

**WHAT YOU  
SHOULD KNOW  
ABOUT SCR  
POWER  
CONTROLLERS**



"What You Should Know About SCR Power Controllers" was written as a practical guide to the selection and successful application of SCR controllers. As such, it is not meant as a comprehensive discussion of power controllers and their functions. If you require more in-depth information on this subject, please contact us at:

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## 1.0 INTRODUCTION TO SCR POWER CONTROL

Since the development of SCR power controllers in the late 1950's, the power handling capabilities of SCR's (silicon controlled rectifiers) have advanced from a few hundred watts to many megawatts. So, too, the use of SCR power controllers in industrial applications has increased dramatically and they are now used in almost every major industry.

## 2.0 MAJOR ADVANTAGES

SCR power controllers provide a relatively economical means of power control. SCR power controllers cost less and are more efficient than saturable core reactors and variable transformers. Compared to contactors, SCR power controllers offer a much finer degree of control and do not suffer from the maintenance problems of mechanical devices. Features and benefits of SCR power controllers over other forms of control include:

### High reliability

Because the SCR power controller is a solid-state device, there are no inherent wear-out modes. Thus, they provide virtually limitless and trouble free operation.

### Infinite resolution

Power, current or voltage can be controlled from zero to 100% with infinite resolution. This capability allows extremely accurate, stepless control of the process.

### Extremely fast response

The SCR controller can switch load power on and off extremely fast providing the means to respond rapidly to command changes, load changes and power supply changes. This feature allows the control of fast responding loads and eliminates the negative effects of variations in load or supply voltages that can occur with other types of control.

### Selectable control parameters

The SCR power controller can control the average load voltage, the RMS value of the load voltage, the RMS or the average load current or load power. It can also provide useful features such as current and voltage limiting. The ability to control the desired parameter as a function of a command signal and to incorporate limiting features is not normally available with other types of control.

### Minimum maintenance

Because they are solid state there are no moving parts to wear out or replace. Therefore, the routine replacement required in some forms of control is eliminated.



**160 AMP SINGLE PHASE SCR CONTROLLER**



**425 AMP THREE-PHASE SCR CONTROLLER**

## 3.0 GENERAL DESCRIPTION

Basically, an SCR power controller consists of the following:

- semiconductor power devices (SCR's and Diodes)
- a control circuit normally referred to as the firing circuit
- a means to dissipate the heat generated from the semiconductor devices
- and protective circuits (fuses and transient suppressors).

## THE SCR

The heart of the SCR power controller is the SCR (silicon controlled rectifier, also sometimes referred to as a thyristor).

The SCR has two states, ON and OFF, and allows current to flow in only one direction. SCR's can remain in the off state even though the applied potential may be several thousand volts; in the on state, they can pass several thousand amperes. When a small signal is applied between the gate and cathode terminals (Figure 2.1), the SCR will turn on in 10-100 microseconds. Once turned on it will remain on until the current through it is reduced below a very low value called the holding current.

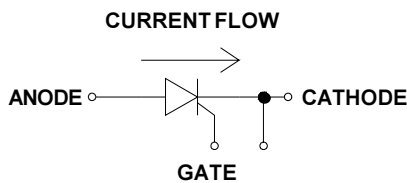


Figure 2.1. SCR symbol

Because the SCR allows current to flow in only one direction, two SCR's are connected in a "back to back" configuration to control AC current (Figure 2.2).

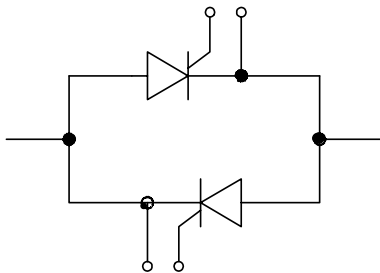


Figure 2.2. AC "Back to Back" Switch

Three types of construction styles are available: the disc or hockey puck, the module, and the stud mount. Modern SCR controllers generally use either the hockey puck or the module construction.

### **Hockey puck SCR's**

The hockey puck style is an assembly that has essentially the same physical shape as a hockey puck. The construction provides excellent cooling of the semiconductor material and is generally used in higher current applications.

## **SCR Modules**

SCR modules are assemblies in which the SCR's are contained in a plastic enclosure with an electrically isolated mounting plate. SCR modules are becoming increasingly popular and modules containing a variety of SCR configurations are available. They are easy and inexpensive to mount to a heatsink, they typically have large surge current ratings and they provide electrical isolation, allowing multiple modules to be mounted on a common heat sink.

## ELECTRONIC CIRCUIT

The electronic circuit controls the operation of the SCR's such that the desired energy applied to the load is proportional to the command signal.

Important tasks of the circuit include:

**Timing:** It is imperative, particularly in applications involving inductive loads such as transformers, that no DC be applied to the load. For the reasons described under Trans-Guard (p.8), DC components can also cause supply transformers to over heat. This requires that the ON time of the back-to-back SCR's be exactly equal. Modern circuits use sophisticated digital phase lock loop techniques which are immune to the electrical noise and varying voltages that are often found in industrial environments.

**Electrical Isolation:** The command signal must be isolated from the supply and load voltage. Plus, excellent isolation is required between the circuits controlling the signals to the gates of the SCR's to prevent false turn-on of the SCR's.

## HEATSINK REQUIREMENTS

SCR's emit about 1.5 watts of energy in the form of heat per ampere conducted. Failure to dissipate this energy is perhaps one of the main sources of SCR failure. The reliability of SCR's decreases about 50% for every 10 degrees centigrade increase of it's semiconductor temperature. Other critical parameters such as the  $dv/dt$  (See glossary) rating and the blocking voltage rating also decrease rapidly with temperature.

The heat generated by the SCR must be dissipated, thus, all controllers have some means to cool the SCR's. Typically an aluminum heatsink with fins to increase the surface area is used to dissipate this energy to air. Controllers with relatively small current capacities rely on natural convection; larger current capacity controllers use a fan to force air past the fins to increase the rate heat is dissipated. Occasionally, SCR controllers with very large current ratings use water cooled heatsinks.

