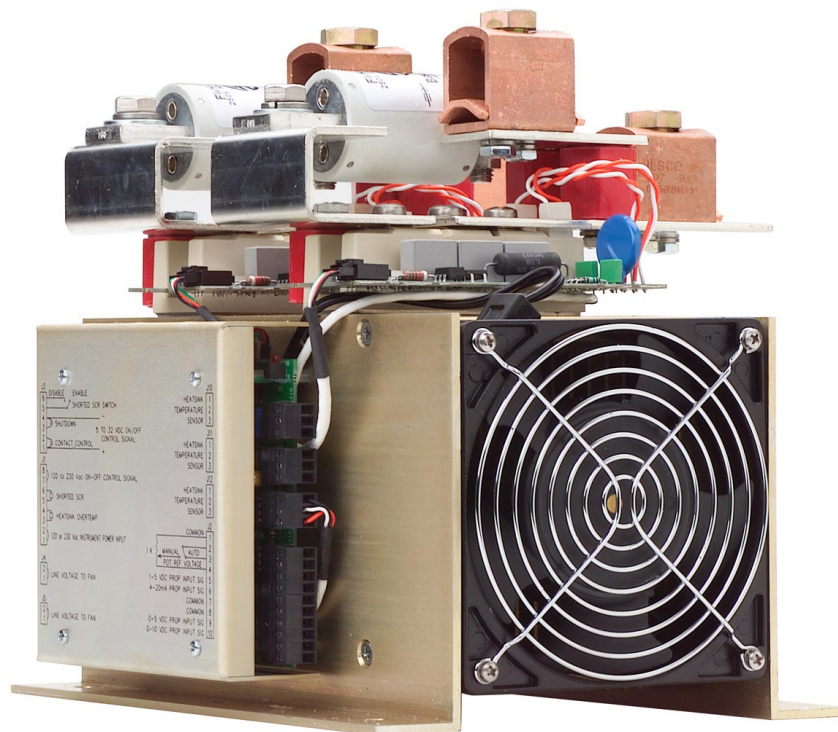


Chromalox®

PRECISION HEAT AND CONTROL

SCR Power Theory Training Manual



CHROMALOX TRAINING



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INTRODUCTION TO SCR POWER THEORY

The purpose of this guide is to teach you the fundamentals of Silicone Controlled Rectifiers (SCR) power regulators. Since the development of SCR power controllers in the late 1950's, the power handling capabilities of the devices has steadily increased from a few hundred watts to many megawatts. Due to the ever increasing reliability and decreasing costs of the devices, the use of the power controllers in industrial applications has increased dramatically and they are now used in almost every major industry. This guide includes an introduction to power theory, closed loop control, an introduction to the SCR, types of SCR's and their applications, three phase applications, and wraps up with a glossary of terms.

POWER CONTROL THEORY

Single Phase AC

An oscilloscope is a device that allows you to take a snapshot of alternating current. If an oscilloscope were connected to a 120 VAC household outlet, the resultant sinusoidal waveform viewed would be as shown in Figure 1. An AC waveform is comprised of positive half cycles and negative half cycles. The point in which the sine wave crosses from negative to positive or positive to negative is the zero voltage reference. A sine wave (60 Hz) is 16.6 ms (8.3 ms/half cycle), there are sixty cycles in one second.

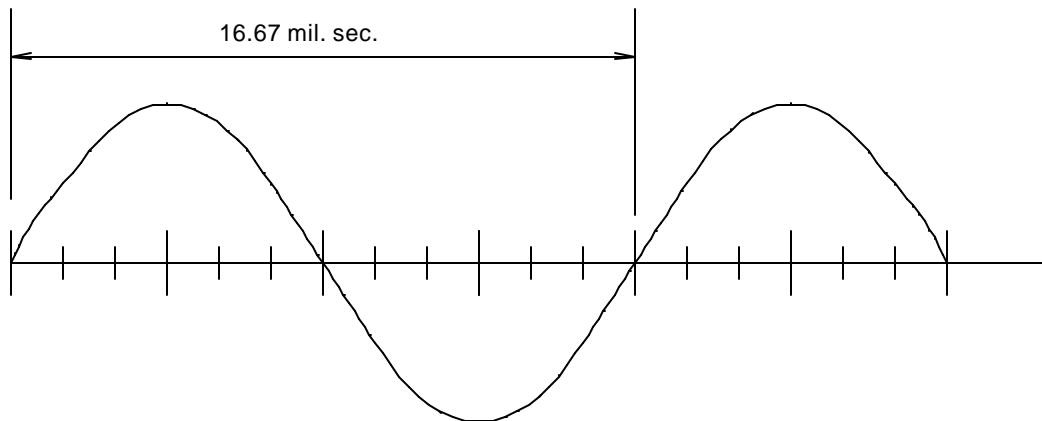


Figure 1: AC sine wave. This is a snapshot of AC power as seen on an oscilloscope.

Typical Closed Loop Application

Why do we need power control or an SCR? SCR's are devices that switch the power to a heater or load to provide control. Precise control of the load results in holding tighter temperatures and typically provides the user with better reproducibility and consistency in the process. A typical application for an SCR power regulator is shown in Figure 2. A resistive load with SCR control is diagrammed. A temperature sensor, usually a thermocouple or RTD (resistance temperature detector), measures the temperature inside the furnace. The output of the temperature sensor is fed to a temperature controller such as the Chromalox 2104. The controller compares the temperature to the setpoint and outputs a control signal to the SCR power regulator. If the temperature is below the setpoint, the control signal causes the regulator to deliver more power (in heating applications). If the temperature is above the setpoint, the regulator is instructed to reduce power to the heaters.

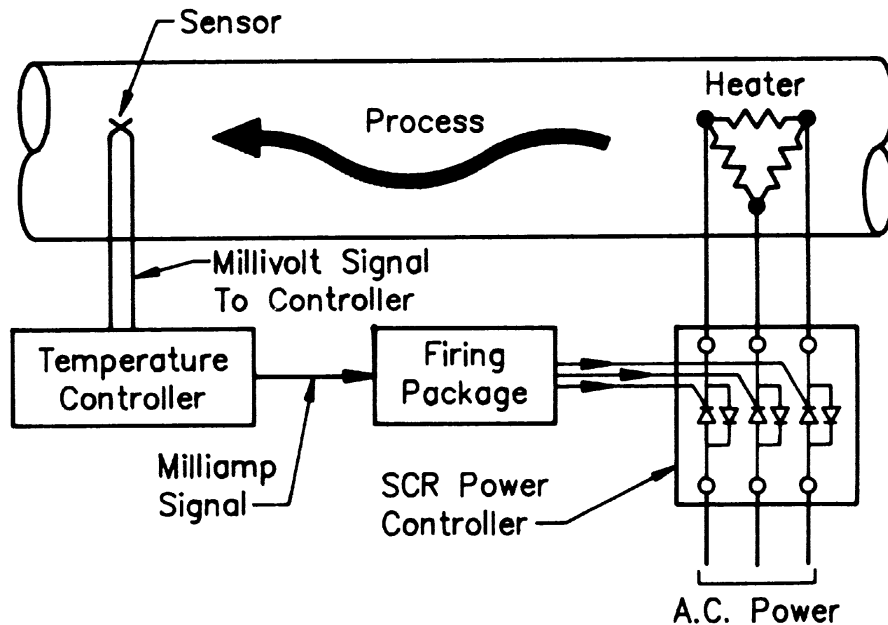


Figure 2: Typical closed loop application utilizing heater, sensor, process control, and SCR.

Mechanical Contactors

Historically, the primary means of switching power to electric heaters has been with mechanical contactors. A contactor rated for one million operations of mechanical life (one operation equals one make or one break) with a thirty second cycle time operating at 50% duty cycle would last approximately 175 days.

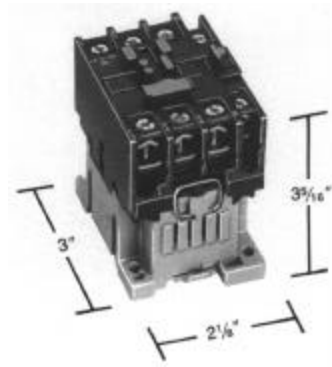


Figure 3: Electrical Contactor

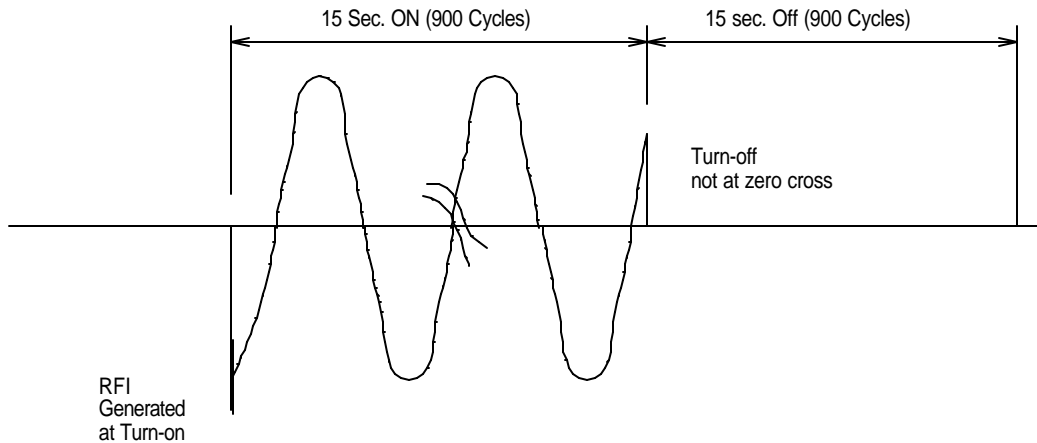


Figure 4: Contactor turning on and off at the non-zero points in the wave.

50% Duty cycle with a 30 second time base.
4 m/b per minute x 60 minutes per hour x 24 hours per day.

$$\frac{1,000,000}{5760} = 173.61 \text{ days}$$

Note: Contactor is off with no control signal and full on when the control signal is present. Standard contactor control signals are 120 VAC and 240 VAC.

Because a contactor cannot be switched faster than a 30-second time base, temperature control will be effected. If the load responds quickly, the temperature will fluctuate during the on and off cycles. Figure 5 shows how the temperature fluctuates during the on and off cycles.

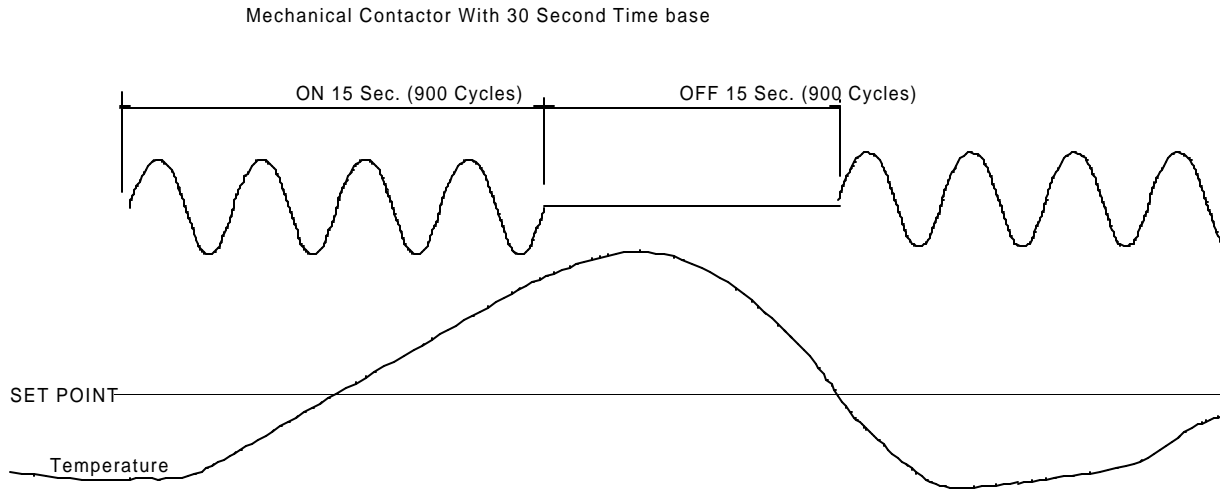


Figure 5: Contactor on a 30-second time cycle. Notice the large fluctuation in temperature that can occur when slowly switching a load.

