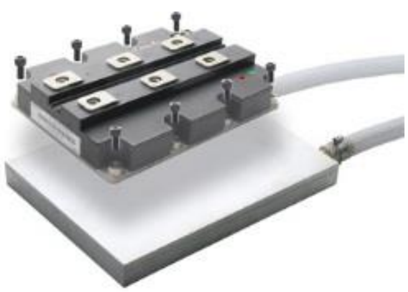
ADVANCEMENTS IN THERMAL MANAGEMENT FOR POWER ELECTRONICS: AIR vs. LIQUID COOLING

Over the past few decades, Power & Energy have emerged as two of the fastest growing industries in electronics. Power conversion, inversion, and rectification as well as battery and fuel cell technologies have become integral to technological growth across all industries.

As power electronic systems become more complex and perform at higher power ranges, the form factors are getting smaller, making heat one of the greatest limiting factors to what can be accomplished. To handle the amount of power being dissipated, air cooling solutions must be optimized and enlarged to adequately remove the excess heat. In some cases, size becomes a limiting factor for forced convection solutions. In these cases where the size or weight of an air cooled system makes it impractical, liquid cooling is fast becoming the most popular alternative method.

Switching from an air cooled system to liquid is not a decision to be made quickly or lightly; there are many factors and possibilities to consider when improving your thermal management to handle higher heat loads. Although market trends indicate that full liquid cooling systems will eventually be the industry standard for cooling power electronics, there are many options and hybrid solutions that can apply the benefits of both as your system evolves or upgrades. If budget or timeline constrictions are such that a direct switch to liquid is unrealistic, optimizing your forced convection solution either through design improvements or by introducing two phase cooling or liquid components are viable interim solutions.



Engineers have been developing liquid systems that are complimentary to existing air cooled solutions that can be expanded to fully replace the air cooled systems over time. This is done by focusing on the electronic devices that can gain immediate benefit with liquid cooling. Utilizing fluid couplings, reliable pump systems, and compact heat exchangers, the system removes heat from the air flow to the liquid where it is transferred and managed elsewhere. In other cases, engineers are opting to fully replace their air cooled systems with liquid cooled to immediately enable higher power outputs and optimize thermal performance.

As you consider the switch to liquid cooling in order to improve the performance of your power electronics devices and facilities, there are several key determining factors:

- What are your size, weight, and thermal performance requirements?
- Can you further optimize your air cooled system?
- How much longer will air cooled systems be a viable thermal solution for your application?
- Are there any limitations on liquid or volume availability?
- How long will it take for investment in liquid cooling to make a return on performance and efficiency?
- How can liquid cooling be implemented or designed into your application? What will be the effect on application/facility down time?
- How and when do you begin?

AIR COOLING BENEFITS

Air cooled systems are significantly less expensive than liquid systems. They do not require regulated or specialized fluids and they are comprised of fewer components that are more economical than components for liquid systems. As they have no liquids to leak and less components to break, they also have less modes of failure. In addition to having higher reliability and lower cost, air cooled systems are also easier to modify or upgrade.

AIR COOLING LIMITATIONS

In typical applications, air cooling systems are comprised of an extruded or bonded fin heat sink and often a fan. When reliability is a significant factor, engineers may forgo a fan and instead opt for passive solutions. Both natural and forced convection have limitations. Natural convection is limited by the total surface area needed to dissipate heat, this necessitates large, heavy solutions that are often impractical.

Forced Convection solutions are limited by pressure drop. Heat sinks with large surface areas in feasible volumes create a high amount of air resistance that hinder the amount of flow and therefore heat transfer that a fan can produce. Larger forced convection solutions also require larger or more fans, increasing the amount of noise generated by the solution.

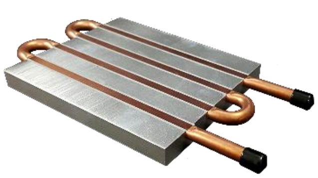
However, the biggest limitation of air cooled solutions is thermal performance. Air does not have the same capacity as liquid to absorb and transfer heat. At a certain threshold, air cooling becomes an insufficient solution and liquid cooling is necessary.

AIR COOLING MODIFICATIONS AND HYBRID SOLUTIONS

There are three common methods of improving your air cooled system. The first is to optimize your heat sink design and fan selection. Generating more air flow, optimizing your fin geometry, or increasing your heat sink volume are ways to improve upon your air cooled solution without introducing additional technologies. The second is to introduce two phase cooling into your design. Heat pipes may be integrated to spread higher power densities or move the heat to an area where it can be more easily dissipated. The third most common method of increasing the performance of an air cooled solution is to start introducing elements of a liquid system such as a passive thermosiphon.

THE EFFICACY OF LIQUID COOLING

Liquid has the capacity to transfer heat up to 4X higher than the capacity of air of the same mass. This enables higher thermal performance in a smaller solution. A liquid cooling system is a hydraulic circuit that typically consists of a cold plate that interfaces with the heat source and device, a pump that circulates the fluid through the system, and a heat exchanger that rejects the heat absorbed by the liquid from the device. Liquid cold plates have a much smaller working envelope than a heat sink that would be used in air cooling for the same application. Additionally, multiple cold plates can be connected to the same exchanger with minimal impact on performance. Liquid cooling grants an additional level of control over the cooling system because it controls inlet temperature to the cold plate as well as flow rate.