#### 4.0 BASIC CONTROL MODES

The power delivered to a load may be regulated or proportioned by SCR power controllers using either the phase-angle or the integral cycle (zero-cross voltage switching) control mode. Each control mode has its own specific advantages and disadvantages and each application should be reviewed to determine the most compatible mode of control.

**Phase-angle:** In phase-angle control each SCR of the back-to-back pair is turned on for a variable portion of the half-cycle that it conducts (Figure 3.1). Power is regulated by advancing or delaying the point at which the SCR is turned ON within each half cycle. Light dimmers are an example of phase-angle control.

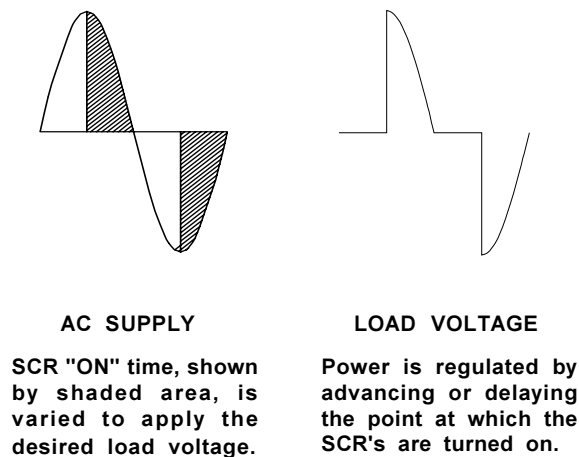


Figure 3.1. Phase-Angle Waveforms

Phase-angle control provides a very fine resolution of power and is used to control fast responding loads such as tungsten-filament lamps or loads in which the resistance changes as a function of temperature. Phase-angle control is required if the load is transformer-coupled or inductive.

Phase-angle controllers are typically more expensive than zero-cross controllers because the phase-angle circuit requires more sophistication than does a zero-cross circuit. Phase-angle control of three-phase power requires SCR's in all three legs and is appreciably more expensive than zero-cross control which only requires SCR's in two of the three legs.

**Zero-cross:** The term zero-cross or synchronous operation of SCR's is derived from the fact that the SCR's are turned on only when the instantaneous value of the sinusoidal waveform is zero. In zero-cross operation, power is applied for a number of continuous half-cycles and then removed for a number of half-cycles to achieve the desired load power in the same manner as power would be controlled with a mechanical switching device. The difference is that the SCR controllers always switch power when the instantaneous value of the applied voltage is zero. Also, the frequency of the on-off cycles can be extremely fast because there is no limit to the number of switching operations the SCR can perform.

Zero-cross controllers can provide two rather distinctively different types of control. *Time proportioning* control is sometimes used when switching large amounts of current can cause voltage variations which affect ambient lighting or other equipment. The disadvantage is that power is applied in longer bursts which can in turn cause control problems and shorten heater life. *Distributive control* is typically somewhat less expensive, provides a much faster cycle rate giving better controllability and longer heater life. It can also be used with much faster responding loads than can time proportioning.

**Zero-cross time proportioning:** Zero-cross time proportion control is accomplished with a fixed or constant time base, therefore the total of power "ON" time and power "OFF" time is always equal to a fixed value. For example, if the time base is ten seconds and the desired power is 50%, then power is applied for 5 seconds and removed for 5 seconds. If the desired power were 25% then power is applied for 2.5 seconds and removed for the remaining period of 7.5 seconds. The disadvantage of time proportioning particularly as the time base is increased is that the load temperature varies considerably between the on-off cycles. This can shorten the life of heater elements and decrease the ability to obtain precise process control.

**Distributive zero-cross:** Distributive zero-cross does not use a fixed or constant time base as is used in time proportioning. The technique used by Control Concepts applies load power for 3 electrical cycles and removes load power for 3 electrical cycles at 50% power. At lower power requirements the controller will apply power for 3 electrical cycles and is then off for the appropriate number of electrical cycles. For example, at 25% power the controller is on for 3 electrical cycles and off for 9 electrical cycles, or on for 3 electrical cycles out of 12. At higher power levels the controller is off for three electrical cycles and on for the appropriate number of electrical cycles. For example at 75% power the controller is on for 9 electrical cycles and off for 3 electrical cycles.

The Control Concepts distributive control technique combines power pulses of short duration to obtain the exact power level proportional to the command or set point signal. For example, 60% power is achieved by combining two power pulses. The first power pulse consists of 4 on cycles and 3 off cycles; the second power pulse consists of 5 on cycles and 3 off cycles, providing a total of 9 on cycles during 15 cycles. Of course, such rapid, short bursts of power would be impossible with mechanical contactors. Zero-cross control is typically less expensive than phase-angle control and generates fewer harmonics. However, zero-cross can only be used to control power to resistive loads that do not change appreciably with temperature or time and which are directly-coupled (no transformer between the SCR controller and the load). Zero-cross control of large power levels can cause supply voltage fluctuations resulting in ambient lighting fluctuations or other problems (See Sync-guard, page 8), and can cause overheating of transformers supplying power to the controller and load (See Trans-guard, page 8).

## 5.0 SPECIAL CONSIDERATIONS: POWER FACTOR AND HARMONICS

The operation of zero-cross or phase-angle SCR controllers can lower the power factor, resulting in a higher electrical cost. Harmonics can be generated which may cause radio frequency interference (RFI) or possibly affect the operation of other equipment.

### Power Factor

The power factor of a single-phase circuit is the ratio of true power in watts, as measured with a wattmeter, to the apparent power in volt-amperes, obtained as the product of voltage and current.

$$\text{P.F.} = \frac{\text{KW}}{\text{KVA}}$$

(The power factor of a balanced polyphase circuit is the same as that of the single phases. When the phases are not balanced the true power factor is indeterminate.)

