SCR Control of Electric Heaters

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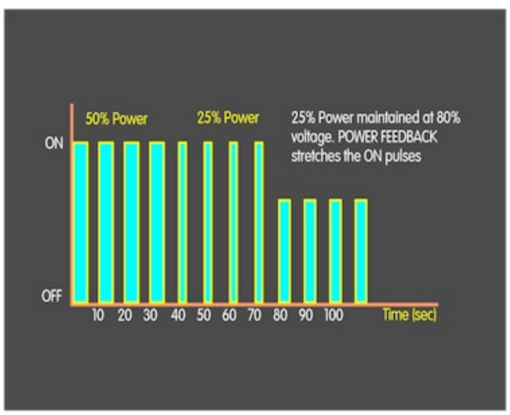
A silicon controlled rectifier (SCR) is nothing more than a rectifying switch. It does not conduct until its gate (a small third terminal) is triggered by a dc pulse or series of pulses. Once triggered into conduction it continues passing current even if the trigger pulse is removed. The current ceases when the applied ac voltage goes through the next zero crossing. The SCR will not conduct again until the line voltage becomes positive and its gate is triggered again. Being a rectifier, two devices in inverse parallel are needed to control ac heater power.
Like a magnetic contactor it can modulate power only in the **time proportioning mode**, meaning that the heater is switched on with a regular cycle time T for a variable time t.

So heater power $P = V^2/R \times t/T$.

V = RMS line voltage R = Load resistance

Magnetic contactors need cycle times 20s or longer to obtain an acceptable service life. Provided the process has a reasonable mass and thermal capacity, temperature fluctuations in sympathy with the ON and OFF cycles can be acceptably small.



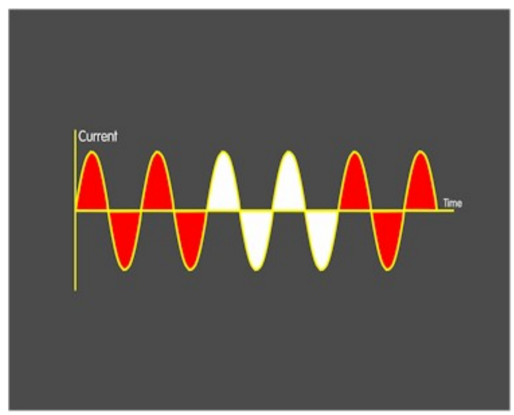


Fig 1. Time Proportioning control showing The effect of power feeedack

Fig 2. SCR fast cycling control

The SCR has no wear out mechanism related to number of switching operations so much higher switching rates can be used bringing higher speed, smoother power delivery and flexibility.

<u>Fast cycling or zero-voltage switching</u>

One stage smoother than magnetic contactor control is zero voltage switching, sometimes called fast cycling or burst firing. See Fig 2. A typical time cycle would be 0.1 seconds on and 0.1s off for 50% power. Note that unlike the magnetic contactor, switch on and off always occur at a zero crossing when there is no current to make and break.
Unless there are special load problems such as severely temperature dependent heater resistance or transformer fed heaters then fast cycling is the preferred and less costly method. It also minimizes radio frequency interference and supply voltage waveform distortion. However if lights share a long supply cable with the heater load they may be seen to flicker slightly at the fast cycle rate as the line impedance makes the load pull down the line voltage. Normal load-current ammeters will pulsate but specially damped meters are available which average the current reading.

The smoothest possible control with a normal ac supply is phase-angle firing whereby switching occurs every half cycle as in the normal lamp dimmer switch. Power is turned up by advancing the switch-on time within each half cycle. See Fig 3.
The instant of switch-on in the cycle is also expressed as firing angle, being the number of degrees of phase angle between switch-on time and the end of the current half cycle.
Even the liveliest tungsten lamp does not have time to go out in the few milliseconds off time so you are delivering what is virtually a smoothly variable ac voltage which gives a steady brightness on the lamp and a steady indication on a normal ammeter.

Power Feedback

In both the above control modes the control circuit can watch the line voltage and adjust the SCR on-time continuously to achieve a constant power in the load regardless of severe fluctuations of line voltage. This relieves the temperature controller of the job of correcting for temperature changes caused by line voltage.

