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The Many Benefits of SCR Power Control

Sponsored by: Advanced Energy Industries, Inc.

In today's competitive, cost-conscious industrial landscape, semiconductor and general manufacturing industries need a reliable, flexible, and precise way to control electric-heating processes. These applications require precise control, ease-of-use, and excellent reliability. SCR power controllers are ideal devices for this purpose.

Silicon-controlled rectifier (SCR) power controllers were developed in the late 1950s, and since then their power capabilities have changed from a few hundred watts to several megawatts. Their use in industrial applications has dramatically increased and they are now used in almost every major industry. These controllers consist of thyristors and a control circuit and can switch electrical loads within milliseconds, billions of times.

Power Controllers Offered by Advanced Energy Industries

Advanced Energy Industries, Inc. (AE), a world leader in precision power and control products, offers several SCR power controllers that meet the toughest design challenges. AE's Thyro line provides accurate temperature control for leading semiconductor and industrial manufacturers. The products include:

- Thyro-S® (newly enhanced)
- Thyro-A® (newly enhanced)
- Thyro-AX®
- Thyro-PX®

Thyro-S and Thyro-A SCR power controllers have been improved with features that significantly improve the customer's ease-of-use experience.

Advantages of SCR Power Controllers

SCR power controllers are more reliable and cost-efficient than other controllers such as variable transformers, contactors, or other mechanical devices. They also offer a finer degree of control and need less maintenance. Some advantages include:

- **Infinite resolution.** SCRs can control the main parameters—voltage, current or power—from zero to 100 percent with almost infinite resolution, allowing for accurate, stepless control of the process.
- **Reliability with minimal maintenance.** As solid-state devices, SCR power controllers are inherently wear-free, so they require little maintenance and have a high mean-time-to-failure rate.
- **High efficiency.** At 99.5 percent efficiency, SCR power controllers offer a distinct advantage over alternative devices such as IGBT-based power supplies and converters.
- **Very fast response.** SCR power controllers—because there are no moving parts in the device—can switch power on and off extremely fast.
- **Selectable parameters.** An SCR power controller can control several electrical parameters: load power, RMS of load voltage and RMS of load current. Also, it can limit current or voltage.

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General Description

The basic elements of an SCR power controller consist of the following:

- **The SCR.** The silicon-controlled rectifier—also referred to as a thyristor—is the heart of the controller.
- **Control circuit.** This circuit controls the main operation of the SCR by switching the SCR on and off at a high rate, so that the exact desirable energy is applied to the load.
- **Heat dissipation elements.** All solid-state power devices (SCRs, TRIACs, etc.) must dissipate generated heat.
- **Protective circuits.** To protect the SCR against surge current, such as in a short circuit or by a voltage spike, AE's SCR power controllers have built-in semiconductor fuses.

SCR Controllers for Thermal Systems

A general thermal system controlled by an SCR power controller is shown in Figure 1. It consists of a heater temperature sensor, a temperature controller, an SCR power controller, a heating element, and the load. The temperature controller output is not connected to the heater, like in a thermal system without an SCR controller. Instead, it is connected to the SCR power controller. The amount of electrical current (load current) supplied to the heater is set by the SCR power controller.

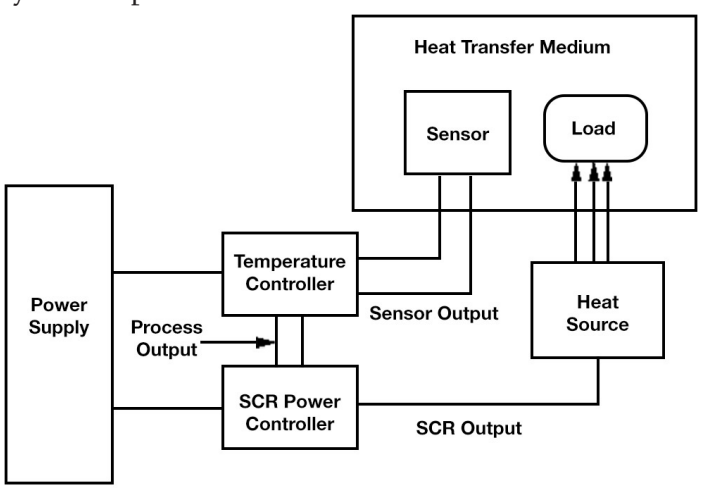

Figure 1: An SCR power controller in a thermal system. (Source: IEEE GlobalSpec)