COMPARISON OF PHASE-ANGLE AND ZERO-CROSS		
PARAMETER	PHASE-ANGLE	ZERO-CROSS
Cost: 1-phase	Slightly more	Slightly less
Cost: 3-phase	Appreciably higher	2-leg control is appreciably less due to lower circuit cost and because only 2 of the 3 supply lines require SCR's. 3-leg control is slightly less because of circuit cost.
Type of loads:	Transformer coupled loads, fast responding loads, loads with large resistance changes, loads requiring current limiting, or soft start.	Resistive loads only. Power can not be applied to a transformer. Moderately fast loads can be controlled with distributive control.
Power factor: (Ref Section 5)	Theoretical value equals (% of applied power/100) <sup>0.5</sup> . Power factor observed on typical utility meter is very close to theoretical power.	Resistive loads only. Power can not be applied to a transformer. Moderately fast loads can be controlled with distributive control. Theoretical value equals (% of applied power/100) <sup>0.5</sup> Power factor observed on typical utility meter approaches unity.
RFI and Harmonics: (Ref Section 5)	Higher harmonics are generated and the potential for RFI is higher.	Harmonics and RFI are very low.
Reliability:	Lower than zero-cross	Higher than phase-angle because fewer components are required and because the SCR turns on when the voltage and current are zero.
Serviceability:	More complex	Easier because of fewer components.

In figure 6.1, consider the supply voltage  $E_s$  to be 480 volts RMS and the load voltage  $E_L$  controlled by the SCR controller to be 240 volts RMS. The load current  $I_L$  is, of course, equal to the supply current  $I_s$  and is equal to  $E_L / R_L$  or 100 amps. The KW of the system is 24. (240 volts X 100 amps) and the KVA is of the system is 48 (480 volts X 100 amps).

$$\begin{aligned} \text{P.F.} &= \frac{24}{48} = \frac{E_L \times I_L}{E_s \times I_L} = \frac{E_L}{E_s} = 0.5 \\ &= (\% \text{ applied power}/100)^{0.5} \end{aligned}$$

The power factor with resistive loads controlled by either phase-angle or zero-cross control is the ratio of the load voltage to the supply voltage and is therefore proportional to  $(\% \text{ applied power}/100)^{0.5}$ .

Tests have shown that most power factor meters supplied by utility companies respond correctly to phase-angle control, but provide near unity power factor for zero-cross control. Newer meters using solid state technology and which sample for a longer time period provide power factor measurements very close to the theoretical values for both phase-angle and zero-cross control.

### Harmonics and RFI

Harmonic wave forms are generated when electrical power is switched and are therefore generated when power is controlled by mechanical contacts, saturable core reactors, SCR controllers and all other power switching devices.

Harmonics are sinusoidal waveforms with frequencies that are integral multiples of the fundamental frequency. For example, a waveform that has twice the frequency of the fundamental frequency is called the second harmonic. All repetitive waveforms are formed by the addition of harmonics. In general, abrupt changes in the waveform or complex waveforms cause the magnitudes of the harmonics to increase, increasing the possibility of interference problems. In SCR control the magnitude of the harmonics are the greatest when the load power is controlled at 50%. Tables 5.1 & 5.2 show the relative magnitude and frequency for zero-cross and phase-angle control.

Although harmonics and RFI are a common concern, very few if any problems have occurred in actual application. This is because harmonics are attenuated by inductance, and because the effects of harmonics are attenuated by proper shielding and grounding of electrical equipment.

Table 5.1 ZERO-CROSS		
Harmonic	Frequency	Magnitude %
1	10	10.90
2	20	0.00
3	30	14.10
4	40	0.00
5	50	34.71
6	60	50.00
7	70	29.80
8	80	0.00
9	90	8.49
10	100	0.00
11	110	4.50
12	120	0.00
13	130	2.88
14	140	0.00
15	150	2.03
16	160	0.00
17	170	1.50
18	180	0.00
19	190	1.18
20	200	0.00
21	210	0.09
22	220	0.00

Table 5.2 PHASE-ANGLE		
Harmonic	Frequency	Magnitude %
1	60	59.70
2	120	0.00
3	180	31.80
4	240	0.00
5	300	10.60
6	360	0.00
7	420	10.60
8	480	0.00
9	540	6.40
10	600	0.00
11	660	6.40
12	720	0.00
13	780	4.60
14	840	0.00
15	900	4.60
16	960	0.00
17	1020	3.50
18	1080	0.00
19	1140	3.50
20	1200	0.00
21	1260	2.90
22	1320	0.00

Note: The 1st or fundamental harmonic of zero-cross is 10 Hertz because power is applied for 3 cycles and removed for 3 cycles at 50% power.

## 6.0 LOAD CONFIGURATIONS AND CONSIDERATIONS

Load configurations and considerations for single-phase control should be obvious from the previous discussion. However, there are several unique load configurations and some important considerations which need to be examined in three-phase applications.

### SINGLE-PHASE LOAD CONNECTIONS

The connections for single-phase are the same for phase-angle (Figure 6.1) and zero-cross (Figure 6.2), the difference between the two being the manner in which the SCR's are controlled.

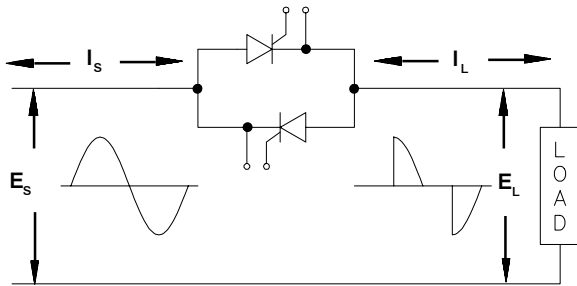


Figure 6.1. Phase angle control at 50% power

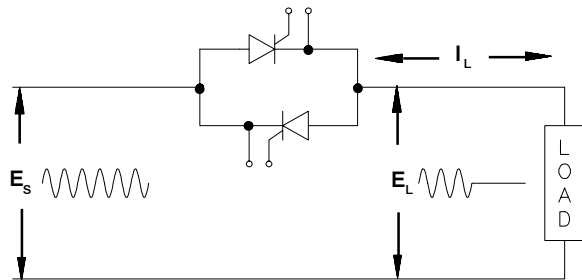


Figure 6.2. Zero-cross at 50% power

## THREE-PHASE LOAD CONNECTIONS

### Phase-angle

Phase-angle control of three-phase requires a total of 6 power switching devices. These devices can be configured as hybrid (3 SCR's & 3 diodes), 6 SCR in-line or 6 SCR inside delta.

