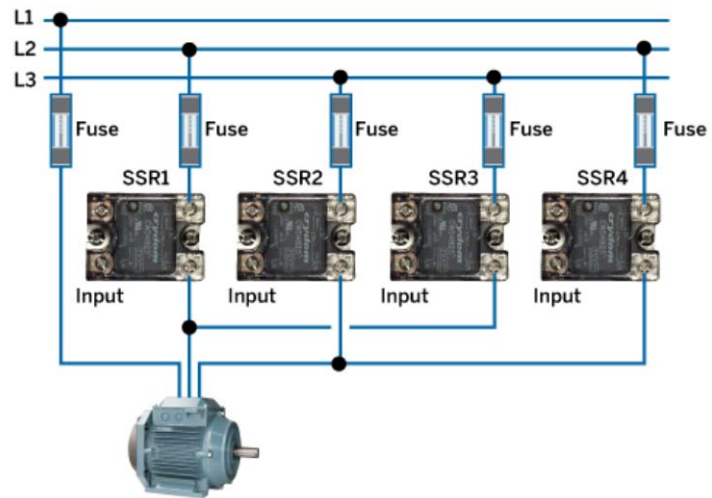


Figure 6 - Four SSR motor-reversing circuit, with direct connection of the third phase to the motor.

Note: Important remarks regarding the use of multiple SSRs in a motor-reversing application:

- 1) *Motors used in reversing applications may be mechanically more robust due to the demands placed upon the motor, but electrically, the same issues apply as for induction motors used in simple start/stop applications as noted earlier.*
- 2) *The system controlling the SSRs must have an interlock circuit that prevents the “forward” and “reverse” relays from turning on simultaneously! Failure to comply with this requirement may result in a phase-to-phase short through the relays.... a very dramatic and unwanted effect.*
- 3) *Relays with internal over voltage protection must not be used in motor-reversing applications. An internal TVS may switch on the output of the SSR when subjected to an electrical transient, effectively creating a phase-to-phase short. A Metal Oxide Varistor (MOV) may be placed across the output of each SSR to provide protection from transients.*
- 4) *A fifth SSR can be used to switch the third phase of the motor if this is required by the application. It is not necessary for this relay to be part of the interlock circuit directly, but it must be energized at the same time as either the “forward” or “reverse” relays to prevent the motor from being damaged when only 2 phases are energized.*



Another and generally preferred solution for many motor reversing applications is to utilize a motor-reversing solid state relay. A motor-reversing SSR offers two significant advantages over the methods discussed previously: 1) all four SSRs are contained in one industry-standard three phase SSR package thus minimizing wiring connections; 2) the interlock circuit is already built into the SSR.

As can be seen in **figure 7**, two of the three phases are wired through a motor-reversing SSR and the third phase is connected directly to the motor. When a logic signal is applied to the “forward” control terminal, the SSR switches L1 and L2 directly to the motor. When the signal is removed from the “forward” control terminal and applied to the “reverse” control terminal, the SSR switches the connection of L1 and L2, which reverses the direction of the motor. If a logic signal is simultaneously placed on the “forward” and “reverse” control terminals, the SSR will shut off or remain off.

External MOVs can be added to the circuit to provide additional protection from over voltage conditions if they are not already included with the reversing SSR. As demonstrated in **Figure 7**, the Reversing SSR has 4 separate output circuits to provide the motor-reversing function and therefore 4 MOVs are required (regardless of whether they are external or already built into the relay). Also, as with any electrical circuit, proper fusing and a suitable disconnect from the AC mains is required.

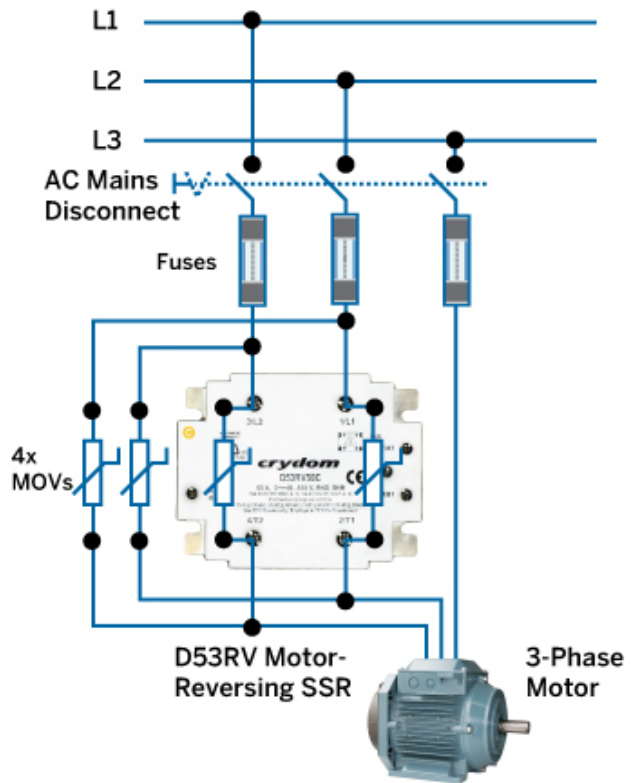


Figure 7 - Simplified Motor-Reversing SSR wiring diagram.