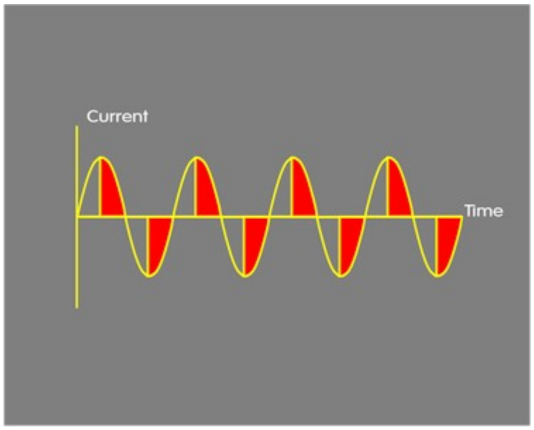


Fig 3. Phase angle control

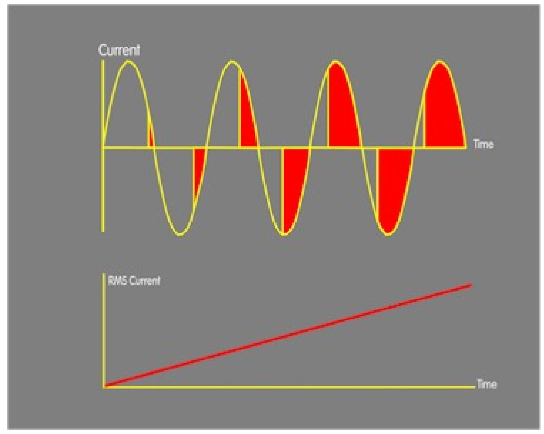


Fig 4. Phase angle control with soft start

Soft Start

Typical problem loads are transformer fed heaters and heaters with very low cold resistance such as tungsten and molybdenum disilicide (Kanthal Super). Such heaters can take a severe high current inrush when first powered up, tripping breakers and blowing fuses. For example a Kanthal super furnace which runs at 100A at working temperature would demand some 1500A at start up if not restricted.
Solution The first step is to make the control circuit perform a soft start whenever power-on or power change is called for. A soft start rations power by restricting the firing angle then advancing it over several cycles as shown in Fig 4.

By the time the soft start is over, a transformer load could be past the threat of inrush and a fast tungsten lamp could be up to a temperature where its own resistance limits the current. Some SCR units allow adjustment of the ramp rate of the soft start to match the type of load.

Current limit

Slower responding heaters need a current limit feature as well as soft start. Here the circuit monitors the current and throttles back the firing angle to hold the current below the safe limit or the required limit for a particular heat process. This limit is usually adjustable by the user or installer but is best made tamper proof.
Soft start plays its part here by restricting the firing angle at switch-on until the current limit takes control.
Warning: If you wire the system such that power is applied to the high power branch containing the SCR after it is applied to the control circuits, you will defeat the soft start and current limit feature and usually blow a fuse.
Note that current limit is not available on the basic fast cycling type of SCR which is often called a solid state contactor.

Voltage Limit

It is possible to put a limit on the SCR firing angle. This puts a limit on the voltage applied to the load and overrides any higher demands for power called for by the temperature controller. It addresses different problems from those addressed by current limit.
For example a new silicon carbide heater will require no more than say half the available line voltage. During its working life its resistance increases and it will eventually need full line voltage in order to deliver full power.
Adjustment of voltage limit upwards as the heater ages ensures that it is not subjected to overvoltage.

This feature also avoids the need for a transformer with a range of taps for output voltage adjustment.

True power control

For silicon carbide heaters and others that have temperature and age dependent resistance, various combinations of current, voltage and power limiting techniques are used. One derivative of these for example is maintenance of a constant relationship between controller signal and heater power, in the face of line voltage variation and resistance changes due to temperature and aging.

Compared with magnetic contactor control, this current and power density limiting capability, combined with elimination of continual heat cycling has yielded an extended life of some 60 % on silicon carbide heaters.