### Hybrid Control

Three-phase hybrid controllers use three SCR's and three diodes (Figure 6.3) to control load power. These controllers are intended primarily for three-wire 'wye' or 'delta' type resistive loads connected directly to the controller (i.e., a transformer is not connected between the load and the controller). The three-phase hybrid controller should not be used in a four wire circuit. The fourth wire common return would allow uncontrolled conduction through the power diodes resulting in approximately 50% power output even though the SCR's were off.

The advantage of hybrid controllers is that the cost is somewhat less than six SCR control because the circuit is less complex and diodes are less costly. However, hybrid controllers should not be used if the load is unbalanced. An unbalanced load controlled with a hybrid controller will result in a DC current flow which, for the same reasons discussed in the section entitled Trans-Guard, can result in supply transformer saturation.

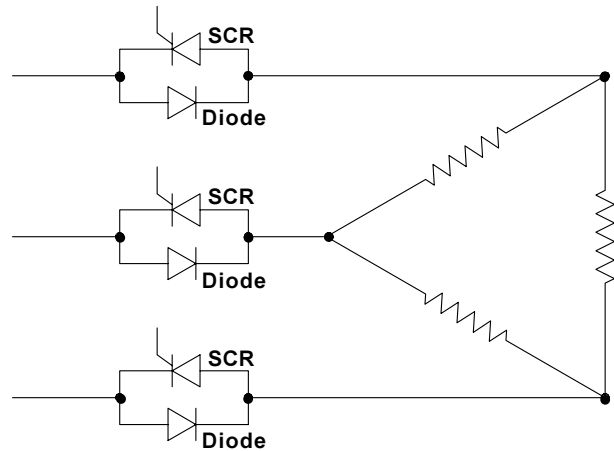


Figure 6.3 Hybrid control



### Six SCR in-line controllers

The Six SCR controller, as the name implies, uses six SCR's (Figure 7.1) to control the load power. This configuration is an ideal configuration for inductive load applications, unbalanced resistive loads and transformer coupled loads. *Caution:* If the controller is operating a transformer, either the primary or the secondary winding must be a delta configuration.

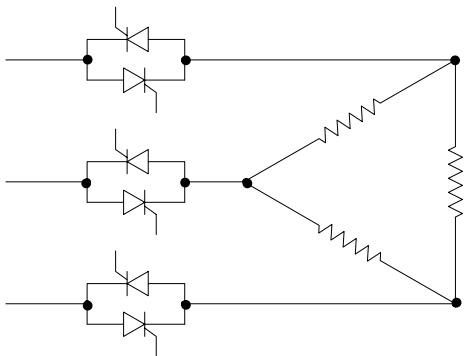


Figure 7.1. Six SCR in-line control

### Six SCR inside delta control

Three phase inside delta control is essentially three single-phase controllers operating from the same command or set point. Typically a six SCR controller can be configured to operate inside delta. It is also possible, of course, to configure three single phase controllers controlled by the same command signal. Because the current in each phase is 57.74% of the line current, smaller and less expensive controllers can be used for inside delta control.

*Caution:* If inside delta control is used in the primary of a three-phase transformer, a six SCR controller must be used and the secondary must be a delta. (Three single phase controllers can not be used inside the delta to operate a three-phase transformer)

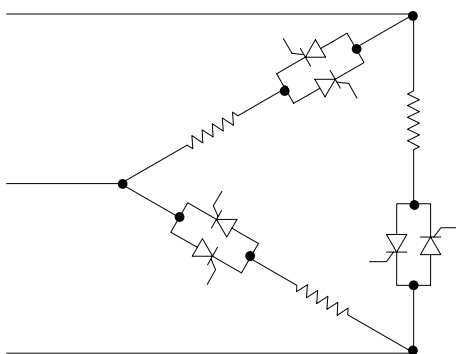


Figure 7.2. Six SCR inside-delta control

### ZERO-CROSSCONTROL

#### Two leg control:

This approach uses a pair of back-to-back SCR's in two of the supply leads to the load (Figure 7.3). If all of the SCR's are off no power can be applied to the load. The two leg control can be used on either "wye" or "delta" loads, however, it can not be used to control four wire loads. As previously mentioned, the primary advantages of the zero-cross control technique are lower cost and extremely low RFI.

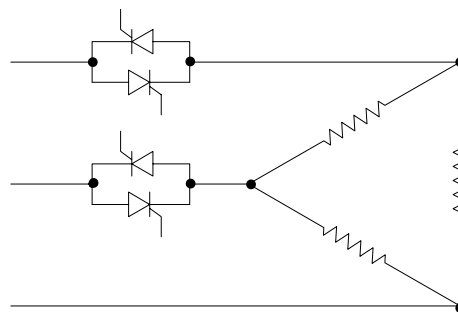


Figure 7.3. 2-leg zero-cross

#### 3-leg control

Some installations require that all three legs of the load be controlled and therefore back-to-back SCR's are placed in all three supply leads. The cost advantage of zero-cross control is reduced with 3-leg control because of the added SCR's and heat sink costs, however, the circuit cost is less than an equivalent phase-angle controller and the advantage of low RFI is retained.

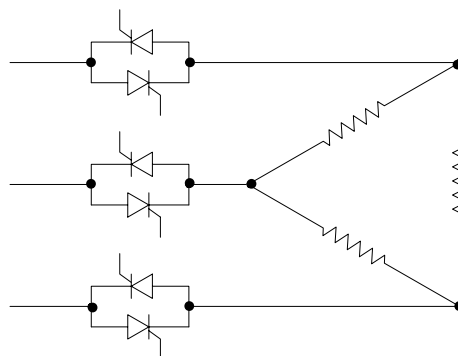


Figure 7.4. 3-leg zero-cross

#### Zero-cross inside delta

Zero-cross using the inside delta technique as described previously can be used to reduce the current rating of the SCR's and in some instances system cost can be reduced.

## 7.0 FEATURES TO IMPROVE PERFORMANCE

### Soft Start & Missing Cycle Detection

These features are required in phase-angle control to assure that the load power is gradually increased from zero to the value set by the command signal if load power is interrupted. This gradual increase of power prevents surge currents and avoids the possibility of saturating inductive loads like transformers.

