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Can you handle it?

THE ABILITY TO ACCURATELY CONTROL THE OUTPUT FROM ELECTRIC VEHICLES IS CRUCIAL. THE SKAI 2 POWER-SYSTEM FAMILY COMBINES ENHANCED TECHNOLOGIES TO FULFIL STRINGENT REQUIREMENTS

RIGHT: **For forklift trucks and other materials-handling applications: the low-voltage, MOSFET-based SKAI 2 suitable for battery supplies between 24-160V with continuous output currents up to 300A**

Power systems for industrial electric vehicles share a wide range of common requirements. High-power handling capability from systems with the lowest possible size and weight is often critical, and the capability to function after tens of thousands of passive temperature cycles and hundreds of thousands, or even millions, of active temperature cycles is important in all designs. Resistance to shock and vibration, coupled with high levels of protection against harsh environments, must be designed into systems from the beginning.

Many design and production techniques are needed to meet these challenges. Power density can be increased by reducing silicon losses, thermal impedance and stray inductance while matching coefficients of thermal expansion, optimising gate control and increasing the level of system integration. Power cycling and thermal cycling capability can be increased by the use of innovative silicon and contact technology.

Semikron's SKAI 2 family of power systems addresses these requirements. This portfolio of products includes inverters, battery chargers and DC-DC converters. It features high-accuracy current, temperature and voltage sensors; gate drivers with protection features; and an integrated DSP controller. Digital and analogue I/O, coupled with CANbus communications, offer versatility of control. Ruggedness and reliability are enhanced by the use of proven pressure-contact technology and sinter technology.

System variety

The SKAI 2 family is able to meet the needs of a wide range of vehicle applications (Figure 1). The SKAI 2 HV is a high-voltage three-phase IGBT inverter that offers unprecedented levels of overload capability. It uses sinter-joint technology to provide an unbreakable joint between silicon and substrate and a big increase in power-cycling capability. Pressure contacts are used instead of solder contacts for power connections and spring contacts replace solder joints for auxiliary connections. This liquid-cooled system handles up to 250kVA continuous power and uses 600V or 1,200V IGBTs and CAL diodes. It is a compact unit, housed in an IP67 enclosure, to offer high shock and vibration ruggedness. IP6K9K protection is also available on request. It includes an integrated fully-programmable digital signal processor and sensors for measurement of DC-bus voltage, phase current and temperature.

The MOSFET-based SKAI 2 LV low-voltage three-phase inverter uses the same pressure- and spring-contact technologies as the HV system. It can be liquid- or air-cooled and handles up to 55kVA continuous power. Based on a 50V, 100V, 150V or 200V MOSFET chip set, it incorporates many of the same features as the IGBT-based systems and therefore offers the benefits to customers of using the same core control system, I/O connections and system structure.

A third type of SKAI 2 system is a multiconverter box. These ultra-small (673 x 297 x 187mm) and robust systems are liquid-cooled for use as auxiliary drives in a wide range of vehicles. They can contain a maximum of three inverters, or a combination of inverters and an active front-end converter, with an additional 12V, 300A or 24V, 170A DC-DC converter for battery charging. A typical system would include a three-phase 40kVA active front-end converter, a three-phase 20kVA drive inverter, a three-phase 10kVA drive inverter, and one of the above DC-DC converters.

This broad family of systems is backed by Semikron's 20 years of experience in the design and production of power systems for a variety of vehicles. Its portfolio of standard products, coupled with support for customised systems development at a local level to high-volume customers around the world, enables its customers to focus on the development of their product and get them to market in the shortest time possible.

Technology developments

There are basic technology drawbacks in existing products that need to be addressed to ensure that the power density and reliability challenges of this fast developing market are met. SKAI 2 systems incorporate these new technologies, ensuring that the latest user expectations are met.

Power modules form the heart of the system and generally comprise either large base-plate modules or many paralleled low-current packages. With either option, the design uses solid copper base plates as a method of transferring the heat from the silicon through to the heat sink, albeit via an insulating substrate. The thermal contact between substrate and copper or copper and heatsink is not consistent over time and will lead to reliability issues as the base plate lifts away from the mating surface in areas that are not mechanically fixed. The material distortion will also increase stresses within the system that could finally result in increasing thermal impedances or even solder joint failure.

Established technologies for power contact also cause problems. As a result of thermal cycling and differential thermal expansion, the soldered joints become stressed within the system, leading to solder fatigue. This phenomenon is made worse by possible voids in the solder joints. Wire-bond interconnects have been used to connect the substrate to power terminals, but again this is far from ideal as the thermal impedance is higher and mechanical forces, due to thermal expansion and external connections, may lead to early-life failures.

Eliminating the base plate resolves the substrate solder issue, ensuring high-temperature cycling capability. This has been achieved by developing a pressure contact technology that uniformly applies pressure across the substrate to the heat sink. This technique ensures a reliable and consistent thermal contact for the life of the product and has the side benefit of extremely low parasitic inductance.

Spring contacts offer a number of advantages over soldered connections for the auxiliary connections, where currents are relatively low. Because there is no rigid connection, mechanical movement is possible. This contact technology also provides a thermal contact to the substrate.

The extensively-used solder process used to connect the silicon chip to the ceramic substrate presents a number of potential problems, including solder delamination, voiding and reduced thermal-cycle capability. Semikron uses silver-sinter technology because it offers a number of advantageous characteristics. Power cycling capability is greatly increased; thermal resistance is reduced by a factor of 15 and the electrical conductivity improved by a factor of five. It also reduces the thermal mismatch, improves the bond strength and avoids the problems of chip movement during the liquid phase.

Fulfilling expectations

To achieve a reliable system many design aspects and accepted technologies need to be enhanced. Base plates are difficult to optimise in power systems. Solder technology has inherent difficulties resulting from delamination, voiding and chip movement during the liquid phase of the solder process, whereas silver-sinter technology offers a mechanically resilient bond and avoids the liquid phase.

Power contacts need to be mechanically decoupled from all forms of movement, while offering low thermal impedances and resulting durability. Pressure-contact load terminals, used in a base plate-free system, provide high-current capacity and allow the mobility needed to tolerate thermal expansion. The multiple terminals also result in reduced internal parasitic inductance.

The 100% solder-free power module used in the systems described here combines these advantages in one package. It has greatly increased the reliability under aggressive temperature cycling and ensures a high-power density and a very robust system so fulfilling the stringent requirements for industrial materials handling. **iVT**

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RIGHT: **The SKAI 2 systems meet the needs of a wide range of vehicle applications**

	LV MOSFET	HV IGBT	Multiconverter Box
			
Application	Material handling, electric vehicles	Full electric and hybrid vehicles	Auxiliary supplies for commercial vehicles
Typical power	< 55kVA	< 250kVA	< 40kVA
DC-link voltage	24V - 160V	150V - 850V	450V - 850V
Topology	single and dual 3-phase inverter water or air-cooled	single 3-phase inverter water-cooled dual 3-phase inverter (planned)	Inverter, DC-DC converter and battery charger

ABOVE LEFT: **The multiconverter box, IGBT-based systems are liquid-cooled for tractors and other heavy industrial vehicles**

ABOVE: **The high-voltage, IGBT-based systems are suitable for DC supplies up to 850V with continuous output currents of up to 300A – ideal for tractors and large agricultural or earthmoving applications**

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