Thyristor switching principles

What is a thyristor?
A thyristor is a semiconductor device which acts as a switch. However, when switched on it can only pass current in one direction. It is in fact a switchable diode sometimes known as a silicon controlled rectifier. To switch alternating current two devices are connected in inverse parallel. Each device is turned on at the appropriate time by a trigger pulse applied to the gate and the device will remain on until the instantaneous load current through it drops to zero. The trigger pulses are generated by a driver - which times the pulses to ensure the thyristor unit output is a function of the input demand signal (e.g. from a controller) in the selected Firing Mode.

Eurotherm thyristor units incorporate the thyristor devices, together with the driver and the heatsink which dissipates the heat generated by the thyristor devices. Many Eurotherm units include internal high speed fuses to protect the thyristors from high overload currents. The benefits of thyristor units are numerous. They offer a reliable long term alternative to electromechanical devices reducing the necessity for ongoing maintenance.

Thyristor units are particularly cost effective for fast systems, for complex loads involving transformers and/or heaters whose resistance changes with temperature or time. They are the best means of controlling electrical heating power. Thyristor units generally offer improved controllability which gives economy and easy serviceability, particularly with the plug-in versions (451 and 464 Series) which reduce down time and maintenance costs. Almost silent in operation, the units can eliminate the switch on surge by operating in synchronisation with the supply, and therefore offer an improved working environment as required by Eurotherm Directives.

What are Firing modes?

Solid state relay or logic firing mode
The control input for this type of thyristor is a ‘Logic’ output from a controller and the thyristor operates like a relay or contactor, i.e. when the logic signal is low the thyristor unit is OFF and when it is high the thyristor unit is ON.

To minimise EMC radiation the thyristor unit switches on at the first zero crossing of the mains voltage, after the logic input goes high.

When the logic input goes low, the unit switches off at the next zero crossing point of the heater current.

Cycle proportioning (fast cycle, slow cycle, single cycle, advanced single cycle)
This is a means of controlling power by time proportioning the output switching. Power is switched to the load for time t with a total cycle time T. The ‘cycle time’ comes under the heading of Fast Cycle, Slow Cycle, Single Cycle or Advanced Single Cycle. They are intended to serve the requirements of different applications. The table below gives further details. Control inputs for this type of thyristor unit are analogue, typically 0-5V or 4-20mA.

<table>
<thead>
<tr>
<th>Control mode</th>
<th>50% Power</th>
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<tbody>
<tr>
<td>Fast cycle (F.C.)</td>
<td>200ms ON and</td>
</tr>
<tr>
<td></td>
<td>200ms OFF typically</td>
</tr>
<tr>
<td>Slow cycle (S.C)</td>
<td>20s ON and</td>
</tr>
<tr>
<td></td>
<td>20s OFF typically</td>
</tr>
<tr>
<td>Single cycle (F.C.1.)</td>
<td>One cycle ON and</td>
</tr>
<tr>
<td></td>
<td>one cycle OFF</td>
</tr>
<tr>
<td>Advanced</td>
<td>Allows half a cycle</td>
</tr>
<tr>
<td>single cycle</td>
<td>to be switched</td>
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</table>

Applications
(F.C.) Ideal for simple resistance loads. May cause supply fluctuations where supply regulation is poor.
(S.C) Straight line control on large thermal mass systems and applications where poor supply regulation would cause flicker on fast cycle
(F.C.1.) Simple resistance loads and where thermal mass of load is small or a low noise alternative to phase angle firing with some heater materials
(S.C.A) Used to reduce flicker in short wave infrared applications

To minimise interference the thyristor unit always switches on when the voltage across the heater is zero and switches off when current through the heater is zero. Each ‘burst’ is therefore a complete number of half cycles of the supply.
Phase Angle (P.A.)
In this mode power is controlled by allowing the thyristors to conduct for part of the ac supply cycle only, see diagram below. The more power required the more the conduction angle is advanced until virtually the whole cycle is conducting for 100% power.
Phase Angle Firing, which always has a soft start, is used for driving transformer loads or loads where current limit is required.
The disadvantage with phase-angle firing is the possible interference and harmonics generated by the rapid switching action.
Filters may be required to comply with local regulations.

Phase Angle start Fast Cycle (P.A. start F.C.)
This is a variant of the cycle proportioning mode in which each ON period consists of a run up in phase angle over several supply cycles to full conduction. Once this state is achieved the remainder of the ON period will be at full conduction. This reduces supply fluctuations and allows current limit to be used.

Options and features

Power feedback
Supply voltage changes will obviously result in power to the load changing. To overcome the effect of supply voltage changes, the controller which drives the thyristor unit or the thyristor unit itself can have power feedback. This instantaneously corrects the power demand to match the actual supply voltage.

