Integrated cooling solutions hot up

High power applications and those needing size and weight reductions are driving innovation in power module cooling systems, Aavid Thermalloy, Arkansas Power Electronics International, Danfoss, and Semikron tell Power Dev'.

It's a grim consequence of thermodynamics that power electronic engineers must continually fight the unwinnable battle against energy loss as heat. But even if complete victory is impossible, ever better weapons, in the shape of designs with improved efficiency and enhanced cooling technology, are bringing the fight to new fronts. That's especially important as applications seek miniaturisation and weight reduction, explains Alex Lostetter, chief executive of Avid at Arkansas Power Electronics International (APEI), which specialises in high density, high power electronics. "If it's an aerospace application, a military aircraft, or a military hybrid electric vehicle, every pound that they can save is important to them," Lostetter told Power Dev'. "We're also finding high demand for miniaturisation in commercial automotives."

As one example, APEI has been working with Toyota to develop a battery charger for the next generation Prius plug-in hybrid models based on SiC transistors and diodes. "They already have a 1 kW plug-in charger using silicon IGBTs, but what we've been able to do is create a 5 kW version that's about one-tenth the size," Lostetter said. "But if you're driving the size down, you're pushing power density performance, and you have to be careful not to exceed the maximum temperature of the devices. And there's less capacity of the thermal management system - the heat sink might be one tenth of the size and mass. There's a lot less room for error, so thermal designs have to be very precise."

To dissipate the heat such systems produce requires low thermal resistance cooling systems, explained Sukhvinder Kang, chief technology officer at Concord, New Hampshire headquartered Aavid Thermalloy. He says the company supplies around 10 per cent of the markets it serves for cooling solutions, meaning it has clearly seen the increase in power density. Kang concedes that Aavid's and the industry's previous products, such as the widely used offset folded fin liquid cold plates "were not up to par" for today's toughest demands, but adds that its newer offerings are.

"Our new vortex liquid cold plate allows de-ionized water to move in a spiral," Kang said. "That mixing allows a very high heat transfer rate to be achieved on the cold plate surface and manage much, much higher power levels. It allows double sided cooling, so it can cool a stack of diodes on both surfaces, for example. The amount of metal in the cross section is very good, so that provides a desirable level of electrical conductivity to connect components, like in a busbar. Thanks to such features, I think we are able to meet now pretty much all of the power module requirements that are out there today."
Lowering thermal resistance is not futile

But Claus Petersen, vice president at Danfoss Customised Power Electronics in Gråsten, Denmark, asserted that cold plates have a key weakness. "To have a good thermal connection you put thermal interface material between the device to be cooled and cold plate," Petersen explained. "Typically it is a paste or a liquid applied in a very thin layer, the thinner the better because it has poor thermal conductivity. The trouble is that after several years it disappears, and the air that remains is a good insulator. You get a big increase in thermal resistance, which in the end has dramatic effects on lifetime."

Consequently Danfoss developed its ShowerPower® cooling systems as a lightweight, compact alternative solution for the automotive industry. "They wanted something that did not weigh anything and that did not take up any space," Petersen explained. "They also did not want to have any temperature gradient across the cooled surface, because it can be very harmful to semiconductors to have them operating at different temperatures at different places in the module."

The ShowerPower® cooler's name refers to how Danfoss achieved this, Petersen added. "Imagine yourself in the shower, holding the module in one hand and the shower handle in the other. You spray water on to the bottom of the hot surface in parallel at exactly the same temperature." As well as nozzles spraying water at the base plate devices are attached to, another set of nozzles let water drain rapidly away. "That gives a very high cooling efficiency and gets rid of temperature gradients across the cooled surface," the executive said.

Though the cooling integrated into Nuremburg, Germany, headquartered Semikron’s SKiiP IGBT modules needs thermal grease between its ceramic baseplate and heat sink or water cooler, the company is actively minimising its layer thicknesses. "In the SKiiP modules we have a 20 μm thick thermal grease layer, compared with 70-100 μm in the standard base plate module," said Thomas Grasshoff, head of product management at Semikron. "We are developing modules with integrated heat sinks, where the thermal grease layer is completely eliminated. Through this integration we can squeeze out 30 per cent more current out of the same chip."

Depending upon their application, Semikron also offers its customers specific heat sinks with the SKiiP module which are able to achieve similar performance to a water cooled version. Being able to buy modules with cooling integrated also offers Semikron customers a more realistic picture when it comes to testing, Grasshoff added. "When you only provide the module, the customers can do a test only in a limited way," he said. "But if you have cooler, driver and power electronics together, you can provide a real burn-in as a functional unit. This is a benefit especially for large inverters in wind and traction applications that need reliability, because we have optimised the system and provide advanced test features."