Selecting SSRs for 3 Phase Induction Motor Applications

To select an SSR for a 3 phase induction motor application, the following information is required:

- Motor Power in HP, watts or KVA
- Nominal AC 3 Phase supply voltage
- Operating ambient temperature for the SSR in the application
- Operation mode: start/stop or reversing

For most motor loads, if the motor's power factor is not known, it is a common practice to assume the load's power factor ($\cos \theta$) \leq 0.85. It is also prudent to include a 20% safety margin to allow for line, load and operational variances.

Once this information is known, one of the following processes can be used to determine the SSR rating for the application and then a suitable model with that rating can be selected:

- A) The most straight forward approach is to coordinate the SSR's horse power/voltage rating with the motor's horse power/operating voltage rating. This approach, excepting details related to the mounting, heat sinking and control voltage selection for the SSR, pretty much eliminates most calculations in the selection process because the transient currents have already been accommodated in the relay rating.
- B) Calculate the motor's worst case line current requirements under start and run conditions at its operating voltage, and then select a suitable SSR based upon its output current/voltage rating. In this case, some calculations using formulas presented earlier in this paper may be required.

Table 3 illustrates typical UL recognized horse power and FLA current ratings for various 3 phase type motor start/stop and reversing SSRs.

| HP Ratings at | Three phase SSR, HP/FLA | | | Reversing SSR, HP/FLA | |
|---------------|-------------------------|-----------|----------|-----------------------|-----------|
| | D53TP25X | D53TP50X | CTR6025 | D53RV25X | D53RV50X |
| 240V | 1HP/4.2A | 3HP/9.6A | - | 1HP/4.2A | 3HP/9.6A |
| 480V | 3HP/4.8A | 7.5HP/11A | 3HP/4.8A | 3HP/4.8A | 7.5HP/11A |
| 600V | 5HP/6.1A | 10HP/11A | - | - | - |

Table 3 - Crydom three phase SSR UL motor controller ratings.



Table 4 illustrates typical UL recognized horse power and FLA current rating for various single phase SSRs suitable for 3 phase motor start/stop and reversing applications

| HP Ratings at | CWD4825-10 | CWD4850-10 | CWD4890-10 | CWD48125-10 |
|---------------|------------|------------|------------|-------------|
| 240V | 3HP/17A | 5HP/28A | 7.5HP/40A | 10HP/50A |
| 480V | 5HP/14A | 7.5HP/21A | 10HP/26A | 15HP/34A |

Table 4 - Crydom single phase SSR UL motor controller ratings.

In the example cited earlier for a 5 HP 440 VAC three phase motor, the line currents were calculated to be 8.2 amps. The addition of a 20% safety margin results in a suggested SSR rating of 9.8 amps per phase or channel. Using method (A) above and **Table 3** for 3 phase SSRs, there is one matching SSR and 1 matching reversing SSR rated >5HP @ >440 VAC. Note that in each case the rated FLA current is greater than the example's calculated current of 9.8 amps. Using **Table 4** for single phase SSRs, there are several possible matches. Again, the FLA current rating for each is greater than the example's 9.8 amps, so an array of 3 (or 4 SSRs for reversing applications) could be selected to control the example 3 phase motor load.

Considerations for SSR power dissipation

Once the minimum SSR output rating for the application is determined based upon horse power or FLA, the power dissipation in the SSR(s) and the ambient temperature that will be present in the SSRs mounting area must be determined to calculate its effect on the required rating.

Most AC output SSRs will have an average on-state forward voltage drop of between 1.0 and 1.2 volts. The effect of this voltage drop is that 1 to 1.2 watts of energy are generated in the power assembly of the SSR per ampere of conducted load current, which must be dissipated into the surrounding environment. Heat Sinks are the most common means of facilitating this dissipation. The solid state relay may be mounted directly to a heat sink if it is purchased as an accessory component, or it may be integral to the SSR itself.