The heat sensor sends a signal to the temperature controller indicating the heat required by the load. The temperature controller's process output signal is sent to the SCR power controller. The controller's electronics uses this signal to calculate the rate needed to switch electrical current on and off to the heater. The switching is extremely fast, so the heater's resistance element experiences very small temperature variation. This is the main advantage of using an SCR power controller. Heating elements are usually made of wire, and using a mechanical relay to turn on a heater often takes 30 seconds or longer. Relays also arc, spark and will burn out on a regular basis—a phenomenon known as thermal shock. Temperature overshoot may also occur. The heater will expand and contract, becoming more and more brittle. The resistance element of the heater goes through a continuous series of long heating and cooling cycles that reduces the heater's life. In an SCR controlled thermal system, the temperature swings are reduced—or eliminated—so the heater life is greatly increased.

Modes of Operation—SCR Firing Methods

The power delivered to the load can be regulated by the controller using one of the following control or firing modes:

- **Zero-cross or burst firing.** In this type of firing method—also called fast cycling—the SCRs are turned on and off only when the instantaneous value of the sine wave is zero. The advantage of this firing mode is the reduction or total elimination of electrical noise transmitted by the SCRs. Sensitive electronic devices may not function properly when electrical noise is present, but zero-cross firing prevents this. Figure 2 shows the diagram of the output of a back-to-back SCR system. Notice that the SCRs are always fired (switched on) at zero voltage. To reduce the electrical noise, they must be switched on and off at the lowest possible voltage level. Once an SCR is turned on, it will remain at the on position until the conducted current falls to zero. This occurs every half-cycle in an AC voltage. An added advantage of this firing mode is that no harmonics are created at the moment of switching.

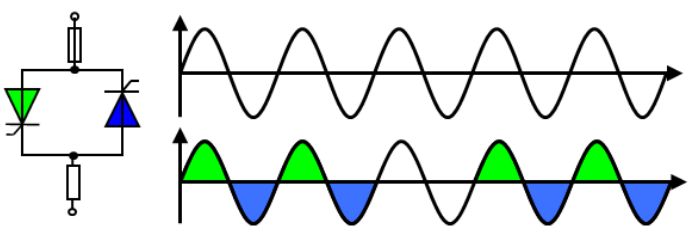

Figure 2: Diagram of a pair of back-to-back SCRs; the alternative current through the back-to-back SCRs. (Source: Advanced Energy)

- **Phase-angle.** In this method, the firing action takes place every consecutive half-cycle in the output AC sine wave. Each SCR (in the back-to-back pair in AC systems) is turned on for a selected variable portion of the half-cycle that it conducts. Therefore, power can be regulated by selecting the point (phase-angle) at which it is desired that the SCR is turned on within its half-cycle. Consequently, the switching time is in milliseconds and no extreme temperature deviations occur.

  Not firing the gate at the exact selected point in the cycle produces poor results. If the SCR is fired early in the half-cycle, the heater's power output will be high because most of the current will travel through the SCR. If the SCR is fired late in the half-cycle, only a small current will pass through the SCR and the heater's

power level will be very low. It is important to note that with this method the SCR is not switched at zero crossing, so significant noise is generated. The noise appears as voltage spikes at the switching phase on the AC sine wave. (Note: the voltage spikes are not shown in Figure 3.)

