Soft-Start Control of Electric Motors

For a three-phase induction motor direct on-line start involves a very high motor starting torque and a very high starting current. Semiconductors in soft-start devices must be extremely robust to resist considerable chip temperature changes and must demonstrate very good load cycle capability. The antiparallel thyristor module SEMISTART for soft-starters provides half the internal thermal impedance of conventional components, thanks to double-sided thyristor chip cooling and thus, ensures high over-current capability for the starting period. **Norbert Schäfer and Ralf Herrmann, SEMIKRON, Nuremberg, Germany**

The anti-parallel thyristor module SEMiSTART (Figure 1), designed specifically for use in soft-start devices, provides half the internal thermal impedance of conventional components in modular designs, thanks to double-sided thyristor chip cooling. This compact module also uses proven pressure contact technology.

In practice, three different types of motor starter control are used which are described in the following.

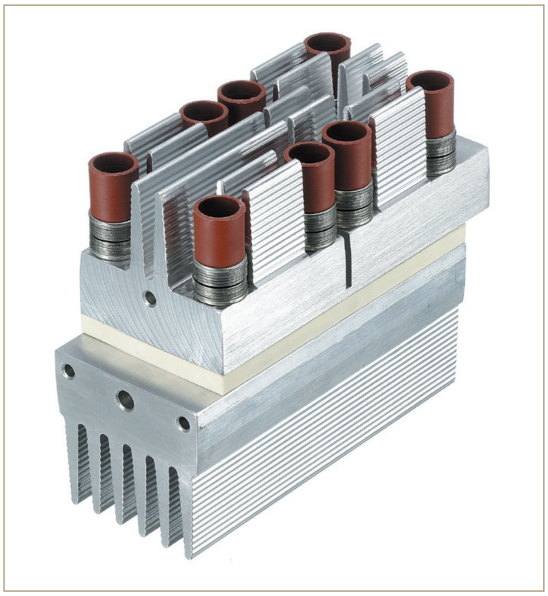

Figure 1: The anti-parallel thyristor module SEMiSTART is designed specifically for use in soft-start devices

Direct on-line starters

For a three-phase induction motor (asynchronous motor), direct on-line start involves a very high motor starting torque and a very high starting current. The high motor starting torque can lead to mechanical damage; for instance, the conveyor belt driven by the three-phase induction motor may tear. The high starting current can also result in voltage spikes in the grid. The larger the motor, the more serious the effects.

To combat such undesired effects, the voltage applied to the induction motor during the start-up phase is controlled. This means that the starting current and, consequently, the starting torque can be limited (see Figure 2).

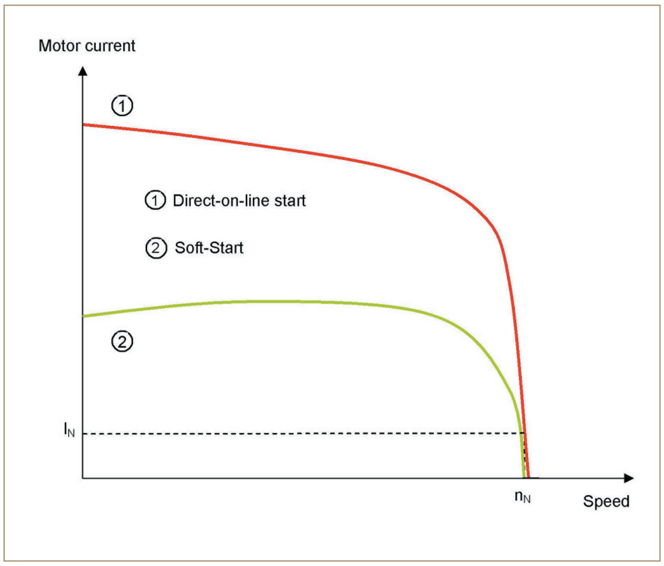

Figure 2: Motor current at direct on-line start and with soft start

Star-delta starters

A simple solution is the star-delta starter (also known as the wye-delta starter). Here, the motor stator windings are connected in star (or wye) connection as the motor accelerates up to its running speed; once the motor reaches near rated speed, the windings are connected in delta. The effect of starting in star connection is that the voltage across each stator winding during the build-up to normal running speed is $1/\sqrt{3}$ of the normal. The changeover from star to delta connection is normally done using a mechanical contactor. As, however, there are only 2 switch connections (star and delta), 'controlling' is not a particularly appropriate term in this case. Moreover, this type of starter 'control' is not low-maintenance, as the mechanical contactors are prone to wear caused by sparking and need to be replaced.