Using the previous example and assuming an average SSR forward voltage drop of 1.1 volts, the total power dissipation for the SSRs in the three phase circuit would be calculated as follows:

$$P_{SSR} = V_f \times I_L \times 3 \quad (7)$$

$$P_{SSR} = 1.1 \times 9.8 \times 3$$

$$P_{SSR} = 32.5 \text{ watts}$$

Therefore, 32.5 watts will have to be dissipated into the ambient surrounding the SSR regardless of whether the SSR has an integral or external heat sink.

Note: In a motor reversing application with the same capacity motor, the total power dissipation in the SSR would be 67% of that calculated for the start/stop operation since only 2 SSRs rather than 3 are used at any one time. The same would be true for three phase applications where only two lines are switched by 2 single phase or 1 dual output SSR.

Selecting three phase SSRs with Integral Heat Sinks

SSRs with integral heat sinks are the easiest to select because most of the thermal calculations have already been considered in its ratings. **Figure 8** is a typical output current rating verses ambient temperature curve for an SSR with integral heat sink. In the example cited above for an Induction motor with calculated line current of 9.8 amps per phase or 29.4 amps in total for all three phases, the SSR represented by this diagram will operate within its allowed ratings up to about 80°C ambient. Should the ambient temperature surrounding the SSR in the application exceed 80°C, a different SSR/heat sink combination with higher rating must be selected.

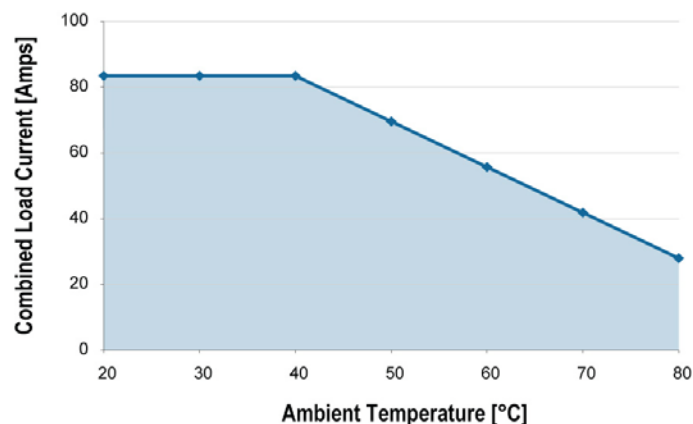


Figure 8 - SSR w/Integral Heat Sink Total Combined Output Rating verse Ambient Temperature

Three phase SSRs with integral heat sinks are available in either DIN rail mount or panel mount. In either case, the selection process is the same. The line current has to be determined along with line voltage and operational ambient temperature. Once this is done, it is a fairly simple matter to consult product specifications and review the output current verses ambient temperature charts similar to **Figure 8**.

In the application example given above of a 5HP Induction motor with 9.8 amps line current per phase, a three phase SSR rated at least 10 amps, FLA, per channel must be selected. However, ambient temperature effects whether the heat sink supplied with the SSR is sufficient to allow proper operation in the example applications 40 °C ambient.



Utilizing the chart in **Figure 8** as an example, indicates that the SSR represented by the chart would easily operate in a 40 °C ambient. However, if the application ambient were higher than 80°C, then an SSR with a higher output rating verses ambient temperature would have be selected (e.g. 25 amps/phase SSR).

When selecting a Crydom DIN rail mounted or Panel Mounted SSR for three phase motor loads, there are two possible options as shown in **Table 5** below.

- One CTRD6025R DIN rail mounted SSR
- One HS053-D53TP25D-10 panel mounted SSR/Heat Sink assembly

Note: Above part numbers are examples only. There is a large selection of suitably rated SSRs available from Crydom.