One major problem with contactors is that they can turn on or off at any point in the sinusoidal wave. If the contactor shuts off when the voltage is not at the zero point an arc will occur. This arc will create radio frequency interference (RFI). RFI creates noise on the line voltage and causes problems with sensitive electronic equipment. Figure 6 shows an actual oscilloscope picture of the arc that occurs on the open and close of a contactor.

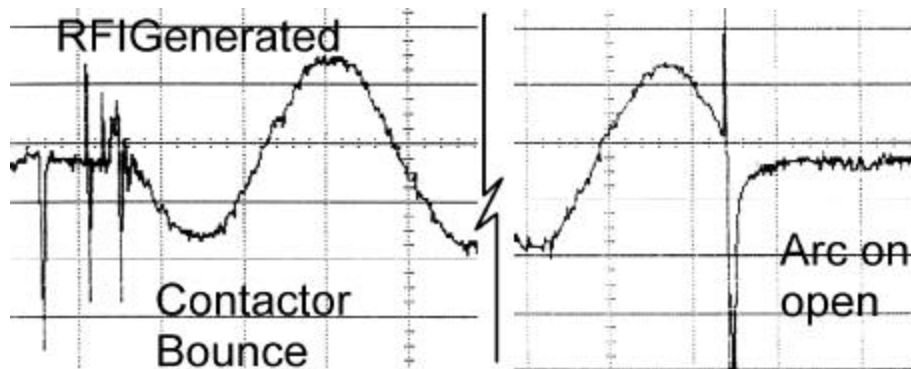


Figure 6: Note the line noise created by the chatter of a closing contactor. If a contactor opens at a non-zero point, an arc will likely occur.

Semiconductor Technology

Semiconductor is a material that has been treated to act as a conductor at times and as an insulator at others. A semiconductor rectifier is a device that has the characteristic of being a conductor when current flows in one direction and an insulator when current attempts to flow in the other direction. The schematic symbol for a semiconductor diode (rectifier) is shown in Figure 7. Current will flow in the direction of the arrow (forward) but will be blocked in the opposite (reverse) direction. If the voltage being applied is of the standard sinusoidal AC form, only ½ of the waveform is conducted (Figure 7).

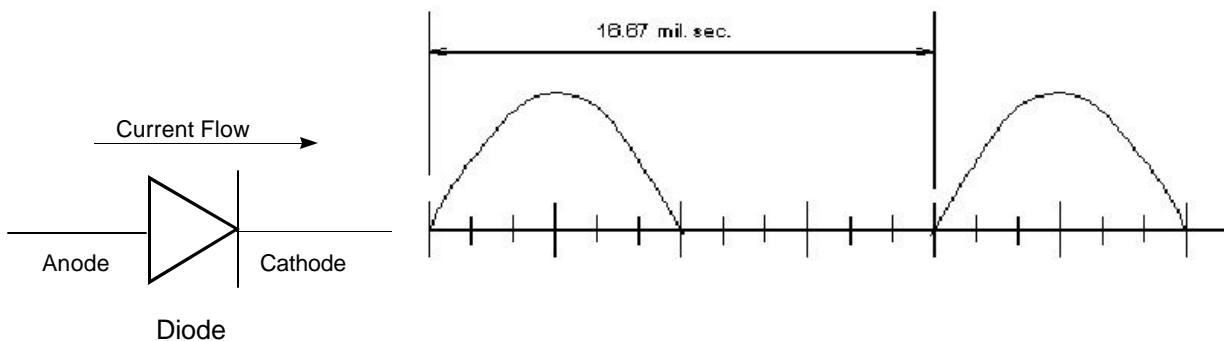


Figure 7: Only half of the duration of the waveform is conducting. The semiconductor conducts when current is flowing in the positive direction and does not conduct when current is flowing in the negative direction. Therefore, current flows during half cycles only.

Common Semiconductor Materials

1. Selenium – One of the original semiconductor materials used for rectifiers. Seldom used anymore.
2. Germanium – The second generation of rectifiers were made from this material. Still used to a small extent.
3. Silicon – The most prevalent semiconductor material in use today. Properties far superior to the other semiconductor materials.

Silicon Controlled Rectifiers

Most Chromalox power packs utilize Silicon Controlled Rectifiers to control power. A Silicon Controlled Rectifier (SCR) is a semiconductor rectifier that has the added feature of controllability. The SCR is capable of conducting OR blocking current in the forward direction, depending upon the gate signal. The SCR, like the diode, will always block current flow in the negative or reverse direction. The act of controlling or turning on an SCR, (i.e. telling it to conduct current) is also known as gating or firing the SCR. If only one SCR in an AC circuit is fired, only one – half of the AC current waveform is conducted (Figure 8).

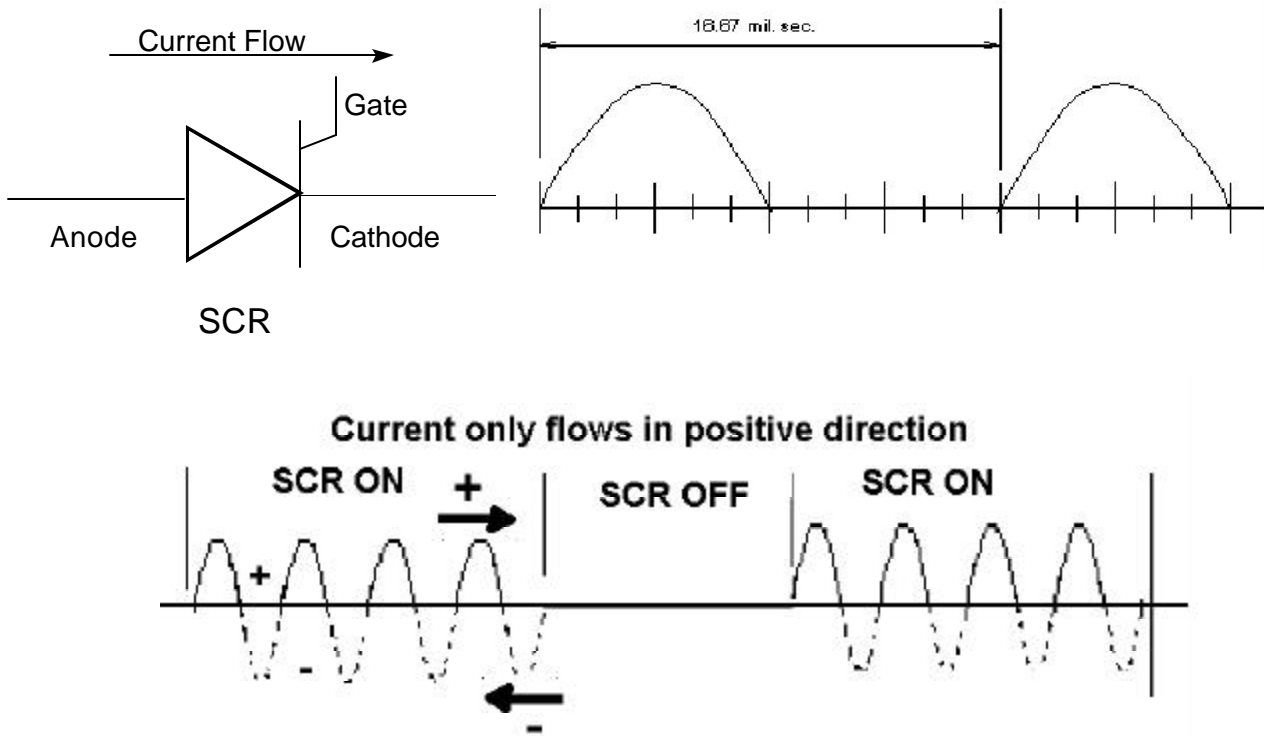


Figure 8: Current flows when the device is gated. The device will only turn off when the gate is turned off and the voltage reaches zero. The device will only conduct current in the positive, forward direction, if it is gated.

In order to deliver maximum power to the load, both halves of the AC waveform must be conducted. To achieve full wave conduction, two SCR's must be used. They must be connected in parallel but opposite directions (Figure 9). This circuit configuration is known as anti-parallel or "back-to-back" configuration.

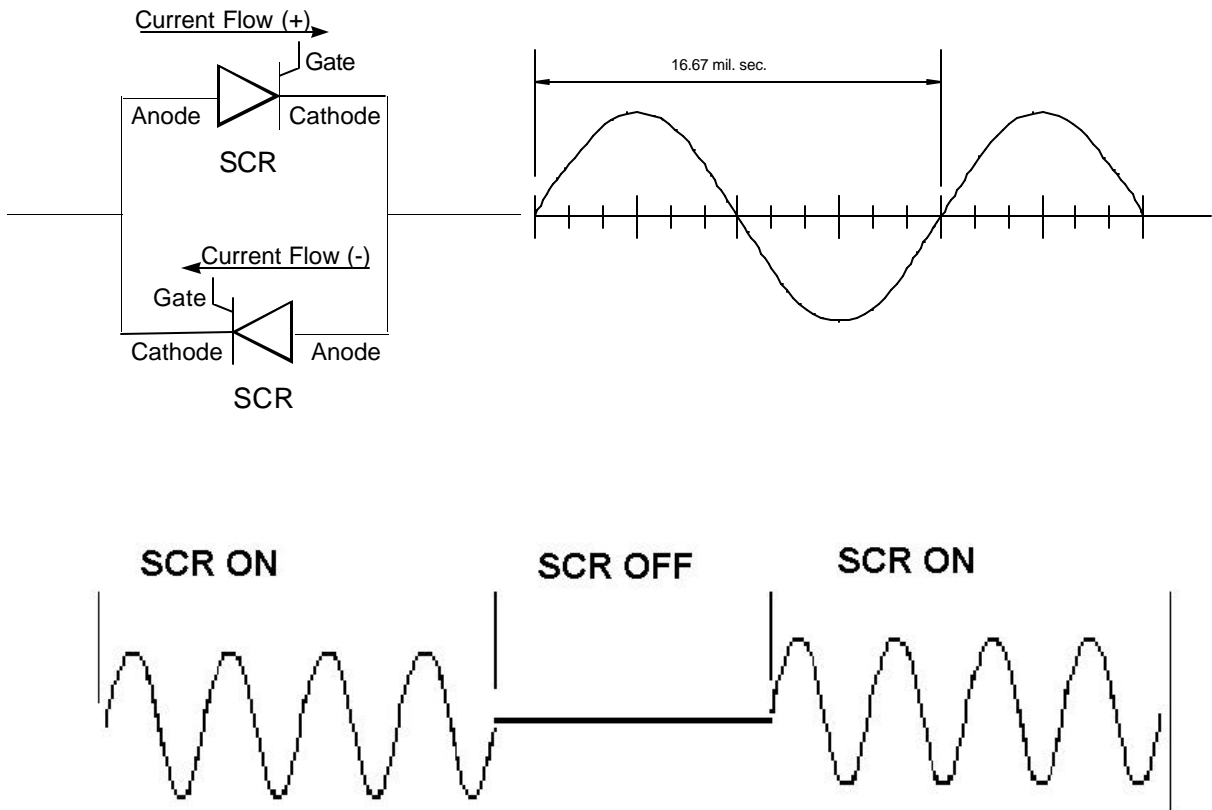


Figure 9: Back-to-back SCR's allow the full wave current to be conducted. The forward SCR conducts during the positive half of the cycle and the reverse SCR conducts during the negative half of the cycle.