### Current Limiting

This feature, available only on phase-angle controllers, provides a means to prevent the load current from exceeding a preset value. Current limiting is used to protect, the load, the SCR controller, fuses, and the system supply from large surge currents that could occur at start up due to loads that have a low resistance when cold.

### Feedback/Feedforward

Either feedback or feedforward provides the means to achieve a linear relation between the desired output and the control or command signal. Feedback implies that the desired parameter is measured and "fed back" to the input of the control such that the output can be increased or decreased if corrective action is required. Feedforward involves a less expensive technique in which the output is simulated in the circuitry and corrective action is taken based upon the simulated circuit response. Both techniques provide a linear output with respect to the control or command signals and eliminate the effects of load and supply variations.

### Over Current Trip

The over current trip feature prevents the SCR's from being turned on if the SCR current has exceeded a preset value during the last half cycle. Essentially, this feature is an electronic fuse which eliminates the need for expensive and troublesome semiconductor fuses. The controller can be reset by either removing and reapplying power or by momentarily closing a remote switch. This feature has proven to be a more reliable protection technique than fast acting fuses.

### Shorted SCR Detection

If an SCR does fail, it typically becomes shorted allowing load current to flow continuously. In the event an SCR shorts, this feature energizes a relay which can be used to activate an alarm or remove system power.

### Sync-Guard

This feature, available on some zero-cross controllers produced by Control Concepts, reduces the possibility of synchronous operation of two or more controllers. It reduces the variations in power demand resulting in a more stable supply voltage and improved power factor. The Sync-Guard feature does not alter the power applied to the load, but adjusts the time when power is applied in such a manner as to reduce the possibility of the controllers being ON and OFF at the same time.

### Trans-Guard

The use of zero-cross controllers on the secondary of a transformer can cause saturation of the transformer resulting in excess transformer temperatures and early failure.

Transformers can be caused to saturate if a DC voltage is applied to the primary. DC voltage can be induced on the primary by DC components in the secondary. The simple half wave rectifier circuit shown in figure 8.1 will induce a DC voltage on the primary due to the fact that the voltage drop across the source resistance during the cycle the diode conducts will lower the primary voltage when the diode conducts. The effect is the same as if a zero-cross controller were not providing an equal number of positive and negative half cycles to the load. Although not shown in figure 8.1, the source inductance can also cause a DC voltage to occur on the transformer primary. The Trans-Guard feature eliminates the problem by always supplying an odd number of ON half-cycles and an even number of OFF half-cycles. This technique guarantees that no DC will occur independent of the source impedance or the load configuration.

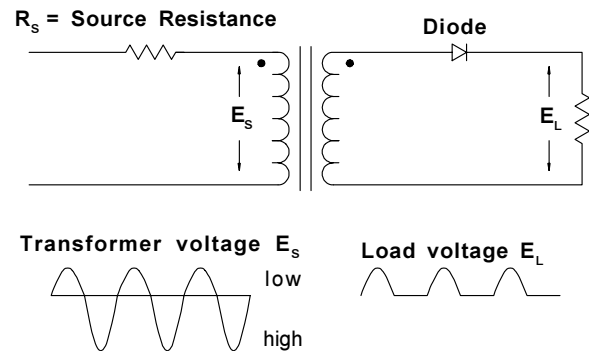


Figure 8.1. Transformer saturation due to secondary DC current

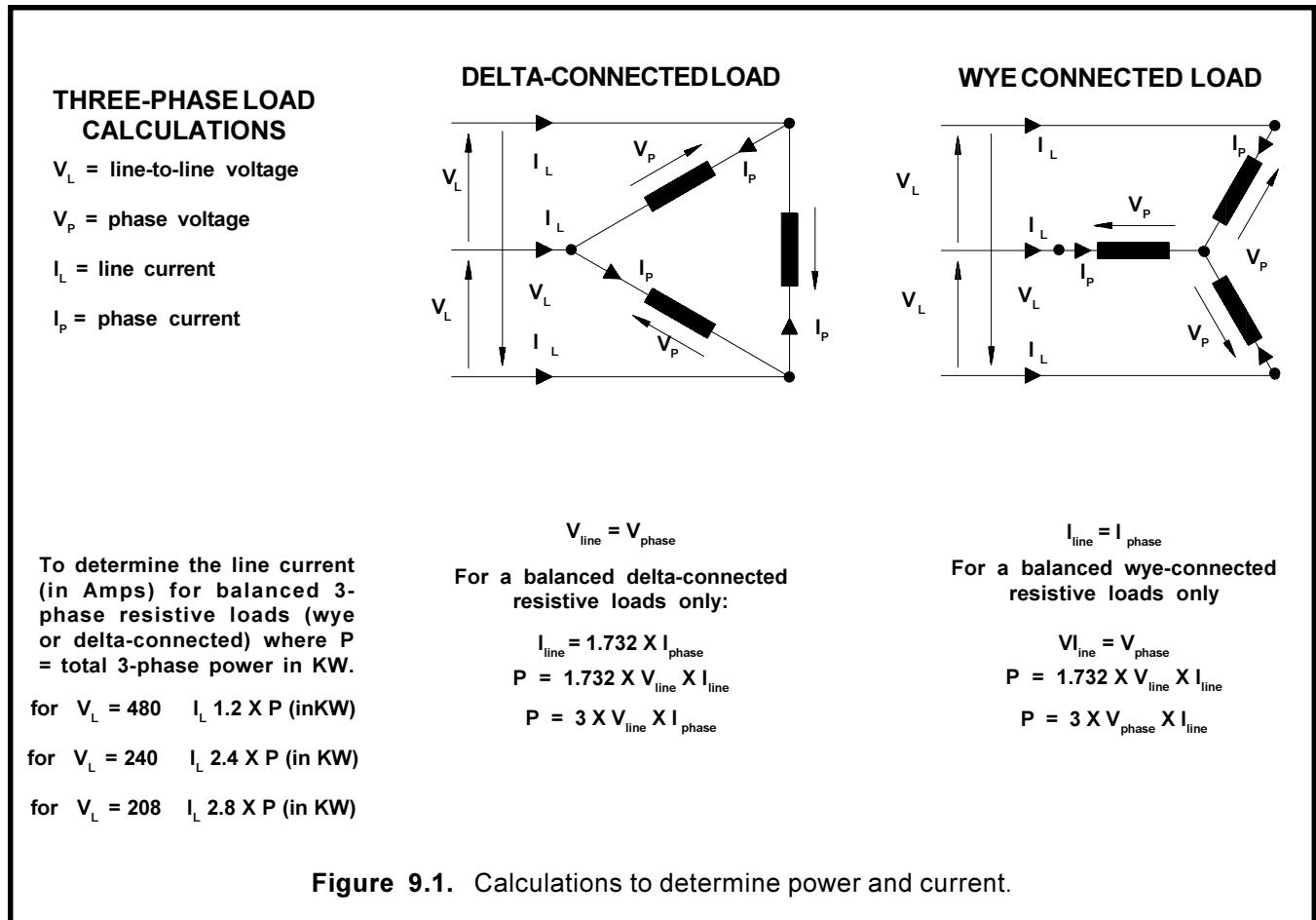
The saturation problem is not likely to occur when the load is a small percentage of the transformer capacity, or when the source resistance and inductance are small. However, the potential problem always exists unless the controller is designed with the feature described above.