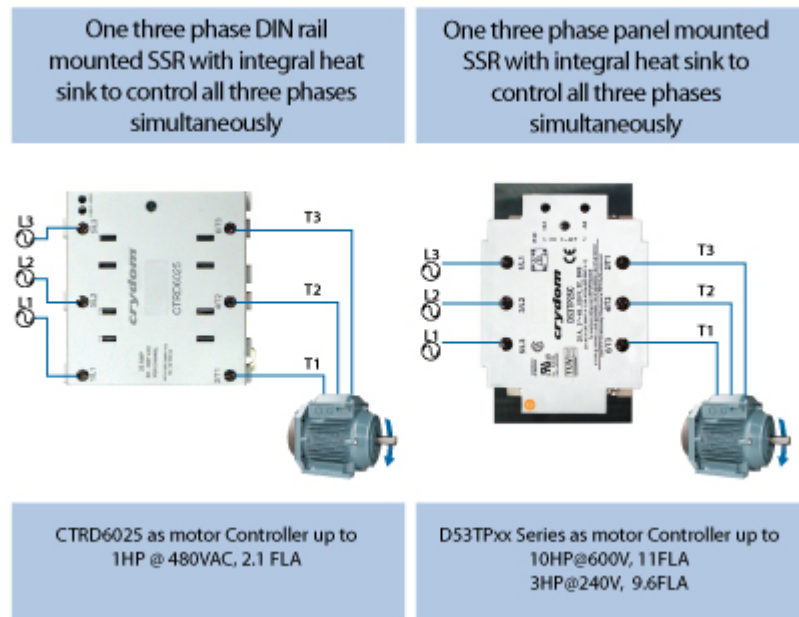


Table 5 - SSR options to implement three phase Induction Motor load control using DIN rail mounted or panel mounted SSR(s) with integral heat sinks.



Selecting three phase SSRs with Separate External Heat Sinks

In those cases where the SSR(s) and heat sink are separate components, it becomes necessary to determine the required minimum value heat sink rating to maintain a safe operating temperature for the SSR. There are numerous technical papers including Crydom White Papers that describe this process in detail and Crydom also provides a simple [Heat Sink Selection Tool](#) on its web site for this purpose should additional information be needed.

Generally, most AC output SSRs have a maximum allowed internal operating temperature of 125°C or less. Consequently, the selection of the SSR is determined by the combination of the SSRs power dissipation due to the application load current, operating ambient temperature where the SSR is mounted, and SSR thermal impedance specification.

The minimum heat sink rating ($R_{\Theta HS}$) in degrees C per watt for a given application can be calculated as follows:

$$R_{\Theta HS} = ((125 - T_{amb}) / P_{SSR}) - R_{\Theta SSR} - R_{\Theta TI} \quad (8)$$

Where:

- T_{amb} = the operating ambient temperature in °C
- P_{SSR} = the total power in watts dissipated in the SSR(s) for all 3 phases
- $R_{\Theta SSR}$ = specified SSR thermal impedance °C/W
- $R_{\Theta TI}$ = specified thermal impedance of the thermal interface material placed between the SSR and heat sink $R_{\Theta SSR}$

Note: the thermal interface material is placed between the mounting surface of the SSR and the heat sink to compensate for any surface irregularities that might increase thermal impedance and diminish SSR performance. These materials generally have a thermal impedance of between 0.03 and 0.1 °C/W depending on their composition and thickness.

In the application example given previously of a 5 HP Induction Motor with 9.8 amps line current per phase, and a three phase SSR rated at 10 amps per channel operating in a 40 °C ambient with $R_{\Theta SSR}$ of 0.25 °C/W, using formula (8), the minimum heat sink rating would be calculated as follows:

$$R_{\Theta HS} = ((125 - 40 / 32.5) - 0.25 - 0.05$$

$$R_{\Theta HS} = 2.3 \text{ °C/W}$$

Crydom Inc.

2320 Paseo de las Americas, Suite 201, San Diego, CA 92154
Tel.: +1 (877) 502 5500 - Fax: +1 (619) 210 1590 - E-mail: sales@crydom.com
www.crydom.com



Figure 9 is a representative thermal derating curve for a typical three phase panel mounted SSR showing its allowed output rating per phase for a motor load verses ambient temperature for various heat sink ratings.

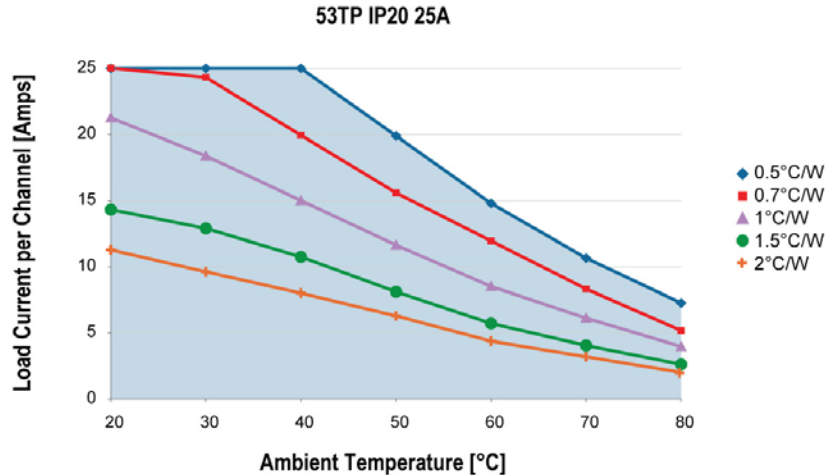


Figure 9 - Output Rating per Phase of a three phase SSR versus Ambient Temperature

In the example calculation and SSR selection above, the calculation determined that a heat sink with at least a 2.3 °C/W rating was required. More efficient heat sinks with lower numerical value thermal impedances can of course be utilized with the beneficial effect of lowering SSR operating temperatures, improved reliability and life expectancy.