SCR CONTROL FIRING

There are several different methods that are utilized to control or fire the SCR's. The firing mode is determined by the electronics mounted on the SCR power pack. This electronics package is called the firing circuit.

The different SCR firing modes fall into two main categories:

1. Zero voltage crossover firing
2. Non-zero voltage crossover firing

These firing methods are presented next with advantages and disadvantages of each method.

Zero Crossover Firing

The firing circuit is a zero crossover type if it allows the SCR's to gate only when the voltage across the SCR is zero. Therefore, the SCR turns on and off only at the zero voltage crossover reference of the sine wave. It should be noted that once an SCR is turned on, it will remain on until the conducted current falls to zero. This occurs naturally every $\frac{1}{2}$ cycle in an AC waveform. An SCR always turns off at a zero voltage crossover (assuming zero phase shift.)

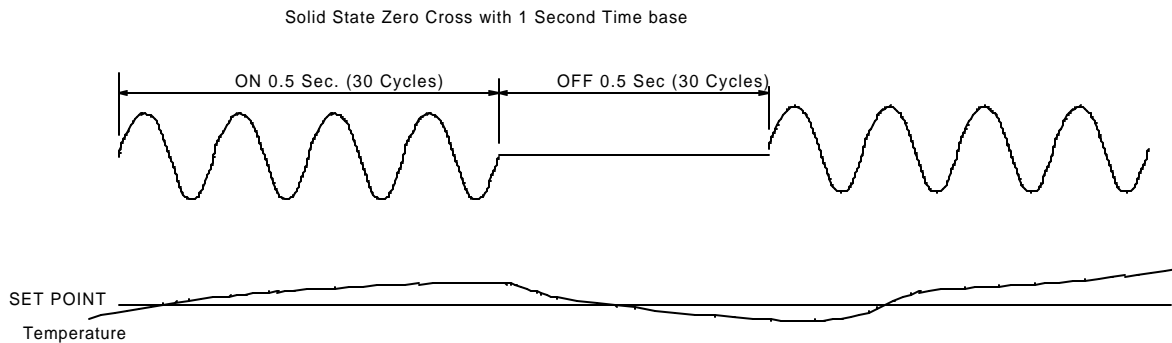


Figure 10: Faster switching and a short time base allows tighter control of the process temperature around setpoint.

Advantages of using solid state zero crossover devices over mechanical devices.

1. Reduced maintenance and operating costs. There are no moving mechanical parts to fail.
2. Electrically quieter. Turns on and off at the zero crossover which does not create RFI.
3. Does not cause line distortion. Figure 6 shows the distortion that can be produced on the line side of a mechanical device.
4. Finer control and extended heater life. SCR's allow for shorter cycle times which increases process stability and decreases heater thermal shock.
5. Heater also exhibits less expansion and contraction caused by the heating and cooling action.

Zero Crossover Firing Techniques

The Zero Voltage Crossover Firing category includes the following firing modes:

- On/Off
- Time Proportional
- Demand Oriented Transfer (DOT)

On/Off

The power pack is off if no input signal is present. The power pack is full on if an input signal is present. There are no intermediate points. The operator or some external hardware is required to determine when the pack should turn on and when it should turn off. Some temperature controllers today have cycle times as low as one second and less.) The waveform from an ON/OFF pack is shown in Figure 11. The On/Off pack is commonly used as a replacement for mechanical contactors to eliminate RFI and allow faster switching times

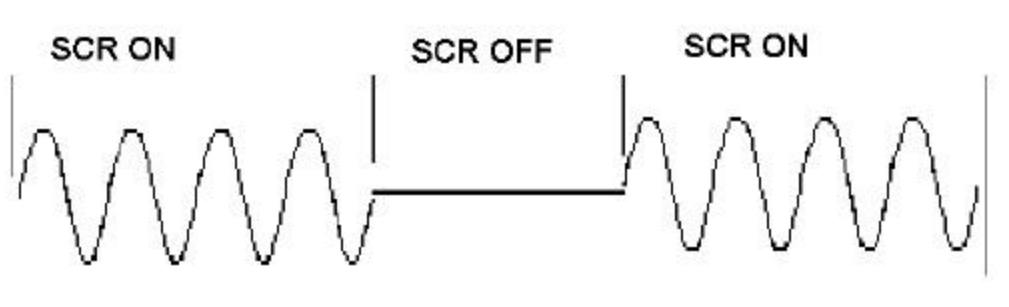


Figure 11: An example of On/Off control.

Standard Control Signals for On/Off Control

3-32VDC Signal

Current or Voltage signals can be converted to a 3-32VDC using a signal converter such as the Vari-watt or the PSR.

Time Proportional

The output of a Time Proportional pack may be full off or full on. The firing circuit determines how long the power pack should be on for a given control signal. The control signal usually comes from a separate controller that monitors the process and adjusts the power pack output accordingly. A Time Proportional power pack has a fixed time base with the output proportioned over that time base. For example: The time base for a particular power pack is 1 second. If a 50% output is required, the output will be on for 0.5 seconds and off for 0.5 seconds. If a 75% output is needed, the output will be on for 45 cycles and off for 15 cycles (1 second or 60 cycle total time base).

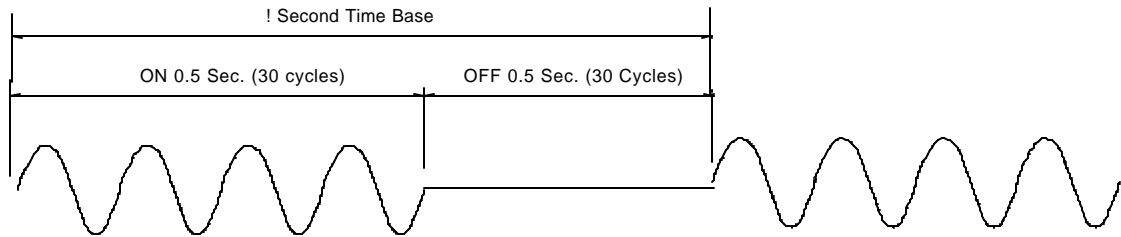


Figure 12: Time proportional control on a one-second time base.

The main advantage over on/off solid state control is the unit will accept proportional inputs. Proportional inputs allow the process controller to vary the load more accurately as the process changes.

Standard Control Signals for Time Proportional Pack

0-5 mA	4-20 mA
0-20 mA	10-50 mA
0-50 mA	0-5VDC
1-5 mA	0-10DC

Demand Oriented Transfer (DOT)

The DOT power pack is a proportional SCR power regulator similar to the Time Proportional version except the time base is not fixed. The time base shrinks to the minimum time base required to give the desired percentage output. Recall that DOT is a Zero Voltage Crossover firing scheme. Further recall that once turned on, an SCR will remain on until the current returns to zero. What these statements imply is that for a pair of SCR's operated in anti-parallel, the absolute minimum time base is 1 cycle, which is approximately 16.6667 milliseconds when used on 60 Hz AC power. If the power pack is required to be at 50% output, the time base will be 2 cycles (1 cycle On, 1 cycle Off). If 75% is required, the pack will be on for 3 cycles and off for 1 cycle for a total time base of 4 cycles (66.67 milliseconds).

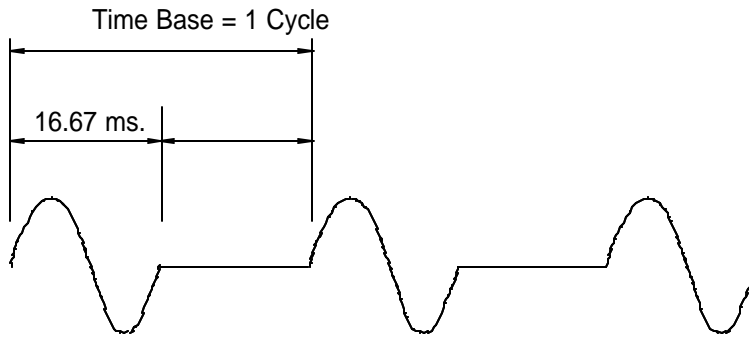


Figure 13: 50% duty cycle is shown using DOT firing. Note that in DOT fire only 33 milliseconds are required for a time base at 50% duty cycle.

Standard Control Signals for DOT Pack

0-5 mA	4-20 mA
0-20 mA	10-50 mA
0-50 mA	0-5 VDC
1-5 mA	0-10 VDC

Time Proportional vs. Demand Oriented Transfer

Controllability is the major difference between the Time Proportional and DOT. If both packs are asked to produce 50% output, the Time Proportional pack will be on for 0.5 seconds and off for 0.5 seconds (assuming standard 1 second time base). The DOT pack will be on for 16.667 milliseconds and off for 16.667 milliseconds. The DOT unit is much faster resulting in tighter control and lesser excursions from the setpoint. Heater life is also extended with DOT firing since the heater is not exposed to continuous power for as long a period of time as it is with Time Proportional control.

NON-ZERO VOLTAGE CROSSOVER FIRING

Phase Angle Firing

There is only one common Non-Zero Voltage Crossover firing mode. It is referred to as Phase Angle firing. Phase Angle firing dissects each individual AC cycle into small parts. The Phase Angle fired unit controls down to the sub-cycle level resulting in extremely tight and accurate control (See Figure 14). Phase angle firing may be used on all types of loads. Since Phase Angle firing controls to the sub-cycle, some added features are available.

1. Current Limit - Retards the output of the power pack to maintain a safe current level.
1. Soft Start - Brings the output voltage of the power pack up to steady state slowly on power up.

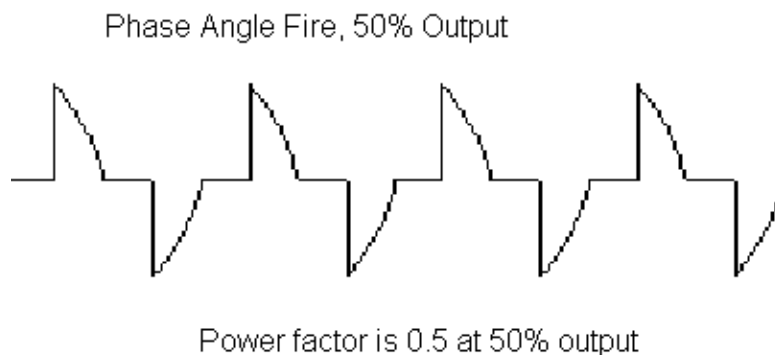


Figure 14: Phase angle firing supplies a saw tooth style waveform.

Standard Control Signals for Phase Angle Pack

0-5 mA	4-20 mA
0-20 mA	10-50 mA
0-50 mA	0-5 VDC
1-5 mA	0-10 VDC

Why Not Use Phase Angle Firing On All Applications?