APEI’s Lostetter noted that as well as in the use of thermal grease, care must be taken in selecting the materials used around it. "If you’re operating in a high temperature environment you have to have good matching of the coefficient of thermal expansion between the base plate and the heat sink in order to maintain thermal and mechanical reliability," he said. He also agrees that water cooling offers particular benefits, for example dramatic potential for weight and size reduction in automotive applications when used with high-temperature operation SiC components.

"Presently in a hybrid you have two cooling systems, one is the radiator for the gas engine and then the second is the cooling system for the power electronics for the electric motor drive," Lostetter said. "Normal silicon electronics can’t function at the temperatures that would be required to use the radiator cooling. SiC devices can operate at higher temperature, meaning you can use that radiator cooling system and pull out the other thermal management system." Therefore APEI has been developing SiC-based modules for the US military to achieve this simplification.

Trends in power module packaging

(January 2012, data available in the Power Packaging survey, open to subscription)
Lostetter says that they are currently being tested in various laboratories, prior to insertion in prototype vehicles. This assessment involves considering the balance of the additional cost of a SiC system against the size and weight benefit.

**Interfacing the challenge**

Semikron also feels the degree of integration in its SKiiP modules promises many advantages, like improved reliability from size reduction cutting the number of interfaces between different materials. "The less interfaces you have, the less possibilities to fail you provide," Grasshoff said. "We can have more optimised design in terms of inductivity, switching behaviour, all the electric characteristics. This is the only possibility to reduce the cost." That means that integration offers advantages both in applications where space is important, like the automotive industry, and where reliability is the number one, like wind power.

Grasshoff said that integrating cooling into power modules has shifted a boundary in the industry, away from where cooling used to be module purchasers' domain. The higher the power needed in their application, the more likely they are to adopt such solutions, he added, meaning that they are used in an especially important part of Semikron’s market. "Entire large inverters are where the benefits are for customers if they buy the integrated solution," he said. "In the range of 30-50 per cent of our business comes from customers of the sort who would use these highly integrated solutions."

As well as in Semikron’s SKiiP modules, this trend can be seen in IGBT modules with integrated water cooling from other module suppliers, noted Aavid Thermalloy’s Kang. But he feels that modules that integrate cooling are only suitable in certain circumstances. "If you wanted to assemble a prototype power system, then buying this bundled solution allows you to get it up and running very quickly," he said. "The downside is that it has many liquid connections that can be potential points of failure. By contrast, we supply a cold plate on which you can mount several IGBTs but has only two liquid connections, and you can also mount and connect passives on it."

Aavid Thermalloy also works very closely with its customers to plan how such cooling solutions interface with the rest of the system. The fastest growing area where its cold plates are involved in such design activity is wind power systems in China, Kang revealed. "That’s a very interesting development as well, because most of our previous wind power customers were European based, but the Chinese companies are investing a lot into liquid cooling solutions in thermal management," he said. Also thanks primarily to the wind power sector, Aavid has recently developed a hydraulic module that provides a specific liquid supply for cooling. "Currently the cooling liquid comes from somewhere like the central cooling unit," Kang explained. "Now you can make a complete system out of our components, including our hydraulic module. It’s designed primarily for wind power and for about 60 kW of heat dissipation, but the technology is very versatile and can be expanded or made smaller as needed."

Wind power is also an important market for Danfoss’ ShowerPower® systems, which Petersen says is set to become “the mainstream technology” in this sector. But even with its popularity, Danfoss is continuing to innovate this solution, for example by moving from water cooling to a 2-phase cooling design. "The liquid will evaporate on the back side of the hot part, which is a lot more efficient," Petersen said. "Using tap water, we can make a phase change cooling system without a compressor, which would be new for the world."
Danfoss is also developing ShowerPower® to fit into increasingly integrated electronics such as those being demonstrated in the automotive industry. Petersen highlights an entirely integrated 80 kW powertrain demonstrated by the German automotive engineering company IAV - though ShowerPower® is not playing a role in that example. “We are using ShowerPower® to build three dimensional power blocks,” he explained. “We can have slotted ShowerPower® coolers in between layers of power electronics, for as many layers as is needed. That takes power density to completely new levels.

While water cooling offers previously unprecedented capabilities, the automotive and wind power industries are unusually ready to adopt them compared to other markets. “Combustion engines, have always been cooled with water, so it was absolutely natural for the automotive industry to use a liquid as a coolant for electronic parts,” Petersen said. “But in industry we are seeing a lot of resistance to having water in electronic systems. The time it takes to overcome these obstacles has surprised me.”

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