## 8.0 SELECTING THE CORRECT CONTROLLER

### 1.0 Determine the current and load configuration

Determine the current and voltage requirements and determine whether the application is to be three-phase or single-phase. (Single-phase controllers will typically be less expensive than three-phase controllers.)

Figure 9.1 shows the calculations to determine power and current.



### 2.0 Determine the control mode

Determine the type of control mode (zero-cross or phase-angle) and features to enhance performance: Transformer coupled loads, fast responding loads, loads that change resistance with age or temperature typically require phase-angle control. Figure 10.1 is a guide to aid in determining the type of control mode to be used.

Zero-cross control is typically less expensive than phase-angle control.

### 3.0 Choose a reliable and serviceable controller.

Expect more than just the obvious. The following, often overlooked features and requirements are critical to the reliability and serviceability of SCR power controllers.

### SPRING LOADED CONNECTIONS

The use of spring washers on all electrical junctions always insures a good connection. Heat is generated in electrical connections because of the resistance of one conductor or bus bar to another. This heat causes expansion and deformation of the connection and in turn can cause the resistance to increase, generating even more heat. The spring applies a constant force to the junction, allowing for the expansion. In addition, all connections should have an electrical compound applied to improve both thermal and electrical conductivity.

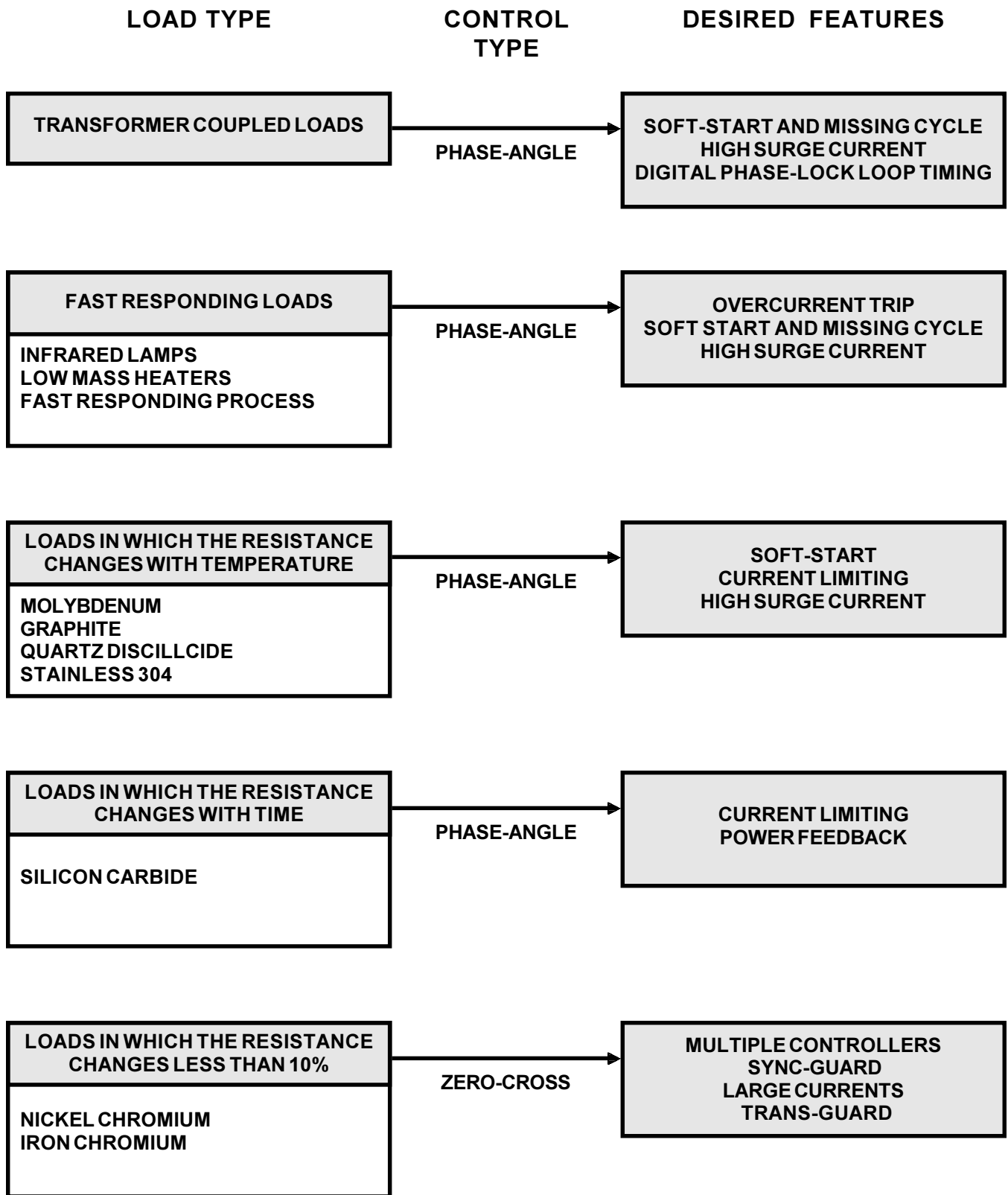


Figure 10.1 SCR Controller Selection Guide

## **LONG LIFE FANS**

Fans are often required to cool the semiconductors in SCR power controllers. Fans with ball bearings or extended life sleeve bearings provide superior performance and long life over less expensive fans with conventional sleeve bearings.