Since Phase Angle firing is a Non-Zero Voltage Crossover Firing mode, the voltage across the SCR will usually not be zero when the SCR is switched on. This sudden switching of such a large voltage (possibly as much as 679 peak voltage in a 480 VAC system) results in large amounts of electrical noise or Radio Frequency Interference (RFI) being emitted (Figure 15.) Such interference can undermine radio communications in the area as well as disrupt any computer operations. Normally, if an engineer can use DOT firing, they will. In cases where Phase Angle Firing is necessary, great care must be taken in shielding all appropriate wiring to minimize the RFI. The unit may also be isolated in its own metal enclosure, thereby helping to confine the RFI.

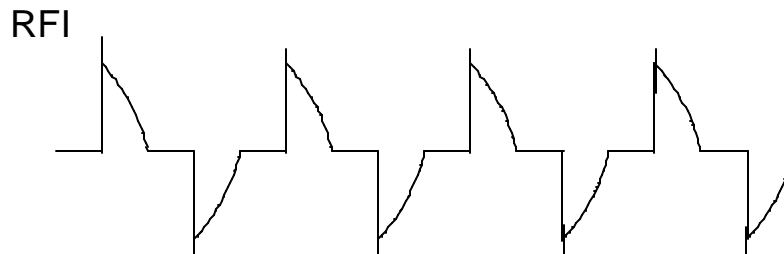


Figure 15: Notice the RFI spikes at the peaks of the waves.

1. Line distortions as discussed previously for mechanical devices may be produced.
2. Power factor is a calculation of available power versus consumed power. Zero crossover units have a power factor of one. Phase Angle units have a power factor of one (at full output). Any power factor less than 0.9 - 0.95 is considered very poor. In some locations, power companies charge a penalty for poor power factors.
3. Harmonics are second generation waveforms. Harmonics cause the 60 Hz sine wave from the power company to be distorted. These waveforms can be caused by equipment such as phase angle power controllers. These distorted

waveforms cause problems for the power company's measurement equipment and can appear to the power company that required power is higher than actual power. In some areas, power companies are charging penalty fees for customers who generate harmful harmonics.

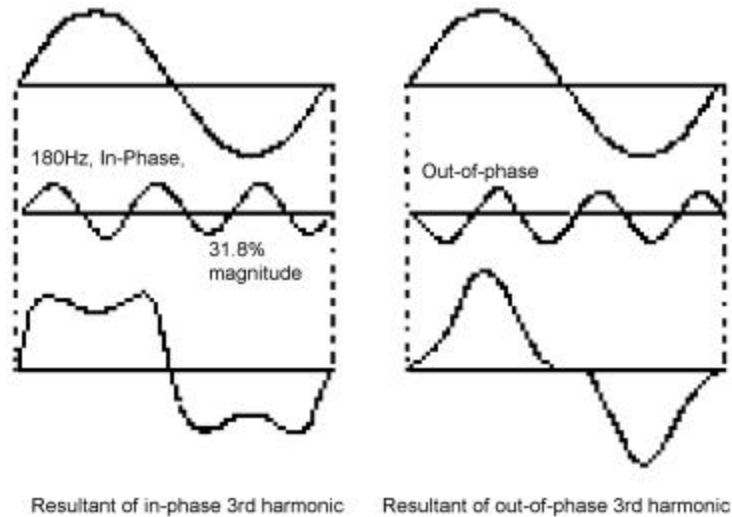


Figure 16: Harmonics caused on the line side due to phase angle fired SCR's.

Phase Angle/Zero Fire Combination Control

Combination firing packages can be utilized on higher end microprocessor based power controls which utilize both phase angle and zero fire. If a process requires Soft Start on start-up, but will operate on zero fire proportional control once up and running, the advantages of both methods may be realized. The Soft Start is programmed into the controller for a specific time. Once the time has elapsed the

Soft Start Zero Fire or Phase Angle/Zero Fire

50% Shown

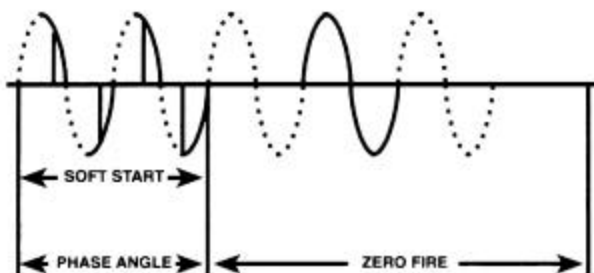


Figure 17: Soft Start utilizing phase angle firing combined with zero cross firing combines the best of both worlds.

controller automatically switches over to proportional zero cross firing scheme.

SCR APPLICATIONS

The application or load driven by the SCR dictates which type of SCR can be used. There are two types of load power: resistive and inductive. Each load may be made up of a resistive component or a resistive and inductive component.

Resistive

Resistive heating elements can be classified into five major applications:

- I) **Low hot to cold ratio.** Elements that exhibit very little resistance increase as the temperature is elevated. This is known as a low hot to cold ratio. Elements in this category are:

Iron Chromium
Aluminum Alloy
80% - 20% Nickel Chromium

The low hot to cold ratio allows the use of Zero Fire SCR units to control the power. Most Chromalox heaters are in this category.

- II) **High inrush applications.** These applications draw a very high current for a short time on power up and then the current decreases as the unit approaches normal operation. Phase angle control should be utilized on these loads. Phase angle provides a feature called Soft Start. Soft Start limits the amperage output on start-up and ramps the amperage slowly from zero output to full operating power as dictated by the process controller. The soft start feature is utilized to overcome the inrush period. Soft Start is shown in Figure 17 below over just a few cycles. In most cases, however, Soft Start is utilized over seconds or minutes slowly increasing the output over hundreds of cycles.

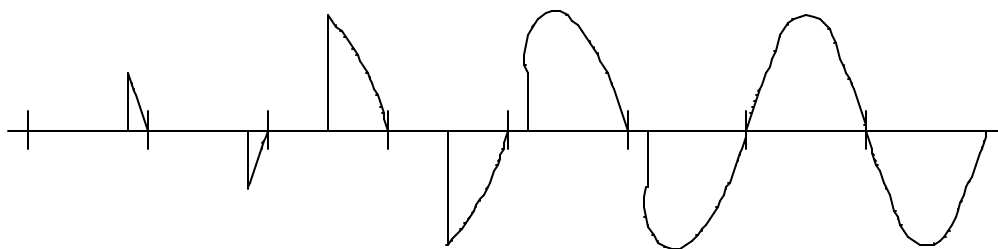


Figure 18: Soft Start slowly increases the amount of voltage applied to the load over a user specified time base.

- III) **High hot to cold ratio elements.** These elements can exhibit a resistance increase as the temperature is elevated. The increase can be in the range of 20:1. This is known as a high hot to cold ratio. Elements in this category are:

Molybdenum
Tungsten
Graphite

Quartz (Tungsten)
Infrared (Tungsten)

The high hot to cold ratio necessitates the use of phase control SCR units to ensure that they are not overpowered during start-up. (Also see transformer coupled loads.) These elements will draw excessive currents when they are cold. As they heat-up the resistance increases and the current decreases to normal operating levels. By limiting the current either by Soft Start or by programming the power pack to limit the amperage (IntelliPac series) the heating element can reach operating temperature without drawing excessive current.

- IV) **Element dry out.** Resistance elements insulated with hygroscopic materials such as magnesium oxide can absorb moisture prior to having power applied or if power has been removed for an extended period of time. If full voltage is applied when this condition exists, the element could be damaged due to amperage leaking to ground through the insulator. Phase Angle control with current limit would be used to apply a low voltage to the heater to bake out the moisture. The current limit level would then be raised or removed from the circuit once the heater reached the manufacturers recommended minimum megOhm ratings.
- V) **Resistance changes over time.** Elements that exhibit a large resistance change with age will benefit from Phase Angle Control. Silicon Carbide (GLO-BAR) is the most common element in this category. The resistance of this element will increase by a factor of four during its useful life. Phase control is normally used with tapped transformers on this type of load so that the voltage may be varied to hold a consistent power output (also see transformer coupled loads). Some microprocessor based controllers can be programmed to hold constant output either by holding amperage constant or by holding wattage constant.

Inductive

All loads that exhibit inductive characteristics, transformer coupled, inductive roll heaters, etc. utilize phase angle control. Transformers are used with phase angle power controllers for elements that require low voltage/high current. Figures 18 through 20 show three typical applications for transformer coupled loads.

Transformer Coupled Loads

Transformers are used to step the voltage down to a load. Voltage is typically stepped down because the resistance of an element is limited and the load requires high amperage with low voltage. The alternate advantage to stepping down the voltage is that amperage is increased proportionally. Therefore, the SCR can switch

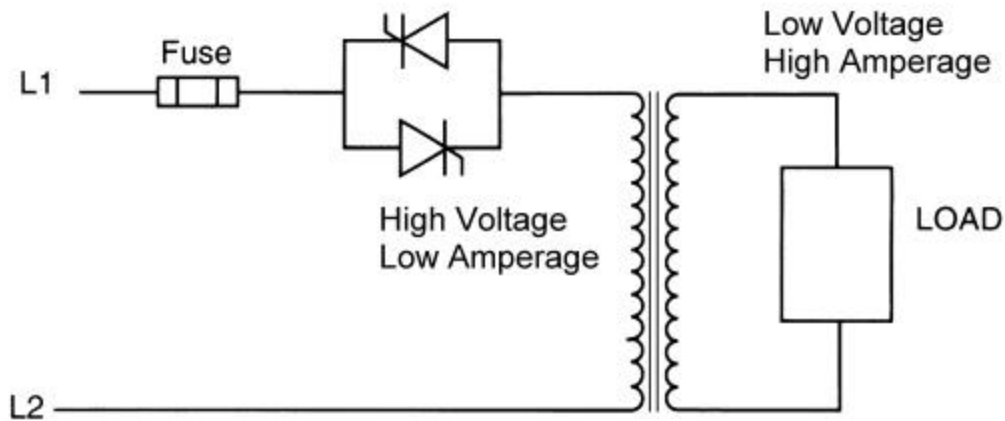


Figure 19: A simple transformer coupled load. Transformers are most often used to step down the voltage to the load. Amperage increases proportionally.

relatively low amperages on the primary side of the transformer while the amperage delivered to the load is quite high. Because a transformer is inductive, phase angle firing must always be used on transformer coupled loads regardless of the element characteristics.

Multi-Tap Transformer Coupled Loads

Multi-tap transformers are often used to couple loads because the characteristics of the load change over time. Specifically, many loads have resistances that increase over the life of the load. The user simply manually moves the tap on the transformer to apply more voltage to the load to get additional output from the same heater as the resistance increases. When the user runs out of taps to change, the element is replaced.

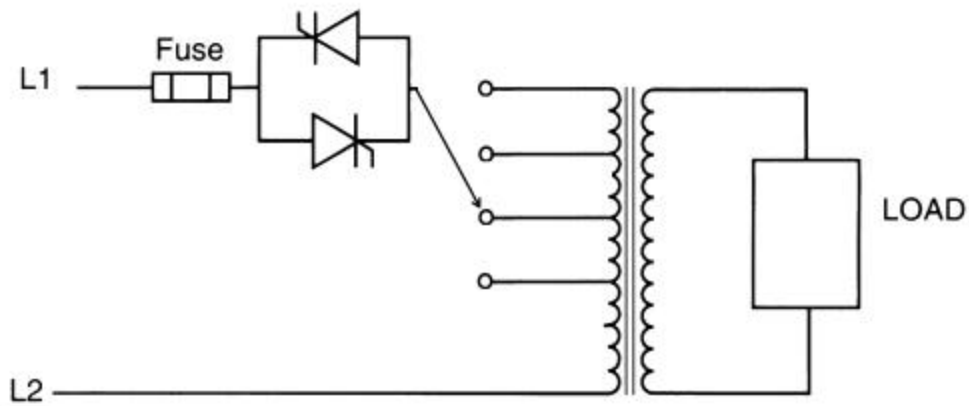


Figure 20: Multi-tap transformers offer the ability to change the amount of voltage applied to a load over time. Many loads exhibit resistance changes as they age. By changing the taps, the power control can operate at its optimum while keeping power factor high.

