# For Wishes Big and Small

## *Reduced costs and space thanks to scaleable power electronics for drive systems*

*Today, electric drives perform different tasks in industrial, public and vehicle applications. These vary from machine tools and pumps to elevators and forklift equipment. On the one hand, this has led to the development of highly specialised inverters; on the other hand, however, standardisation is becoming increasingly important in order to save costs. One possible way of covering different application requirements is to create a common hardware platform through relevant software parameterization. In addition, inverter manufacturers often wish to be able to cover various power classes within a single hardware platform and have scalable components into the bargain.*


*By Thomas Grasshoff, Head of Product Management International, Semikron*

For almost sixty years, SEMIKRON has been factoring in inverter manufacturers' requirements when developing power electronic components for inverters. Thanks to a platform strategy – i.e. the use of identical or scaleable module cases for different applications and power classes – inverters can be configured to meet different demands.

Electric inverter systems have had to meet demands as regards cost efficiency and size optimization. Only around 10% of all motors in use worldwide feature power electronic control systems. An inverter-controlled motor uses up to 30% less electric energy than a non-controlled motor. In fact, motor inverters bear huge potential for cutting CO2 emissions and improving energy efficiency. To achieve maximum efficiency in a drive system, however, the ideal combination of control, cooling and choice of silicon is needed. This can be achieved by using optimised switching topologies, resonant inverters and higher switching frequencies, which in turn brings about smaller inductances and, consequently, reduced costs and volume. The increasingly dynamic networks need better-quality inverter output signals and have to meet increased EMC (electromagnetic compatibility) requirements at the same time. Standards and approval regulations are becoming increasingly complex, while pressure to shorten development times is rising. The best way to meet these diametrically opposed requirements is to use a module platform concept which can then be adapted for use in different power classes.

**Platform strategy boosts efficiency**

Examples of such module platforms are the MiniSKiiP and SEMIX IGBT families. MiniSKiiP covers a power range of 1kW to 37kW in 4 different casing sizes. There are up to 3 different current classes for each case size, meaning that a single PCB layout can cover the different power classes of an inverter platform.

| Module type | MiniSKiiP 2 | MiniSKiiP 2 | MiniSKiiP 2 |
|---|---|---|---|
| Nominal current rating | 35A | 50A | 75A |
| Typ. inverter power | 7,5kW | 11kW | 15kW |

*Table 1: Current classes of 6-Pack IGBT modules and corresponding inverter power classes*

Scalability is not only necessary for module case size; in fact, it has to be continued in the choice of packaging technology and the layout of connection elements. In MiniSKiiP, for example, the power and gate terminals are located in a position on the driver board that makes sense for the entire circuitry. This means that the layout can be easily scaled for bigger power classes. This results in increased efficiency in inverter development.

In SEMiX-IGBT modules, scaling is done by altering the module length. As a result, identical DC link designs and inverter designs can be used. This is particularly useful for the medium-power inverter range of 15 - 200kW, where there are smaller lot sizes than in the low power range.

In all four module sizes, the location of the power and gate terminals is scaled. The module length varies, depending on the power class. This scalability is continued in the internal module design. In SEMIX modules, depending on the power class, up to 4 DCB´s can be connected in parallel with a full half bridge topology each. This allows for a large number of identical parts in module production, resulting in consistent production quality. In module application, this means comparable switching behaviour, as the layout of the half bridges is identical and the same commutation paths are available.

**Thermal modelling helps detect side effects**

Besides choice of module platform, in-site monitoring also plays an important role. Since all modules are to operate under optimised thermal conditions, it is necessary to monitor the temperature permanently. All modules feature an integrated temperature sensor. Besides the temperature of the individual module, thermal side effects also have to be taken into account. This includes thermal cross-talk, boundary effects and disturbances in thermal distribution. Thermal modelling can help recognise design-related risks in advance.

Advances in semiconductor technology allow for the development of IGBT´s with increasingly fine structures and faster switching properties. Over the past few years the reduction of chip thickness has led to a reduction in chip area by more than 60% for the same rated current. For current packaging technology, thin-film wafer technology has reached its limits. This can be seen in the fact that for the 70µm-thick 600V IGBT3 chips, the maximum short circuit time of 10 µs has been reduced to 6µs. The substantial heat that results in the case of a short circuit can no longer be stored in a thin-film chip alone and the module thermal properties do not enable the resultant heat to be dissipated quickly enough. The reduction in chip area has made it possible to increase packaging density; current ratings per module area are steadily increasing – at 8 -10 W/cm² the limits of air-controlled heat sinks have been reached. Further concentration of heat density means that increasingly complex heat sink solutions are needed, cancelling out any cost savings achieved. The costs for power electronics can be reduced in two ways only – by way of higher operating temperatures and improved chip cooling. In order to achieve a higher power yield from the silicon area, the maximum junction temperatures of IGBT´s and freewheeling diodes are increased. The need for short circuit protection in application sets a physical limit, since, as the temperatures increase, the off-state currents go up exponentially.