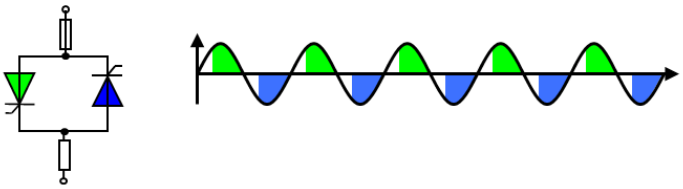

Figure 3: Phase-angle mode. (Source: Advanced Energy)

- **On/off control.** An SCR power controller working in this firing mode is off if no input signal is present—otherwise, it is fully on. This method provides switching in the same way as mechanical or mercury relays but with the advantage of much faster cycle times.

Selecting SCR Power Controllers

There are three basic types of heating loads suitable for SCRs switching: (a) heaters with constant resistance elements, (b) heaters with variable resistance elements and (c) transformer-coupled heaters (these are mainly inductive loads). The load can be single-phase, two-phase or three-phase (two-leg or three-leg).

In general, to select a controller one must determine:

- The current and voltage requirements and the load configuration (single-phase, two-phase or three-phase).
- The control mode, depending on the type of load and the heating application. The control mode can be voltage control, current control, or power control.
- The firing mode needed, depending on the type of load one wants to switch.

Use of Power Controllers in the Semiconductor and Industrial Markets

The semiconductor industry is known for its rapid product development cycle. Its main goals have always been manufacturing cost reduction, increasing chip speed and decreasing chip size. Behind all these technological goals is the quest for smaller node size. These trends, however, may encounter substantial technological obstacles in their path to realization, so better tools are needed to manufacture these chips.

The quest for further shrinking has accelerated changes in the materials and methods used for fabrication. As a result, the process has become more complex through the use of chemicals, changes in operating conditions and other factors. Therefore, the requirements for temperature control and precise high voltage devices are becoming more demanding. Advanced Energy's advanced power and thermal process control solutions will give OEMs a real advantage in manufacturing capabilities and will improve their semiconductor manufacturing tool performance and yield.

For the semiconductor industry, tight measurement and control of wafer temperature are imperative in most fabrication processes, particularly rapid thermal processing (RTP) and epitaxial (EPI) silicon growth of semiconductor wafers. Advanced Energy provides advanced solutions to meet each customer's toughest activities. The reliable and flexible Thyro family of SCR power controllers ensures high quality, reliability and reproducibility in critical tasks by providing precise thermal profiles and advanced thermal process controls.

- The rugged Thyro-S® (SCR) thyristor switch switches electric load for current, voltage and power at a high rate. Designed for simple mounting and easy operation, it can be easily integrated into a wide range of applications. With rated voltages of 230 V, 400 V and 500 V and rated current from 16 A to 280 A, it can be interfaced to many industrial buses (PROFIBUS® DP, DeviceNet®, Ethernet/IP® and others).
- The digital Thyro-A® power controller, with highly flexible interfacing for the load and power supply side, controls power precisely and reliably for RTP, EPI, and many other types of applications. Rated at up to 600 V and 1,500 A, it provides high resistance against short-circuit current and blocking voltage provided by the integrated semiconductor fuses.

Conclusion

There are many advantages in using SCR controls over other temperature control methods. Some of these include:

- Closer (PID) process control
- Better response time
- Extended heater life
- Reduced maintenance costs
- Reduced power consumption

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ABOUT ADVANCED ENERGY INDUSTRIES, INC.

Advanced Energy provides thermal control technology uniquely suited to operate in semiconductor applications, targeted for critical plasma-based processes for lower device damage, higher throughput, and higher yields. As today's market demands faster chips and cheaper devices to improve semiconductor manufacturing tool performance and yield, the need for more accurate and precise power and thermal devices is greater than ever. AE is a well-recognized "power-house" that pays attention to showcasing power and thermal capabilities, carving out a greater space along the value chain for OEMs. For more information, visit http://www.advanced-energy.com/.