Automatic Tap Changing Transformer Coupled Loads

Instead of manually changing the taps on the transformer a second SCR may be utilized to phase fire in the other tap of the transformer. Figure 20 shows how the two SCR's fire both taps of the transformer to result in a more complete waveform without manually changing taps. If the ratios between SCR "A" and SCR "B" are optimized, the harmonic component (and the resultant power factor) can be reduced and save the user large power factor penalties charged by Electric Utilities.

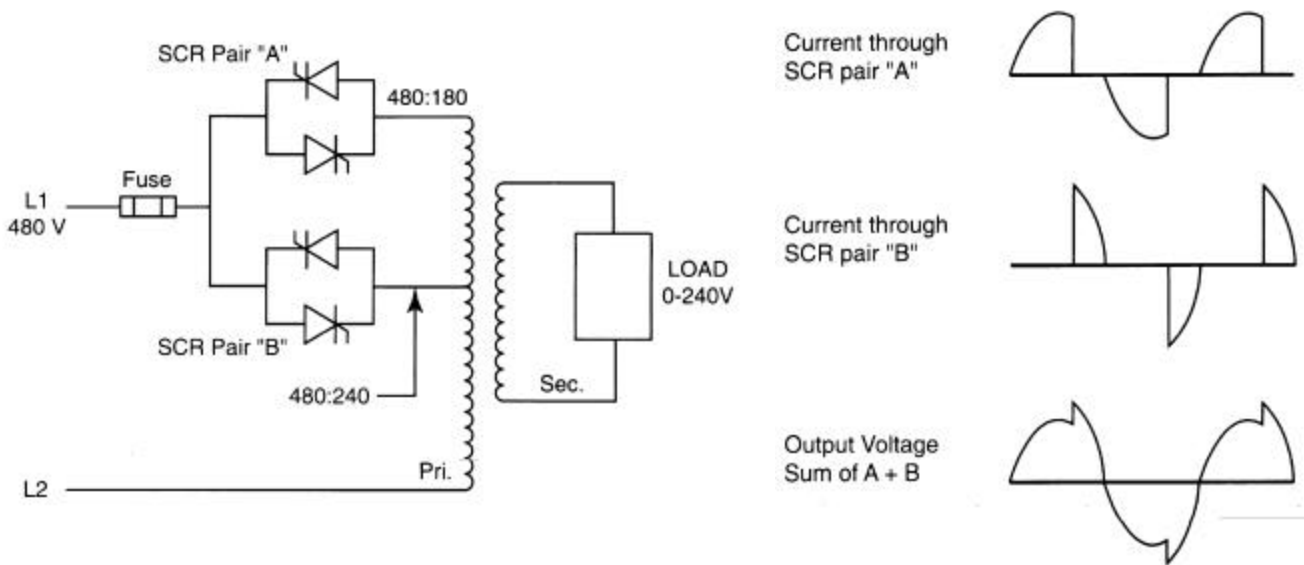


Figure 21: An automatic tap changer allows the power factor to be reduced by optimizing the tap ratios.

SINGLE AND THREE PHASE POWER FUNDAMENTALS

Up to now the text has centered on a simple single load. This simplifies the discussion, but in the real world most loads are three phase. The next section deals with defining the differences between single and three phase and why three phase is advantageous.

Load Configurations and Power

When specifying power control, it is necessary to recognize whether the application is single phase or three phase. In a single-phase system, one pair of SCR's is used to control the power output through one current path or leg. A single phase SCR power pack along with a single-phase current calculation is shown in Figure 21.

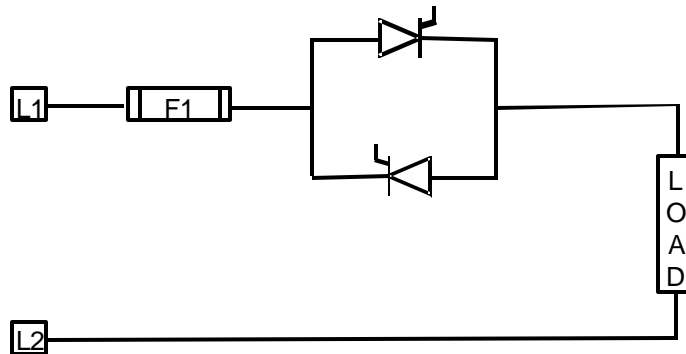


Figure 22: Basic single-phase load.

Example: Assume the load is 48kW and the voltage applied to L1 and L2 is 480V.

$$\frac{48000 \text{ W}}{480 \text{ VAC}} = 100\text{A}$$

For larger power consuming loads, three phase systems are normally used. The voltage between any two legs of a three-phase system is a sinusoidal AC waveform like the single-phase voltage. The voltage waveform between each successive pair of legs, however, is displaced in time. In a three-phase system, each AC waveform is displaced by 120 electrical degrees from the other two. This corresponds to 5.56 milliseconds for a 60 Hz system. See Figure 22.

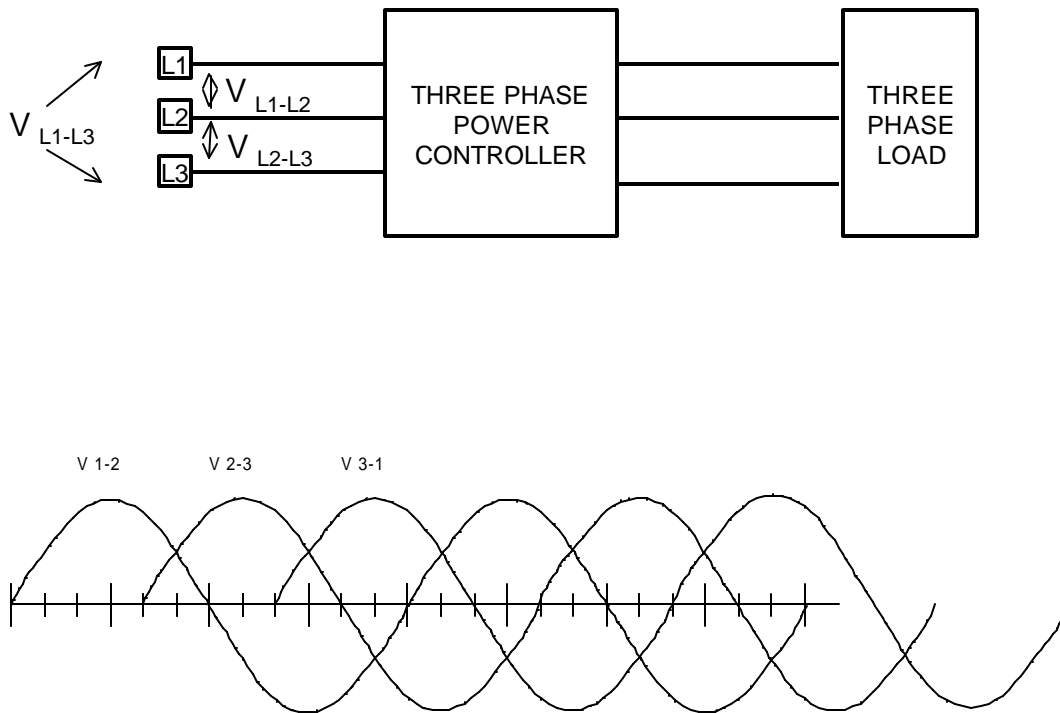


Figure 23: Design of a three-phase system.

Example of a Balanced Delta Calculation: Assume that the load is still 48kW, but this time the circuit is connected to 3 phase.

$$\frac{48,000W}{480 \text{ VAC} \times \sqrt{3}} = \frac{100}{\sqrt{3} \text{ or } 1.73} = 57.7 \text{ Amps}$$

Typical Three Phase Load Configurations

Three phase loads are normally connected in either a three-wire or four-wire configuration. Three wire loads are: DELTA and ungrounded WYE. The only common four-wire load is a grounded WYE. See Figure 23. A four-wire grounded WYE is simply an ungrounded three-wire WYE with the center point of the WYE connected to ground.

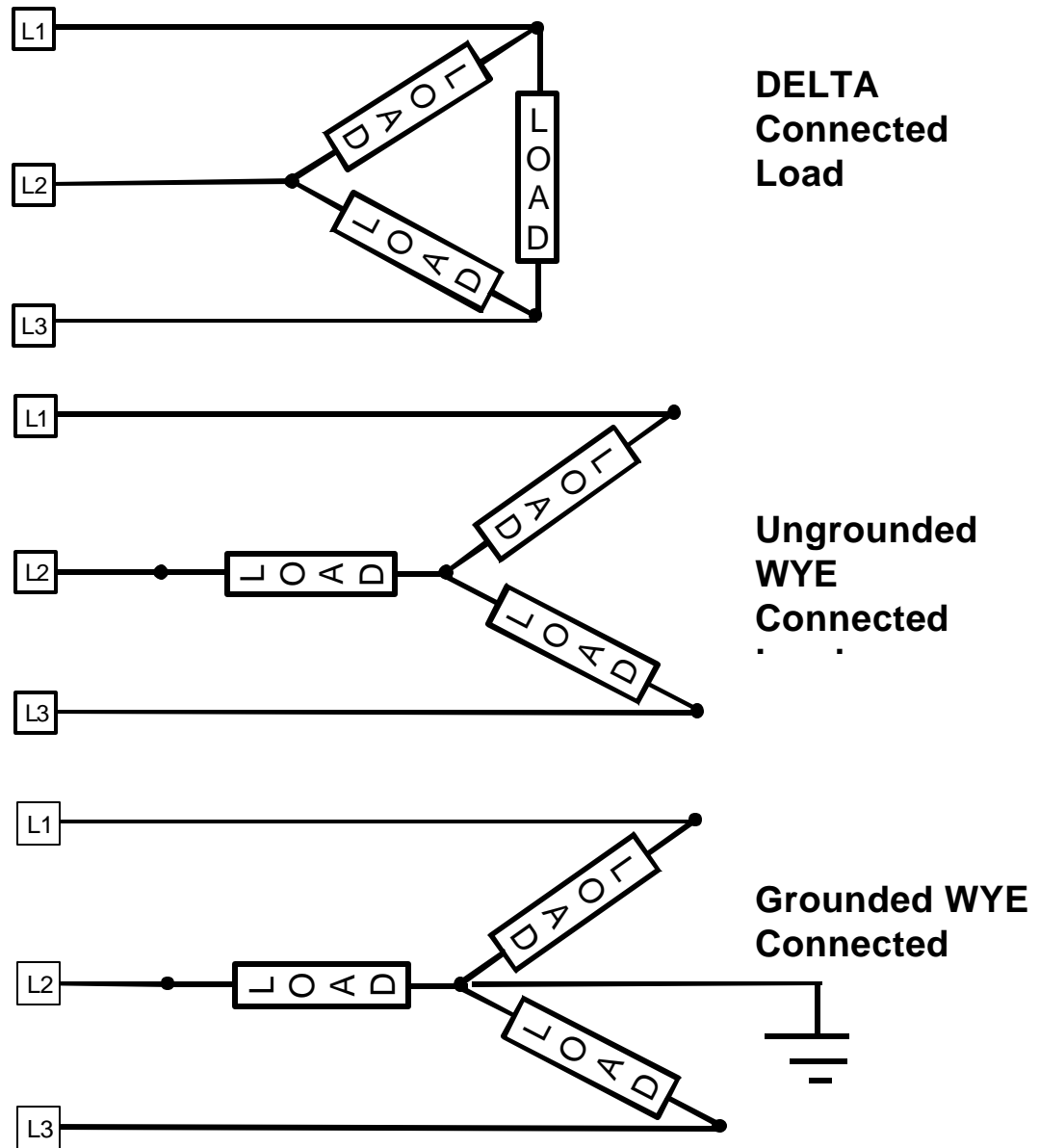


Figure 24: DELTA, WYE, and grounded WYE load configurations.