**Optimised packaging technology**

A 25K increase in IGBT operating temperature allows for up to 15% higher effective current, depending on the switching frequency. On the other hand, an increase in operating temperatures can lead to accelerated ageing effects, thus reducing service life. This must be compensated for by improving packaging technology. At elevated operating temperatures, the solder connections between the baseplate and ceramic substrate or between the chip and ceramic substrate constitute the weakest point in the module. Owing to the different coefficients of thermal expansion of the different materials being used, high temperature fluctuations and excessive load cycles can result in fatigue effects known as micro-cracks in the solders.

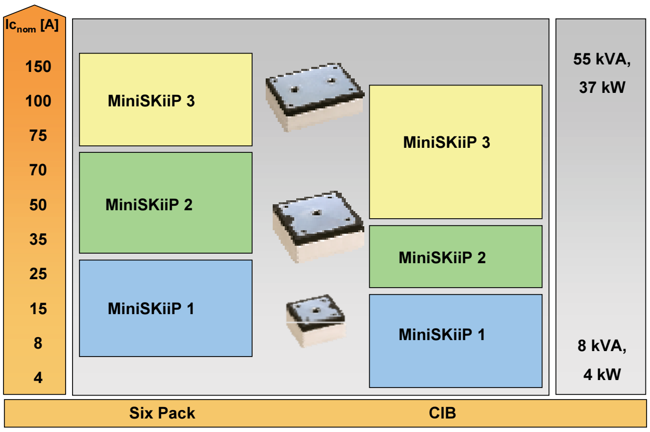


*Figure 1: The case sizes and power classes of the MiniSKiiP IGBT module series cover a power range of 1 kW to 37kW.*

Towards the end of the module cycle life, this leads to increased thermal resistances and thus to higher temperatures that will ultimately destroy the wire bond connections. A possible solution to this problem would be to omit the base plate and use a pressure contact system and take heat-distributing layout measures instead. As the ceramic substrate is relatively flexible and the pressure is built up by way of a number of mechanical "fingers", very close contact between heat sink and DCB is achieved. This is why the thermal paste layer, which is responsible for up to 70% of the thermal resistance in a power module, can be reduced to a minimum of 20- 30µm.

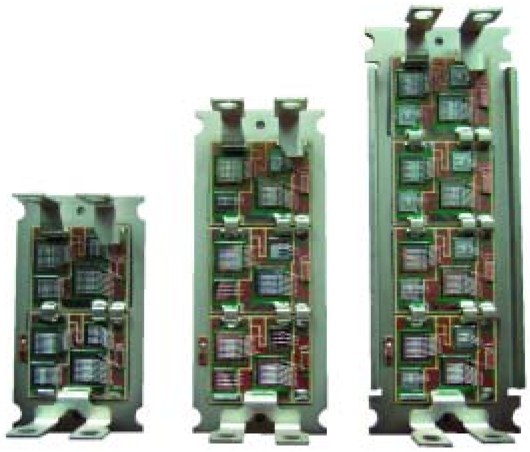

*Figure 2: Internal module scalability for SEMiX 2, 3 and 4 – same form factor for different power classes*

The thermal paste layer in modules with a base plate is three times as thick in order compensate for the thermal warping that occurs between the base plate and the heat sink. In baseplate-free modules featuring pressure contacts, the thermal performance is up to 25% higher than that in modules with a base plate. The latest technological development is the replacement of chip solders by a sintered chip layer. The much higher melting point reduces ageing caused by temperature and load cycling to a minimum. Load cycling capability can thus be increased up to a factor of 5, meaning that compromises no longer have to be made in power module dimensioning for inverter products. In terms of reliability, the weakest point in a power module is now the ultra-sound bond connection on the chip upper and the ceramic substrate. Module manufacturers are currently all focussing on the development of new contact methods for the top chip surface in order to make reliable chip connections.

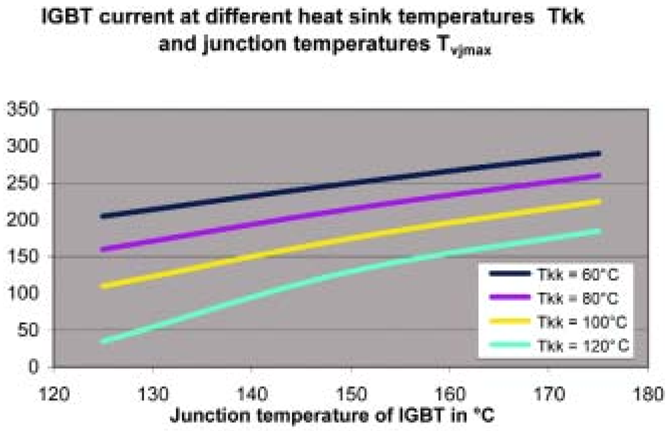


*Figure 3: Dependence of inverter output current on maximum junction temperature and heatsink temperature. Higher heatsink or IGBT junction temperatures allow for higher inverter output powers.*

The aforementioned platform concept enables manufacturers to use identical module concepts in inverters of different power classes. This includes, for example, general-purpose and servo inverters with different overload conditions and precision requirements. MiniSKiiP IGBT modules for the 1 - 37 kW power class and SEMiX modules for 15 - 200 kW feature scaleable connection technology and external dimensions for entire inverter families. Ongoing developments in packaging technology for power modules are paving the way for solutions for higher operating temperatures, for example heat sink temperatures of over 100°C, thus resulting in more cost-efficient and more compact solutions.

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