## **POWER CONNECTORS**

Connectors used to connect the supply leads and the load leads should be designed to remain secure when field wiring is installed. (The typical installer of the controller will over-torque the connectors; if the connectors become loose under these conditions problems with the controller will develop.) The connectors should also be located such that it is convenient to use a wrench and apply the right torque during installation. Additionally, a design which allows the air from the semiconductor cooling fans to pass over the large current connectors cools the connection and improves reliability.

## **FORCE INDICATING CLAMPS**

SCR'S and diodes of the hockey puck design must be "squeezed" between the heat sinks by spring loaded clamps to assure electrical and thermal conductivity. To facilitate field replacement (serviceability) of the semiconductor, the spring clamps should have a force indicator to determine the proper force.

## **STATUS INDICATORS**

Status indicators consist of small LEDs that provide information regarding the magnitude of the command signal, the magnitude of the load current, the status of features such as over-current trip and shorted SCR detection. Controllers so equipped can be easily and safely serviced by inexperienced personnel.

## **TRANSIENT PROTECTION**

Rapid voltage changes (dv/dt) and high voltage transients are common in industrial applications. Under such conditions, the SCR's can turn on, causing undesired surge currents or outputs if proper protection is not provided. Unprotected SCR's can actually be destroyed by repeated transients. If an SCR is turned on due to a transient, it is possible for very high current densities to destroy a small portion of the SCR. If this is repeated even higher current densities occur until failure. To prevent damage or failure due to high voltage transients, SCR's should have a high blocking voltage (1400 volts for 480 Vac) and must be protected with fast acting MOV's (metal oxide varistors). Further, a series resistor and capacitor circuit should be connected across the SCR's to provide a shunt for high frequency transients (dv/dt).

## **SINGLE PLUG-IN CIRCUIT BOARD**

The use of a single circuit plug-in circuit board greatly improves serviceability. For example, circuit cards can be switched from one controller to another when diagnosing problems. Also, use of a plug-in board eliminates the possibility of mis-wiring during service. In addition, if the circuit can be used on all controllers independent of current rating then only one card is required for spare parts.

## **CIRCUIT SYNCHRONIZATION AND TIMING**

To synchronize with line frequency, many controllers use the zero-cross (the start of the AC voltage cycle) as a reference to determine the conduction or "ON" time of the SCR. However, this may be difficult because of electrical noise in the industrial environment. Use of a filter in the zero-cross detection circuit helps to reject electrical noise and is acceptable for some applications. Controllers intended for transformer coupled loads require a very precise and noise immune technique. Here, request a phase-locked digital circuit to determine the zero-cross by a voltage integration technique. Transformer load applications require that all SCR's be turned "ON" for precisely the same amount of time to avoid applying DC. The phase-locked self adjusting digital clock technique provides the means to achieve extremely accurate timing and can be used "as is" on 50 or 60 Hertz applications.

## **THE GATE DRIVE**

SCR's are turned "ON" by the injection of current into the gate. The input impedance of the gate changes drastically during turn on. Therefore, a gate drive circuit, particularly on large SCR's, is required to inject the desired current independent of the gate impedance.

A technique using optical couplers to initiate a fast rising constant current source has proven to provide reliable operation and excellent electrical isolation. An SCR is turned on approximately 2 million times in eight hours and can be slowly destroyed if the gate drive is inadequate.

## **COOLING**

A 10°C increase in semiconductor temperature will decrease reliability by 50%. It is difficult for the user to determine if adequate cooling is provided. However characteristics of adequate cooling include: a) The ability to operate continuously in a 55°C ambient environment with no de-rating. b) Extremely smooth surfaces on which the SCR's are mounted. c) The use of a thermal compound on all electrical connections to aid thermal conduction and to prevent oxide formation. d) Proper containment of the cooling air such that all of the air provided by the fan passes over the heat sink.

### **SURGE CURRENT**

Certain loads, such as transformers or loads with a low cold resistance like infrared lamps, can have a large surge current. Therefore, the surge current rating of the controller must be adequate to protect the SCR's from damage in the event the SCR's are turned on by transients. Any surge current that may occur is dependent upon the load and the source resistance and is difficult to determine. However, a surge current rating of 12 times rated current has proven to provide very satisfactory reliability.

### **PANEL SPACE REQUIREMENTS**

Electrical enclosures are expensive. Therefore, a physically smaller controller saves enclosure costs. In addition a smaller and relatively light weight controller can be shipped faster and less expensively.

### **EXPERIENCE AND KNOWLEDGE OF THE VENDOR**

There are a great many factors which affect the application of SCR power controllers. An experienced and knowledgeable vendor is best able to provide the assistance and recommend the best product for the application.

### **9.0 ENCLOSURE SELECTION**

As is true of any solid-state device, the reliability of an SCR power controller is greatly increased if operated within its temperature range and if kept free of contaminants. Therefore, the selection of the enclosure and the means to cool it are very important.

### **HEAT DISSIPATION CONSIDERATIONS**

The enclosure should have proper ventilation or cooling to dissipate the heat generated by the equipment within it. An SCR power controller dissipates about 1.5 watts per ampere of current it controls. Therefore, a 100 amp single-phase controller dissipates about 150 watts, a 2-leg 100 amp zero-cross controller dissipates about 300 watts and a 100 amp 3-phase phase-angle controller dissipates about 450 watts. The heat generated within the enclosure can be dissipated by one of the following:

### **CONVECTION**

The internal temperature of a NEMA 1 enclosure increases above the external ambient temperature about 4°F per watt dissipated per square foot of exposed surface area. The temperature rise in degrees Fahrenheit can be approximated by dividing the total watts dissipated inside the enclosure by the exposed surface area in square feet and multiplying this number by 4. For example if a NEMA 1 enclosure with 100 square feet of exposed surface area contained equipment dissipating 900 watts, then the watts dissipated per square foot is 9 and the internal temperature can be estimated at 36°F above the outside ambient temperature.