THREE PHASE SCR CONNECTION CONFIGURATIONS

The SCR connection configuration is driven by all of the factors discussed up to this point. Specifically, these include the load configuration, the type of firing method, and the type of load or application being controlled. The configurations can be divided into two main types of configurations; two leg and three leg SCR power control.

Two Leg SCR Power Control

The current that enters any phase or leg of a 3-wire load, as shown in Figure 24, must exit via the other two legs. This means that a 3-wire load can be controlled by switching the current in only two phases. This is called two-leg control. Two-leg control may be utilized in DELTA loads that are zero cross-fired and ungrounded WYE connected loads that are zero cross-fired. An example of a two leg DELTA connection is shown below in Figure 24.

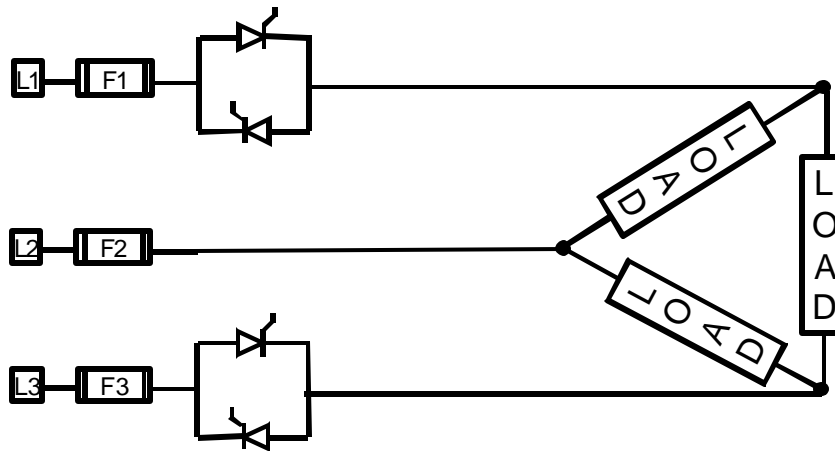


Figure 25: Two leg SCR power control.

Three Leg SCR Power Control

Three-leg control may be used in all applications but is required in grounded WYE and phase angle control applications. Three-leg control is also referred to as six SCR control. There are other variations to six SCR control which include hybrid control and inside delta control.

Grounded WYE Control

In a 4-wire system, the current in each leg will exit through the neutral or ground connection. Therefore, the current in all three legs must be controlled to achieve control. See Figure 25 below for an example.

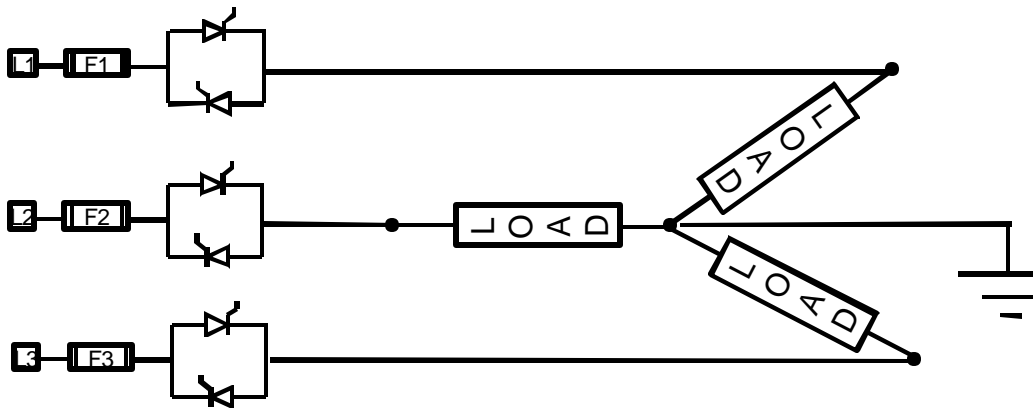
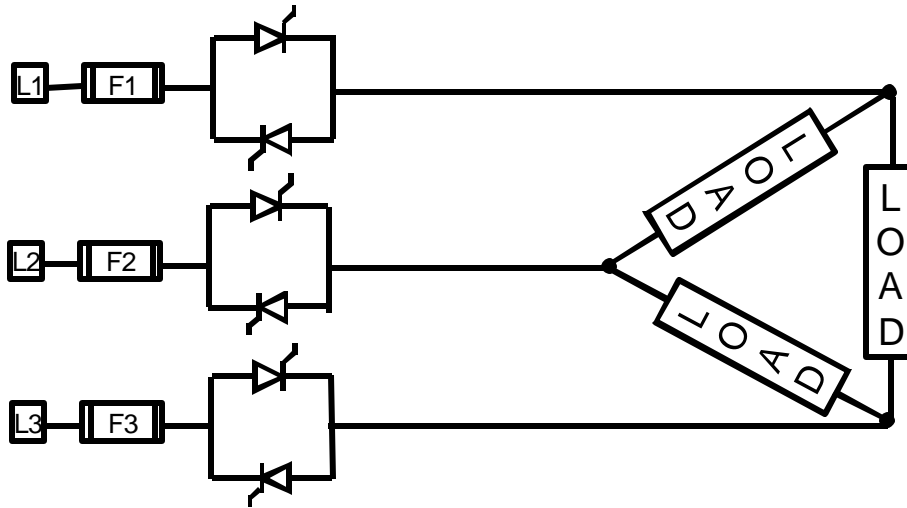


Figure 26: Grounded WYE, 4 wire, power control.

Phase Angle Control

Because phase angle control splits each individual cycle of the waveform, each leg of the power supply must be controlled. Whether the load is DELTA or WYE, if phase angle control is utilized three-leg control must be used. A DELTA phase



angle configurations is shown below in Figure 26.

Figure 27: Three leg SCR power control utilizes six SCR's.

Inside Delta Control

Inside DELTA control places the SCR directly in the DELTA circuit. This takes advantage of the lower current inside the DELTA circuit. The current in each phase of a delta circuit is approximately 58% ($1/\sqrt{3}$) of the line current. This allows the use of a smaller SCR power control device because the amperage is smaller. If inside DELTA control is used in the primary of a three-phase transformer (transformer coupled loads) a six SCR configuration must be used and the secondary must be DELTA connected. Three single-phase controllers cannot be used inside the delta to operate a three-phase transformer. An illustration of inside DELTA control is shown below.

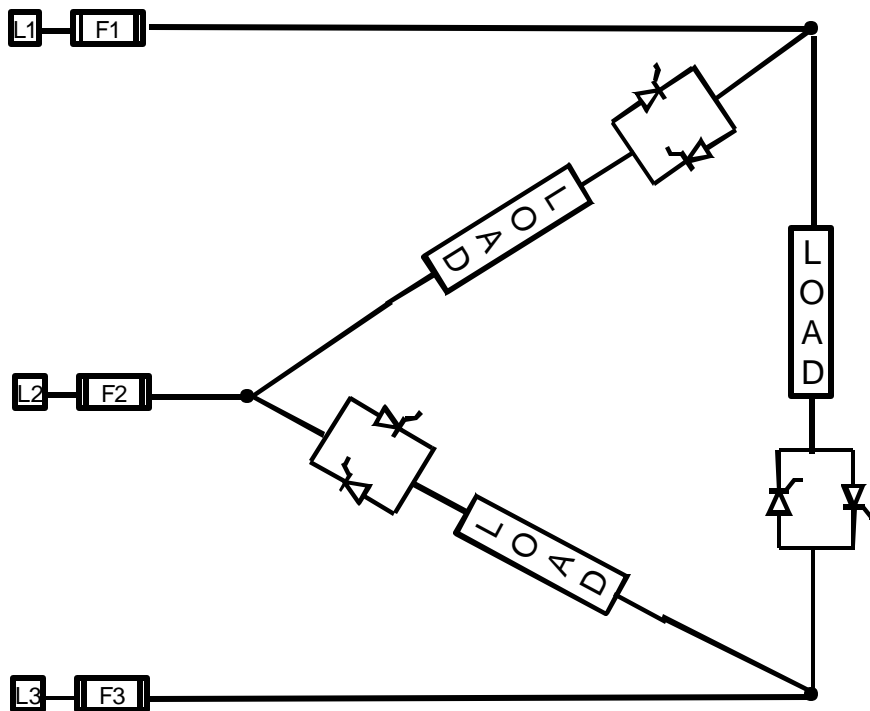


Figure 28: Inside DELTA control reduces the amperage rating required for the SCR.

Hybrid Control

Three phase hybrid controllers use an SCR and a diode mounted back to back in a three-leg SCR power control scheme. These are used in phase angle control schemes where there is no transformer coupling of the load. Hybrid connected loads may not be used if the load is unbalanced or in grounded WYE connected loads. Grounded WYE connected loads would result in the controller conducting 50% of the time. The only advantage to hybrid control is cost. The disadvantage of hybrid is that if the load becomes unbalanced a DC current flow will result. This DC component will affect the upstream supply transformer and cause heat build up, which could cause the transformer to fail.

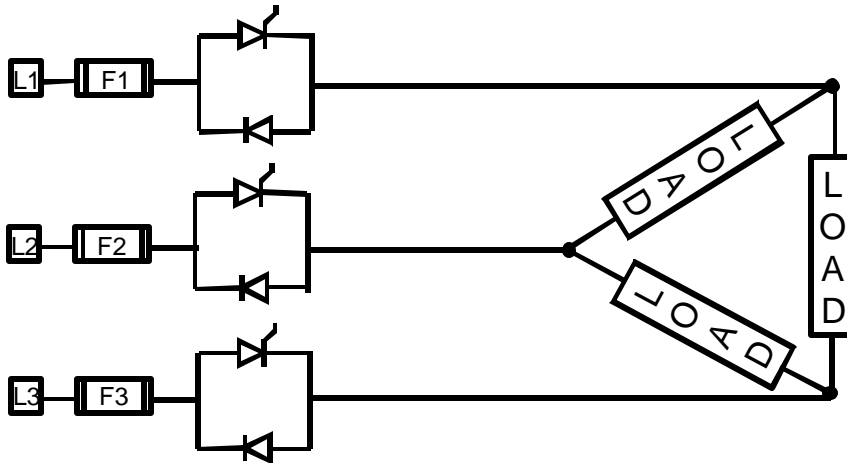


Figure 29: Hybrid control uses a diode back to back with an SCR.

Application Summary

Table 1 contains the major element types, their resistance ratios (hot/cold), operating voltages, control type utilized and load type. Control Type indicates how the load is switched. Zero refers to zero cross-fired and phase refers to phase angle fired power control. Transformer coupled load connection indicates an inductive load or a load that utilizes a transformer in between the element and the power control device to step down the voltage and increase the amperage. Resistive/direct indicates that the load is generally connected directly to the power-switching device.