Partial Load Failure (PLF)
This is an optional circuit which continuously monitors the load resistance and detects an increase arising, for example, from failure of one arm of a parallel connected load. When a partial load failure is detected an output to an external alarm can be given. The PLF setting is adjusted with the thyristor unit working normally and delivering current to the load.

Overload circuit
This option is only available with PLF on certain equipment and is designed to detect overload currents in the region of twice the partial load failure setting or greater. When it operates, the thyristors are prevented from firing, a front panel lamp lights and relay or logic alarm output is activated.

Current limit
With low cold-resistance loads, if used in cycle proportioning modes, the first complete cycle could cause a current surge and blow a fuse. Phase-angle operation starts from zero and advances until a current limit is reached. The conduction angle is then regulated to keep the current within safe limits.

Inhibit or enable
This feature can be used in conjunction with external interlock circuits. It allows the thyristor to be shut down by operation of external contacts.

Delayed triggering
Delayed triggering is used in conjunction with cycle proportioning modes where a mixed inductive/resistive load such as a transformer supplied heater is used. A preset angle can be adjusted corresponding to the ‘lag’ angle which will prevent inrush surge currents when using zero voltage switching of inductive loads. Highly inductive loads will require ‘soft-start’ or current limiting.

Power control
Power control requires I and/or V to be measured and can be an advantage in open loop non-temperature controlled applications where it is the energy input which is to be controlled.
Thyristor installation and safety

Installation
The thyristors must be installed in accordance with Eurotherm recommendations expressed in the installation guide supplied with each unit, and also in accordance with local wiring regulations. Adequate ventilation or forced cooling must be provided to maintain the ambient conditions inside the control panel enclosure within the operating specification.

Fuse protection
Eurotherm thyristor units are generally supplied with high speed fuses, designed to protect the thyristor device against short circuit currents resulting from load or wiring faults. The high speed fuse does not provide protection against sustained medium scale overload, and it is therefore necessary to fit a standard circuit protection fuse (HRC fuse or circuit breaker) in the supply lines.

Mounting and enclosures
Most Eurotherm thyristor units are designed to work in ambient temperatures up to 50°C. It should be noted that thyristor units generate a significant amount of heat internally through the thyristor itself, the fuse and the cabling. A general rule is to reckon that a thyristor unit, and its fuse, will generate 2 watts of heat per amp per phase.

Neutral currents on 3 phase installations
Under certain circumstances, such as four wire phase angle installations, open circuit heaters or unbalanced loading can cause, substantial neutral currents to flow, particularly if current limit is operating. Neutral cable sizing should therefore be chosen with care. With balanced load resistances neutral cable current rating should be twice the line current for safety under all possible circumstances.

Power factor
In large installations poor power factor may increase the cost of the electrical power supplied. Phase angle firing gives a sharp rise in current when turned on and may cause a distorted supply waveform. The apparent power factor can therefore be adversely affected. Fast cycle, slow cycle and single cycle are all zero switched firing modes with no current waveform distortion and therefore do not affect power factor.

Plant safety
The thyristor unit is a control device, and should not be used as a safe means of removing power from the load. When plant or personnel safety is at risk, a circuit breaker or contactor must be fitted in the supply lines to the thyristor unit, and arranged to automatically trip in the event, for example, of a plant emergency stop, or over-temperature switch operating.

Personnel safety
The thyristor unit does not provide an effective means of isolation in its “OFF” or “DISABLED” state, due to leakage currents through the various protection components around the thyristor itself. In particular, when using a 2 phase thyristor to control a 3 phase load, the complete load and associated wiring will be at the potential of the uncontrolled phase in the OFF state.

It is therefore imperative that an effective means of isolation is provided, and working practices set up to ensure that the thyristor unit and associated circuitry are made safe before any maintenance work takes place.

If in doubt; ask
If you are in any doubt about the application of these or any other Eurotherm products, please ask for guidance.
Some useful definitions

Terms used to describe thyristor stack ratings are defined as follows:
Line volts - Voltage between any 2 lines of a 3 phase supply.
Phase volts - Voltage between any line and neutral of a 3 phase supply or voltage between the 2 wires of a single phase supply.
Line current - The full load current flowing in one of the three incoming lines in a three phase system.
Phase current - The full load current flowing through one of the three heaters in a three phase load.
ILine = IPhase for single-phase or 3 phase star
For a balanced 3 phase system only:
Line voltage V = √3 phase voltage Vp
Power in a 3 phase load
= 3 x Vp x Ip x power factor
= √3 x VL x IL x power factor
where
Ip = Power/(3 x Vp x power factor) thus
IL = Power/(√3 x VL x power factor)

Selection

In isolated applications, where the load(s) controlled by the thyristor unit(s) form a major portion of the users total electrical load, or where the unit is in a remote location, supplied via long lengths of distribution cable, problems may be experienced with harmonic interference (resulting from phase angle control) or voltage dipping effects (resulting from burst firing control).
If you have any selection enquiries please contact Eurotherm.