### **FORCED AIR**

If the enclosure can not be cooled by convection then it may be possible to ventilate the enclosure by forcing air through it with a fan. The size of the fan can be determined by the following equation relating air flow in cubic feet per minute (CFM) to the power in watts (W) dissipated within the enclosure and the allowable temperature rise (DF) above ambient that can be tolerated within the enclosure.

$$CFM = \frac{3.16 \times W}{DF}$$

For example, if the power to be dissipated by forced air cooling is 900 watts and the maximum allowable temperature rise within the enclosure is 15°F then the air flow required would be:

$$CFM = \frac{3.16 \times 900}{15} = 189.6$$

### **COOLING WHEN A SEALED ENCLOSURE IS REQUIRED**

If the enclosure must be totally sealed because of water tight requirements, or extremely dusty conditions, etc., then other means of cooling such as air to air exchangers, water to air exchangers or air conditioning units specifically designed for cooling electrical enclosures can be used. (A kilowatt-hour equals 3413 BTUs)

## 10.0 FUSING AND DISCONNECT MEANS

The proper selection of fuses and other protection techniques can greatly affect the reliability of SCR controllers. Some SCR controllers are provided with fuses to protect the SCR's, some controllers have electronic fusing, and low cost controllers are provided with no SCR fusing. It is important to note that fuses provided with the controller are intended to protect the SCR's and may not be the correct fuse for load protection. The type of fuse depends, of course, on the load and the local and national codes. In general a fast acting fuse such as the JJS or JJN fuses provided by Bussmann have proven to be a good compromise for reliability, cost and protection. The vendor of the controller should be able to recommend the type of fuses required for any specific application.

SCR's have a small leakage current in the off state. Therefore, it is imperative that a mechanical disconnect be used to completely remove power prior to servicing. Controllers with over-current trip can be configured to operate shunt trip or under voltage trip circuit breakers to remove power in the event a load fault occurs.

## 11.0 MAINTENANCE

The SCR controller should be inspected periodically to determine that the electrical connections are tight and that the heat sinks are clean. The ability of the heat sink to dissipate heat is greatly reduced if dirt and grime have accumulated on it and it must be cleaned if dirty. Normally the cause of dirty heat sinks is failure to provide filtered air to air cooled enclosures or failure to clean the filters.

The electrical connections on new installations should be periodically inspected and tightened per the manufacturers instructions. Proper maintenance of the equipment will greatly increase the reliability of the controller.

## 12.0 GLOSSARY OF TERMS

**ANODE** - The positive power terminal of an SCR or Diode.

**AVE** - The average value of a particular parameter such as voltage or current.

**CATHODE** - The negative power terminal of a SCR or Diode.

**CURRENT LIMITING** - A means to limit the maximum amount of current applied to the load.

**COMMAND SIGNAL** - An input variable applied to an SCR power controller to adjust it's output.

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

**CURRENT FEEDBACK** - A means to maintain the applied current to the load. The applied current is maintained as a linear function of the command signal regardless of line voltage and load changes.

**CT** - Current Transformer; a device used for sensing current. It's output is an electrically isolated signal proportional to the measured current.

**di/dt** - The rate of rise of applied current to an SCR as the unit turns on.

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

**DISTRIBUTIVE CONTROL** - A means of controlling the on/off time of the SCR's to obtain a desired power output to the load.

**dv/dt** - Refers to the maximum rate of rise of applied voltage across an "off" SCR that will NOT cause a false turn-on. Usually stated as volts/second.

**FORWARD DROP** - The voltage drop across a semiconductor when that device is conducting current in it's normal forward direction.

**GATE** - The signal terminal of an SCR. The terminal used to turn on an SCR.

**HEATSINK** - Device used to transfer heat away from either an SCR or Diode.

**HYBRID** - Refers to a particular arrangement of SCR's and Diodes in an SCR power controller. Three SCR's and three Diodes.

**I<sup>2</sup>T** - Amperes squared times seconds. Refers to the subcycle current characteristics of either an SCR or a fast clearing fuse.

**INLINE** - Refers to the manner in which the SCR's are connected in three-phase applications.

**INSIDE-DELTA** - Refers to the manner in which the SCR's are connected in three-phase applications.

**INRUSH CURRENT** - That current which surges into a low impedance load or that which is drawn by a transformer during saturation.

**LED** - Light Emitting Diode. Often used as status indicators.

**MOV - Metal Oxide Varistor.** A device used to protect SCR's and Diodes from voltage transients.

**OVER CURRENT TRIP** - A detection and shutdown circuit which interrupts the operation of the SCR's if the SCR current has exceeded a preset value.

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

**PHASE-ANGLE** - An SCR firing mode in which the SCR's are turned ON for a portion of each half of an AC cycle.

**PHASE LOCK LOOP** - 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.

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

**RC - Resistance/Capacitance network.** Connected across the SCR's the RC is used to slow down the rate of applied voltage (dv/dt) to the SCR's to prevent the SCR's from being falsely turned ON by a voltage transient. This is often referred to as a dv/dt circuit.

**RESISTANCE** - The characteristics of a material which inhibit the flow of current, measured in ohms. Resistance is the inverse of conductance.

**RESPONSE** - The ability to respond to a command change measured in time or cycles.

**RFI - Radio Frequency Interference;** High frequency interference generated by phase-angle fired SCR's and other sources.

**RMS - Root Mean Squared;** refers to the heating value of voltage and current parameters.

**SCR - Silicon Controlled Rectifier;** The device used to switch the power to the load in SCR power controllers. A three terminal member of the thyristor semiconductor family.

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

**SOFT START** - A gradual application of voltage or power to the load to prevent current inrush.

**SPAN ADJUSTMENT** - Typically, a potentiometer adjustment to match the controllers output to the command signal. Also sometimes referred to as gain. Adjusted with the command signal at 100% so the power controllers output is full ON.

**SUPPRESSOR** - A device for clamping excessive voltage transients. See MOV.

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

**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 load power in which SCR's are turned ON only at the beginning of an AC cycle. Therefore, switching always occurs when the applied voltage is zero.