Table 1: Summary of common applications and their power control configurations.

Element Type	Typical Hot/Cold Ratio		Normal Operating Voltage	Typical Control Type	Typical SCR Load Connection
	Ratio	Characteristic			
Quartz Heaters/Quartz Infrared Applications					
Nickel Chromium (Quartz Tube)	1.1:1	Low	Line	Zero, Phase, Contactor	Resistive/Direct
Tungsten (Quartz Lamp)	20:1	High	Reduced/Line	Phase	Transformer Coupled/Direct
Other Infrared Applications (tubular, ceramic, wide area)					
Nickel Chromium	1.1:1	Low	Line	Zero, Phase, Contactor	Resistive/Direct
General Resistance Heating (sheathed and open coil resistance elements)					
Iron Chromium	1.1:1	Low	Line	Zero, Phase, Contactor	Resistive/Direct
Nickel Chromium (80% / 20%)	1.1:1	Low	Line	Zero, Phase, Contactor	Resistive/Direct
Nickel Chromium (35% / 20%)	1.2:1	Medium	Line	Zero, Phase, Contactor	Resistive/Direct
Specialized Element Materials					
Molybdenum	15:1	High	Reduced	Phase	Transformer Coupled
Tungsten	20:1	High	Reduced	Phase	Transformer Coupled
Graphite	20:1	High	Reduced	Phase	Transformer Coupled
Silicon-Carbide (Glo-Bar)	0.8:1	Low	Reduced	Phase	Tapped Transformer Coupled

WATT LOSSES

SCR power controllers are not perfect conductors. All SCR's exhibit some voltage drop across the device. A conservative voltage drop that is generally used is 1.5V for each device. If current is flowing a voltage drop generates heat (wattage equals amperage times voltage drop or $P = I \times E$). This heat must be dissipated to keep the SCR at a reasonable operating temperature. To calculate the amount of heat created by an SCR, the following equations may be used as a guideline.

Single Phase: $1.5V$ (voltage drop) x current rating = Wattage

Example: A single SCR supplying a 50-amp load will produce,

$$1.5V \times 50A = 75 \text{ watts}$$

Three Phase: $1.5V$ x current rating x 2 or 3 (# of controlled legs)

Example: A two leg SCR controlling a 50-amp load will produce,

$$1.5 \times 50A \times 2 = 150W$$

POWER CONTROLLER FEATURES AND ACCESSORIES

Fusing

Most SCR power control assemblies come with fuses as an option or standard. There are many different types of fuses that are used in overcurrent protection, however, SCR requirements are more stringent than the fuse requirements for typical AC power distribution systems. SCR's are typically protected with I^2t fusing. A high speed fuse is needed to protect the SCR. The silicon embedded in the SCR has a low transient thermal capacity. The heating effect produced by low, medium, and high fault currents can quickly cause permanent damage to an SCR. I^2t fusing is an ultra current limiting short circuit fuse designed to protect against these faults. I^2t is a performance measurement of a fuses current limiting short circuit performance. From an engineers perspective it refers to RMS amperes-squared seconds which is a fuse parameter that indicates the heating effect associated with a current pulse. I^2t

fusing is typically not designed to protect the load and is generally combined with sub-circuit fusing designed specifically for load protection.

Shorted SCR Detection

Shorted SCR detection is designed to identify when an SCR has failed in the shorted mode. It is difficult to identify that one SCR is shorted (i.e. constantly conducting whether gated or not) and is consequently on all the time. Shorted SCR detection warns the user before the process temperatures can run away or cause heater failure. This is also beneficial if a load typically runs close to 100% on. The shorted SCR may not be identified until the process is shut down. When the process is shut down and one SCR is shorted, the circuit could remain on and cause an overheat condition. An LED and contact closure typically signal this condition.

Current Transformer (CT)

High end SCR power controls typically come with CT's as an option or standard. CT's are simply a toroidal coil of copper wire. The load wiring is run through the toroid and when current is drawn on the load a current is induced in the toroid wiring. This current is a smaller current proportional to the total load current and can be fed back to the power controller or a meter. This current is used for tracking power, amperage, and output feedback to the firing card. Typical uses are covered in more detail below.

Partial Load Failure Indication

With the feedback of a CT indicating how much amperage is being delivered it is easy to add many valuable features to the power package. One valuable feature that is available is Partial Load Failure Indication. By comparing the power output being requested by the controller to the percentage of amperage being delivered by the power package a partial load failure can be identified. A partial load failure refers to a load made up of multiple heaters where some of the heaters have failed. In many cases the loss of the individual heaters is not readily identifiable. Partial Load Failure compares the current draw to a predetermined value and if the current is too low a contact closure is made.

Line Voltage Regulation

Monitoring line voltage is another method that is often used to add features to a power package. Voltage regulation monitors the line voltage and if it drops the power controller boosts the output percentage from the power controller. In on/off control the percentage output is increased and in phase angle the phase is shifted to increase output voltage. Line Voltage Regulation allows more power to be applied

in a low voltage situation as soon as it occurs, rather than waiting for the temperature controller to identify that temperature has dropped.

Emergency Shut Down Contact

Emergency shut down contact is another method to interrupt the power controllers output. The controller is connected to a dry contact. The dry contact simply turns the output on or off as required. This is an excellent override method. NOTE: The emergency shut down feature is not a positive off device. When servicing any electrical device the power should always be shut off at the main disconnect first.

Flexible Input Signals

Many firing cards are designed to take in various input signals including voltage and mA signals. With adjustable zero and gain pots various input signals can be scaled for the controller. This allows more flexibility in the field if the controller is to be used in a new application or the temperature controller is changed.

Flexible Line Voltage

Many power control firing boards are self powered off of the line voltage. This reduces wiring of the power controls because no control power wiring is needed. Because the firing card has a step down transformer to power it, if the power package is used in another application at a different line voltage the firing card may not operate. Many power controls come with Flexible Line Voltage where the transformer can be re-wired to operate on another line voltage without replacing the firing board. This adds flexibility for an OEM panel builder who can stock one size for multiple applications while reducing wiring and installation time.

Manual Bias

Manual bias is an override feature that adds to the output more power than is being requested by the temperature controller. In loads that cannot be turned off for any reason without effecting the process this feature is extremely valuable. It allows the user to continue to provide output from the power control even though the temperature controller is off line or being adjusted. In some cases this manual bias can be adjusted remotely. This allows the operator to give the load a temporary boost without making adjustments to the temperature controller.

CONTROLLING YOUR COSTS

Original Equipment Manufacturers

New innovative designs in power controllers can help original equipment manufacturers (OEM) reduce their material and labor costs. Below is a list of features to look for in an SCR product that can help an OEM reduce their material and labor in panel assembly.

1. Reduce Material Costs
 - a. Smaller footprint SCR's reduce panel size requirements. Look for advanced materials like bonded fin heat sinks rather than bulky old fashioned extruded heat sinks.
 - b. Flexible Input/Output wiring allows wiring to be reduced. A supplier should provide lugs that allow input and output wiring to route in any direction so as to eliminate wire bending and increased panel size requirements.
 - c. Power packs should include power distribution located directly on the output bussing eliminating the need for sub-circuit terminal blocks.
 - d. By utilizing an SCR power pack rather than a contactor many sub-circuits can be controlled with one unit rather than using multiple contactors. Multiple contactors result in increased overall material and space requirements as well as failure points.
2. Reduce Power Control Footprint by Utilizing Power Packs with Large Amps per Area of Foot Print
 - a. Increases space for other components
 - b. Assembly is easier with more space to work with
 - c. Less real-estate is required compared to multiple contactors switching high amperage loads
3. Reduced Labor Costs with Flexible Power Input/Output Lugs
 - a. Lugs and Terminal Blocks Built-In to Power Pack- No need to wire to a power distribution block and then on to fusing. Sub-circuit distribution is directly on the output power lugs thus eliminating labor.
 - b. Flexible Input/Output Wiring- Allows you to meet your end customer's needs and optimize labor requirements regardless of where the customer wants their wiring to go-in and go-out of the panel.
4. Look for Worldwide Designs (UL, cUL, CE)
 - a. Reduced liability- international third party listings prevent start-up delays due to local inspectors. Recommend power packs with UL, cUL, and CE.
 - b. Participate in worldwide sales opportunities- No need to select alternate suppliers when quoting internationally.

- c. Utilize Power Packs with automatic switching power supply which allow 100-250VAC control circuits.
5. Reduce Inventory Costs with Common Parts, Regardless of Amperage
 - a. Use common components regardless of the variation in amperage you use, so replacement parts are common. Look for designs that utilize common motherboard, trigger circuits, and optional accessories that fit all amperage ratings. This reduces replacement part carrying inventory costs.
6. Improved Customer Satisfaction
 - a. Utilizing Flexible Input/Output Wiring to meet any customer's specification
 - b. Utilizing one common design in the field is easier to service. Commonality and simple design require less service parts to stock when standardized on common replacement parts.
7. Product Standardization and Part Number Reduction
 - a. Look for plug and play options in one design. Only pay for the features that you need with optional plug and play features.
 - b. Consolidate vendors- worldwide acceptance means you only need one vendor thus reducing your purchasing administration costs.

Reduce Your Operational Downtime

Industrial Users of SCR Power Packs recognize the value of tight power control on their production yields. Below is a list of SCR Power Pack features to look for to maximize your production up-time and improve production yields while reducing your overall maintenance costs.

1. Worker safety- Touch safe design means the heat sinks are not electrically hot. Many power pack builders utilize hot heat sink designs putting their customers at risk.
2. Reduce maintenance
 - a. Look for crimp lug design wire attachments to reduce hot spots. Try to reduce the number of total wiring connections in the panel by utilizing built in power distribution right on the power pack.
3. Reduce Downtime
 - a. Utilize a Potential Downtime Warning on heat sink temperature- get early indication of a maintenance requirement prior to shutting your entire process down. Reduces scrap. Some power pack builders simply shut the entire power pack down on high heat sink temperature, stopping your process.
 - b. Look for plug and play modules which will make repairs of SCR power packs easier with only one common inventory of replacement parts.