Soft-starters

To control the voltage applied to the induction motor during the start-up phase, a soft-start device (soft starter), is needed.

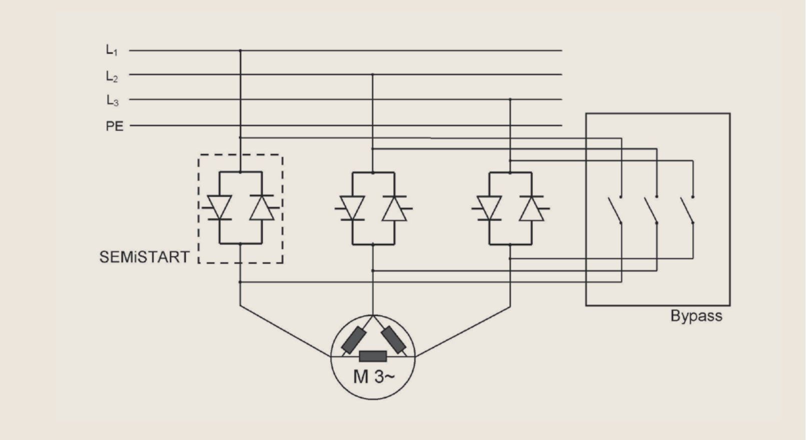

Figure 3: **Principle schematic of a soft starter**

In soft starters, thyristors are used for voltage control (see Figure 3).

Two anti-parallel thyristors are connected in series between the motor windings and the grid. During the run-up to normal running speed (ramp-up), the voltage across the motor windings is then controlled by way of phase control. Depending on when the thyristors are fired (trigger delay angle a), this means that the starting torque and the starting current can be set to desired values. A further advantage of soft-start control is that the starting time can also be controlled.

The current flowing through the thyristors produces power dissipation in the semiconductors. This power dissipation heats up the semiconductors, which then have to be cooled. To prevent further power dissipation in the semiconductors after the ramp-up phase, the semiconductors are bypassed by a mechanical switch (mechanical contactor). This bypass switch can be relatively small since it does not have to switch large loads. A further plus is that the contacts of the bypass switch do not 'burn' down. As the system has already reached normal running speed, no large voltage drop that has to be switched by the contacts of the bypass switch occurs. The only voltage drop is that resulting from the mechanical design and that across the fired thyristors. This means that no large loads are being switched, which is why soft-starters are low-maintenance devices.

Semiconductor requirements

To ensure that a soft-starter is both compact and cost-efficient without compromising reliability, the semiconductors used in a soft-starter must meet a number of important requirements.

Even when a soft-starter is used the starting current during the starting phase of a drive system is still several times larger than the rated current (3-5 times higher). In large-scale systems, the peak starting current is often several thousand amperes. The semiconductors used therefore have to be able to carry this high starting current during the start phase. At the same time, however, the soft-starter must be cost-optimised and as compact as possible. For this reason, the semiconductors used (including heatsink) must be as small as possible.

Thus, for reasons of cost, thyristor components whose rated current is far lower than the large system starting current are used in practice. This is why the thyristor chips heat up substantially during the brief start phase, e.g. from $T_{Start} = 40°C$ to $T_{Ramp-up} = 130°C$, resulting in a chip temperature difference of 90K. If a system is switched on 3 times per hour, 8 hours a day on 365 days a year, the total number of load changes after 10 years is 87,600. These thyristors must be able to carry the overload current that occurs during the start phase for decades.

Up till now, manufacturers of soft-starters have had difficulties in finding the optimum semiconductors for their devices on the market. This is where the anti-parallel thyristor module SEMiSTART steps in, as this module was developed specifically for use in soft-start devices.

Mounting and connecting technology

There are a number of different ways of assembling and connecting a silicon chip. In many modules, the silicon chip is soldered on both sides (anode and cathode side) with single-sided module cooling (see Figure 4).