When selecting a Crydom Panel Mounted SSR for three phase motor loads there are three possible options as shown in **Table 6** below.

The following options are deemed suitable for the current example:

- One D53TP10D-10 three phase SSR + HS103
- Three CWD4810-10 single-phase SSR + HS103
- One CC4825D2VR Dual SSR + HS201

Note: Above part numbers are examples only. There is a large selection of suitably rated SSRs available from Crydom.

Once the SSR has been selected the next step is to use the [Heat Sink Selection Tool](#) to complete the SSR and Heat sink selection.

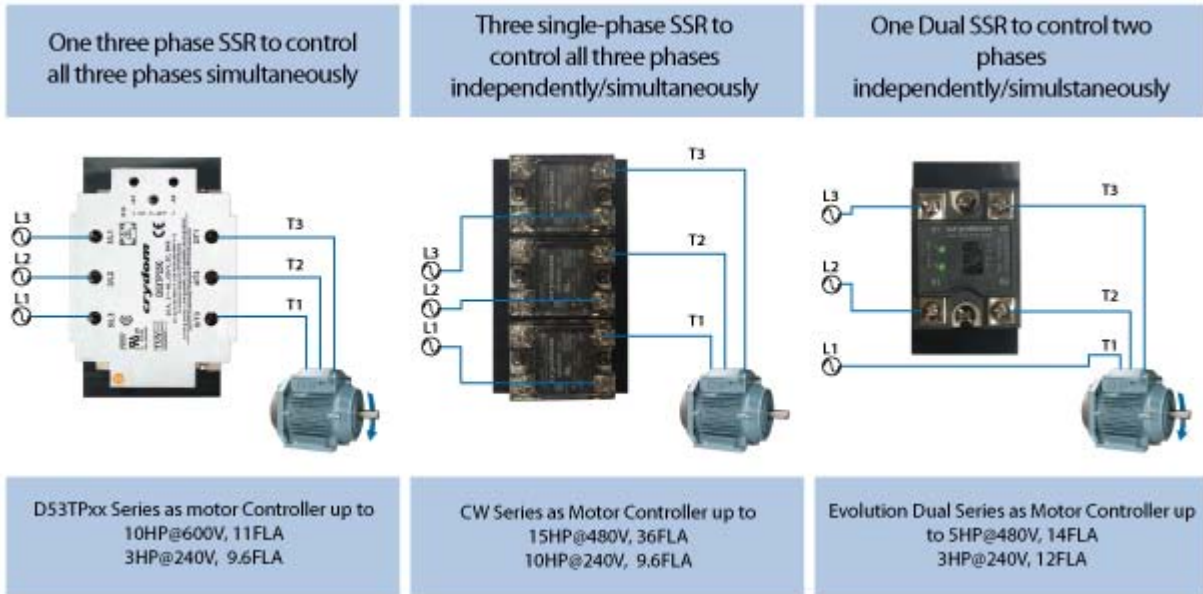


Table 6 - SSR options to implement three phase Induction Motor load control using Panel mounted SSR(s) with external heat sink.



SUMMARY

Solid State Relays, whether single or three phase, are ideal for the control of three phase induction motors. Proper selection of the SSR for any given application requires knowledge of the motor's power rating, operation voltage, ambient temperature and wiring configuration/function. A variety of SSRs are available for a wide range of operating conditions up to 600 VAC and > 50 amps per phase, in either Panel or DIN rail mount configurations. Heat sinking is required for the proper operation of SSRs in all applications and technical information on their selection is readily available.

For additional information on Solid State Relays with Motor Controller ratings, contact Crydom or visit www.crydom.com.

+++++

Copyright © 2011 Crydom Inc., All rights reserved.

The materials and information on this document are intended for informational purposes only. Materials are copyrighted and are protected by worldwide copyright laws and treaty provisions. They may not be copied, reproduced, modified, published, uploaded, posted, transmitted, or distributed in any way, without Crydom's prior written permission. Crydom does not warrant the accuracy or completeness of the information, text, graphics, links or other items contained within this document. Crydom may make changes to these materials, or to the products described therein, at any time without notice. Crydom makes no commitment to update the Materials.