POTENTIAL RISKS & TRADE OFFS OF LIQUID COOLING

Some have been reticent to adopt liquid cooling because of the additional complexity and the fear of leakage. Complexity often increases the cost of the solution and the amount of maintenance required to keep the system running. However the additional costs are mitigated in that the improved cooling performance will increase the lifetime and reliability of your device.

Because of its complexity, liquid cooling requires better planning and design to incorporate into your power electronics. Although the cold plate is much smaller than an extrusion or heat sink, the overall solutions tends to occupy more volume once the heat exchangers, tubes, reservoir, and pumps are all taken into account. Engineers must take all of this into account during the initial design phase in order to avoid complications later on. With proper foresight, the complexity of the systems can be beneficial as there is more flexibility in system design.

LIQUID COOLING SOLUTIONS

THE BOYD HYDROSINK™

The Boyd HydroSink™ system is a configurable method of combining a standard set of optimized heat exchangers, fans, pumps, valves, reservoirs, fittings, sensors, and control boards with custom cold plates to design the best possible liquid cooling solution for given requirements.

HydroSinks™ offer more flexibility in design and installation than standard liquid cooling systems because they are configurable and more easily adapted to design requirements. Sealing and connecting of the liquid cold plate, control board, and customer machine controls within the enclosure are also customizable.

As Boyd HydroSinks™ are largely comprised of a set of standard optimized components, they are more cost effective than traditional custom liquid cooling and their air cooled counterparts.

HydroSink™ with clear enclosure

Currently the Boyd HydroSink™ is available in two basic compact system sizes, Small and Medium. Actual size of the final customer HydroSink™ system varies by configuration. Sizes are based around fan size and cooling performance. Small operates at a temperature rise 7-20 °C per kW, while the Medium operates at a rise of 3-9°C per kW.

BOYD LIQUID COLD PLATES

Customized Boyd Liquid Cold Plates are an integral part of the HydroSink™ system. Boyd offers four distinct, innovative cold plate designs developed to optimize the overall system based on application and requirements. All Boyd cold plates are constructed for worry-free liquid cooling utilizing specialized certification procedures to ensure leak-free, reliable solutions.

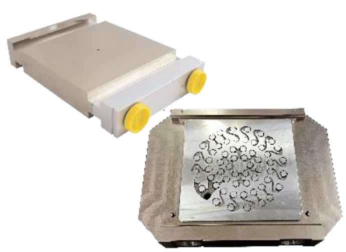
Hi-Contact™ Tube Cold Plates

Boyd Hi-Contact™ tube liquid cold plates feature a high performance assembly utilizing a continuous tube press fit into an extruded aluminum plate. The patented geometry used in the Boyd Hi-Contact™ process moves the fluid closer to the device generating heat, achieving the best thermal performance from a tube cold plate. To further increase the performance of Boyd's Hi-Contact™ liquid cold plates, a thermal epoxy is applied to the joint to provide a gap free thermal interface between the tube and the plate. Hi-Contact™ plates are easy to customize and are available in standard sizes.

Blister Cold Plates

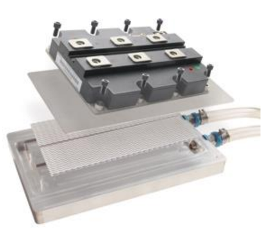
Blister technology stamps channels into the base plate, eliminating channel machining and greatly lowering manufacturing costs. A leak free joint is created between the base and cover plate and the blister channels to allow greater flexibility to drill mounting holes in the topside of the cold plate without regard for the location of the liquid channels.

Vortex Liquid Cold Plates



Boyd Vortex Liquid Cold Plates are designed to cool extremely high power applications. These cold plates were initially developed for applications where a high compressive load may be applied such as when cooling SCR type devices. Using patented flow path geometry, both sides of Vortex Liquid Cold Plates are evenly cooled; therefore they can provide equal and consistent performance across both surfaces and lend themselves to creating more predictable environments.

Extended Surface Liquid Cold Plates



Boyd Extended Surface Liquid Cold Plates have increased internal surface area which allows for better overall heat transfer. Innovative technologies and manufacturing processes are used to increase the liquid to plate contact area within the liquid cold plate. Their vacuum brazed construction ensures leak free joints while maintaining high thermal conductivity. Boyd Extended Surface Liquid Cold Plates are specially fabricated to improve design flexibility and can be easily customized for optimized flow paths for application designs

FINAL THOUGHTS

The key to effective design for liquid cooling and optimized air cooled systems is to consider your thermal management as early in the design phase as possible. Boyd offers design, engineering, and testing services that can come in at any phase and develop the best possible solution based on requirements, constraints, timeline, budget, and any other critical factors.

With design centers around the world, Boyd can provide any customer the necessary engineering services to design and manufacture a fully optimized system. Engineers are available at every phase from analyzing if there is a need for liquid cooling or air cooling, to developing an optimized, integrated system, to reliability and validation testing of the entire device.

To request a free consultation about your current cooling solutions or for help finding the right thermal solution for your Power Electronic Applications click here.