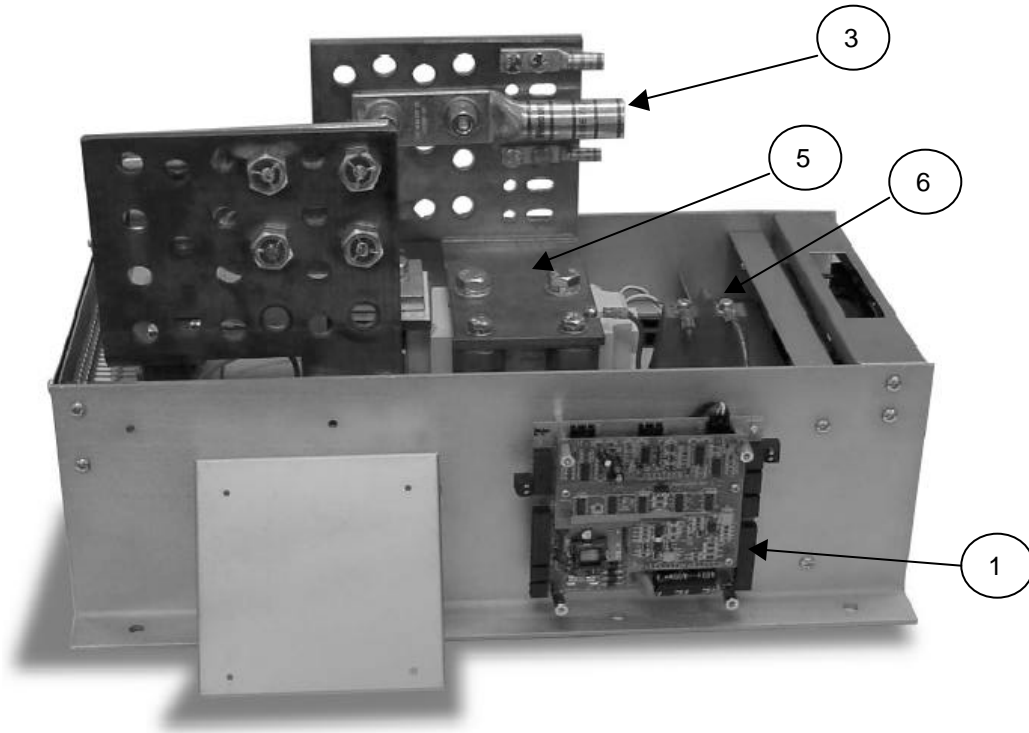
- c. Use only high end fans- SCR's must be kept cool. High quality fans keep maintenance minimized and your process up and running.
 - d. Shorted SCR Detection- Identify process upsets immediately before a batch is spoiled.
 - e. Transient Voltage Detection. Stop transients from misfiring your SCR.
4. Third Party Approval
 - a. May reduce insurance costs
 - b. Reduces risk of inspector asking for equipment changes
 5. Reduced spare parts inventory
 - a. Stock only one replacement board regardless of the number and sizes of SCR Power Packs your plant uses
 6. Better Yields on your process with tighter control
 - a. DOT Fire technology reduces the time base to a single cycle (1/60th of a second). This allows the heater to be switched on and off very quickly for very tight temperature control. Tight temperature control extends heater life and provides better yields for you process.
 7. Reduce Power Factor and RFI to save energy costs and line noise
 - a. DOT Fire technology reduces the time base to a single cycle (1/60th of a second) while still switching the power at zero voltage potential. This may eliminate the need for a phase angle fire switching scheme which contributes to power factor and plant power line noise and harmonics. Zero potential switching reduces line harmonics and does not affect power factor.

ANATOMY OF A POWER CONTROLLER

An SCR is shown on the next page to illustrate the individual components discussed in this manual.

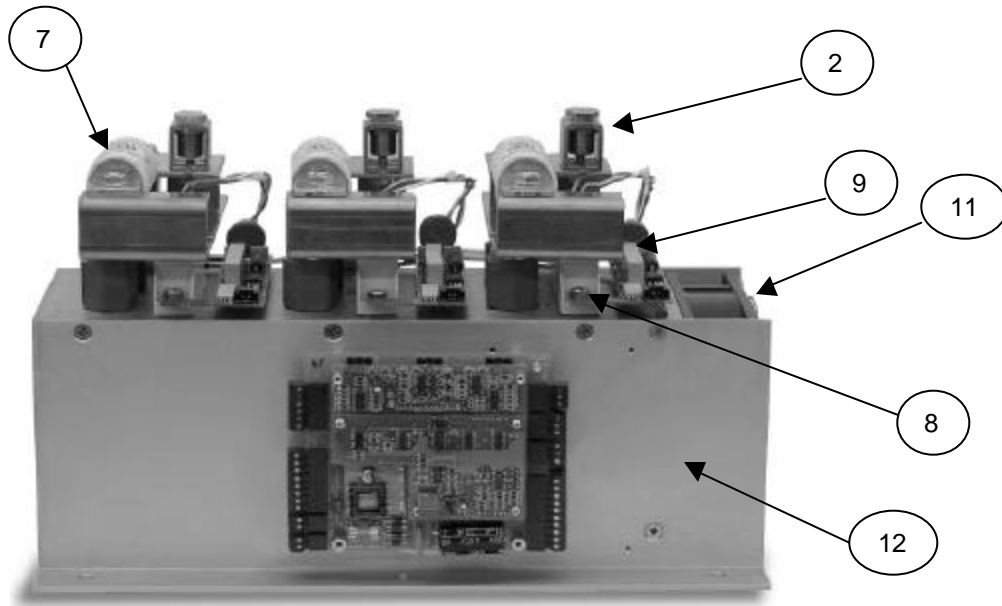
List of Major Features

1. **Firing Card-** Controls the gating of the SCR. Also may house advanced plug and play boards for SCR failure detection and other features. Control signal is connected here.
2. **Power Connection Lugs-** Terminals where power connection is made for load switching.
3. **Power Connection Lugs with Power Distribution-** Additional holes are provided so that multiple crimp lugs may be utilized for power distribution to multiple circuits.
4. **Current Transformer -** Used for measuring current in current limiting, Partial Load Failure Detection, and Soft Start applications. (Not Shown)
5. **Bus Bar-** Used to carry power from terminal connections to switching device.
6. **Ground Lug-** Used for ground connection.
7. **I²T Fuse-** Fast acting fuse used to protect the SCR from damaging high current.
8. **SCR-** Actual power switching semiconductive device.
9. **MOV and dV/dT Protection Board-** Contains circuitry that protects the SCR from transient voltages, spikes, and noise that could cause false firing or failure.
10. **Mounting-** Support panel used to mount the unit to an enclosure.
11. **Cooling Fan-** Fan used to dissipate heat from the heat sink.
12. **Heat Sink-** Bonded fin used to pull the heat away from the SCR.



Touch Safe

*Shown without cover



Open Design

GLOSSARY OF COMMON POWER CONTROL TERMS

AC- Alternating Current.

AL ROMAN EFFECT, THE - In the event of an SCR failure the failure mode will always occur in the mode that is most detrimental to the process. In other words an SCR can fail either short or open circuit, *The Al Roman Effect* predicts that the failure mode will be the mode that the user does not want to happen. *The Al Roman Effect* is why overtemperature protection and/or a shut down device is recommended when using an SCR.

ANODE- The positive power terminal of an SCR or diode.

CATHODE- The negative power terminal of an SCR or diode.

CURRENT LIMITING- A means to limit the maximum amount of current that can be delivered by the power control device.

COMMAND SIGNAL- The input signal to an SCR power controller that communicates the amount of output required from the output of the process control device.

CONDUCTANCE- The ability of a material to conduct electricity. Conductance is the inverse of resistance.

CURRENT FEEDBACK- The ability to measure the amount of current delivered to the load and feed it back to the power controller for measurement, control, or to limit current.

CT- Current Transformer; A device used to measure current. The unit typically consists of a donut shaped device that houses a coil of copper wire. The main load wire passes through the donut and generates a current in the coil proportional to the load current.

di/dt- The rate of current change over a time change. It is a measure of how fast current changes over time.

DIODE- A semiconductor which allows current to pass in one direction only.

DOT- Demand Oriented Transfer; Power is controlled using zero Crossover firing in the smallest time base possible. 25% output would consist of 1 cycle on and 3 cycles off.

dV/dt- A Resistance Capacitance Network connected across the SCR to filter out high frequency voltage noise and transient changes in the line voltage to prevent the SCR from being falsely turned on.

FORWARD DROP- The voltage drop across a semiconductor when the device is conducting current in its normal forward direction. This drop is typically 1.5 Volts for most SCR devices.

GATE- The signal terminal of an SCR. When voltage is applied to the gate the SCR conducts in its normal forward direction.

HEATSINK- Device used to transfer heat away from the SCR or the diode.

HYBRID- Refers to a particular arrangement of SCR's and diodes in an SCR power controller. Three SCR's are used in conjunction with three diodes.

I²T- Amps squared times seconds; Refers to the current characteristics of a fast clearing fuse.

INSIDE DELTA- Refers to a method of connecting the SCR's inside the delta load circuit instead of on the feeder wires.

INRUSH CURRENT- A current surge, typically at start-up, due to inductance or low resistance in the load.

LED- Light Emitting Diode; A small semiconductive light used to indicate status of a controller.

MOV- Metal Oxide Varistor; A device used to protect an SCR from voltage spikes and transients.

OVER CURRENT TRIP- A detection and shutdown circuit which interrupts the operation of the circuit if the current exceeds a preset value.

PEAK- Refers to a maximum instantaneous value of voltage or current.

PHASE ANGLE CONTROL- An SCR firing mode in which the SCR's are turned on for a portion of each individual half-wave AC cycle.

PHASE LOCK LOOP- PLL; An electronic circuit which automatically adjusts itself to maintain synchronization with the line frequency for precise SCR timing.

PIV- Peak Inverse Voltage; Refers to the voltage rating of an SCR or diode. It is the voltage that the component can block in the reverse direction.

POWER FACTOR- Power factor can effect the cost of power from the utility. In engineering terms it is the difference in phase of the voltage sinusoid and the current sinusoid. In terms of SCR power control power factor is effected by the percentage of the wave form that is being dissected in phase angle power control. The more of the wave that is being cut the lower the power factor. Power factor ranges from 0 to 1 and is often referred to as a percentage. Power factor of one is ideal.

PLUG AND PLAY- Additional plug in boards that can be utilized for adding advanced features to the power control. An example would shorted SCR detection.

PT- Potential Transformer; used to isolate and/or change a voltage from one voltage level to another.

RC- Resistance Capacitance Network; connected across the SCR to filter out high frequency voltage noise and transient changes in the line voltage (dV/dt) to prevent the SCR from being falsely turned on. This is more commonly referred to as dV/dt protection.

RESISTANCE- The characteristic of a material to conduct or resist the flow of current. Resistance is measured in ohms.

RESPONSE- The ability of the power controller to respond to output control.

RFI- Radio Frequency Interference; high frequency interference generated by phase angle fired SCR's or contactor bounce.

RMS- Root Mean Squared. An arithmetic term that refers to the effective value of voltage or current. This is the value that we measure with a meter. It is the peak voltage divided by the square root of two. For example, 120 volts rms has a sinusoidal wave that peaks at +/-170 volts. RMS refers to the actual work or energy that can be delivered from alternating voltage.

RTD- Resistance Temperature Detector. A device whose resistance changes with temperature and is used as an input to a temperature controller.

SCR- Silicon Controlled Rectifier; a semi-conductive device that conducts power when the device is triggered or gated.

SEMICONDUCTOR- Solid state device for controlling electrical signals or power.

SOFT START- A gradual application of voltage or power to the load to prevent high current at start-up due to inrush.

SPAN ADJUSTMENT- Typically a potentiometer adjustment to match the controllers output to the command signal. Also referred to as gain and is adjusted with the command signal at 100% so the power controller output is full on.

SUPPRESSER- A device for clamping excessive voltage transients. See MOV.

THERMOCOUPLE- A junction of two dissimilar metals that produces a small voltage. The voltage varies with temperature and is used as an input to a temperature controller.

THYRISTOR- The name of a semiconductor family, including SCR's and Triacs.

TIME PROPORTIONING- A control mode in which the on and the off time of an SCR are adjusted to provide the desired load power.

VOLTAGE CONTROL- A circuit which provides a linear voltage to the load proportional to the command signal and compensates for line voltage changes.

ZERO ADJUSTMENT- Typically a potentiometer adjustment to match the command signal to the controllers output. Adjusted with the command signal at 0% so the power controllers output is off.

ZERO CROSS FIRING- A method of controlling the load power in which the SCR's are turned on or off only at the beginning or end of the AC cycle. Switching always occurs when the applied voltage is zero.

NOTES

NOTES