The heat that builds up in the module is dissipated to the heatsink via the baseplate (single-sided cooling). A particular problem here is the different thermal expansion coefficients of the individual components used in a thyristor module. In modules with soldered connections, the thyristor chip, solder and copper (main terminals) have different expansion coefficients.

Over time, these different coefficients lead to fatigue in the solder that connects the chip and the copper terminal due to load cycle operation. As a result, delamination of the solder layer occurs, i.e. fine hairline cracks appear in the solder layer. The solder fatigue cracking then results in an increase in thermal impedance which, in turn, leads to an increase in chip temperature and, ultimately chip failure. In fact, it is not unusual for chip failure to occur in soldered modules.

In modules based on pressure contact technology, by way of contrast, the chip is connected between the main terminals by contact pressure. In these modules, the chip is not soldered between the main terminals. Instead, very high contact pressure (several kN) is applied to 'retain' the chip between the main terminals. In practice it has been shown that, especially in applications with large power loads

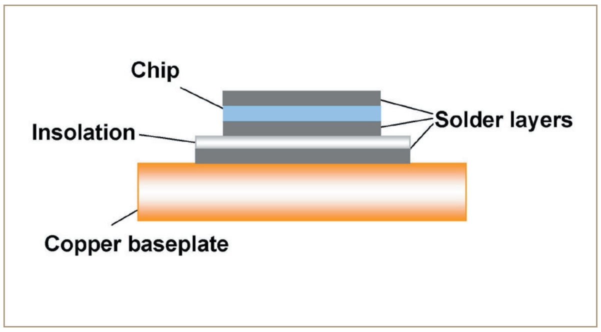

Figure 4: **Principle behind the solder contact module**

(rated currents >200A), the load cycle capability of the components connected using pressure contact technology is far superior owing to the non-use of soldered connections.

This is why Semikron recommends using pressure-contacted components in soft-start devices with larger rated currents. And it is this very pressure contact technology that is used in SEMiSTART (see Figure 5).

In SEMiSTART modules the two thyristor chips are 'pressed' between two heatsinks.

This type of mounting and connection does not contain solder layers, which is why the SEMiSTART modules boast very good load cycle capability and, consequently, a long service life.

The heatsinks are optimally dimensioned for the chip dimensions and for use in soft-start devices. The result is very compact modules. The total thermal resistance between the thyristor chips and heatsink is far lower than that of other conventional components. As the chips are pressed directly between two heatsinks and are cooled on both sides, the thermal resistances are very low. Another advantage is that very little mounting effort is necessary for SEMiSTART modules: no special clamps are needed as is the case when assembling capsule thyristors. Plus, no thermal paste is needed as in the case of module assembly.

SEMiSTART modules can, of course, also be used in other applications, e.g. protective circuits. SEMiSTART modules come in three different sizes and a total of 5 different current classes. The current range is 500A – 3000A for a maximum current flow time (ramp-up time) of 20 seconds. The thyristors have a maximum off-state voltage of 1800V.

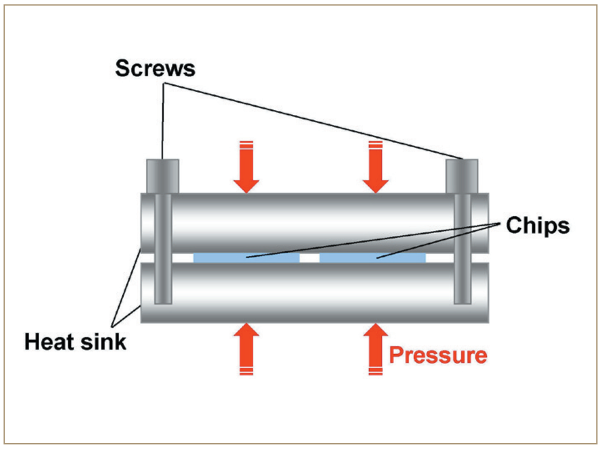

Figure 5: Pressure contact technology used in the SEMiSTART module

Conclusion

The market for soft-starters will continue to grow over the coming years as the advantages that these components boast over conventional solutions become more apparent. The antiparallel thyristor module SEMISTART for soft-starters provides half the internal thermal impedance of conventional components thanks to double-sided thyristor chip cooling and its compact design. Extremely high overcurrents are therefore possible for a short period. What's more, thanks to the use of pressure contact technology, these modules offer a high degree of reliability.