

# Optimized Liquid-Cooled Power Conversion

## Introduction:

Historically, the vast majority of power conversion solutions have been utilized by either natural or forced convection cooling. However, certain application situations, such as high power levels or the need for protection from environmental contaminants, may dictate conduction cooling to a liquid-cooled heat dissipation element as the preferred solution.

When considering packaging and component options for a liquid-cooled power conversion solution, a number of basic questions need to be addressed. These include the electrical topology to be employed; power converter modularity along with incremental converter size and power rating; physical environment size constraints, temperature rating of components, and ease of manufacturing and repeatability for quality and system cost control.

## Liquid Cooling Technology Background:

Liquids, such as water, provide the ability to transfer heat very effectively. Table 1 shows the differences in thermal conductivity between water, copper, and air.

Liquid cooling does not come without its issues. Among these are safety (due to the compresence of liquid and electricity) and cost (due to plumbing, cooling, circulation systems, and heat exchanger cost). However, as industrial process requirements, data processing and communication networks and military systems continue to require ever-increasing power, there is a compelling need to have cost-effective, reliable liquid-cooled power conversion systems.

## Electrical Topology Considerations:

The typical paradigm for realizing how power AC/DC systems is to utilize large components to handle the current and energy densities presented. While constructing the converter around very high power conversion building blocks may seem logical from the viewpoint of minimizing component count, it presents the system with a number of compromises.

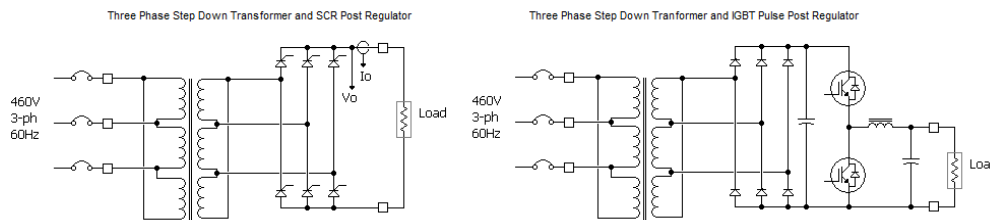


Figure 1 - Typical High Power DC System Realization

Due to considerations of inter-wiring inductance and circuit capacitance, large physical component

size generally limits the converters operating switching frequency. This in turn limits system control bandwidth and can compromise operational considerations (speed, precision, accuracy, etc.). These effects become even more pronounced if the converter utilizes silicon controlled rectifiers operating at the incoming power line frequency.

Large converter building blocks also present challenges to system scalability, limiting the ability to optimize the power converter size for a given system deployment. In addition, providing redundant channels to assure no loss of performance if one of these building blocks suffers a failure is often not economically feasible. Likewise, the ability to modularize these building blocks so as to simplify repair and maintenance is also compromised.

Given these considerations, Astrodyne TDI has advocated a building block approach that facilitates the use of printed wiring boards to carry the required currents (for repeatability), utilizes packages and components commonly found in the mainstream power supply market (for ability and cost), and allow operation at switching frequencies up to 200kHz or more (to reduce size). Core converter circuits producing power on the order of 5-6W meet these general requirements.

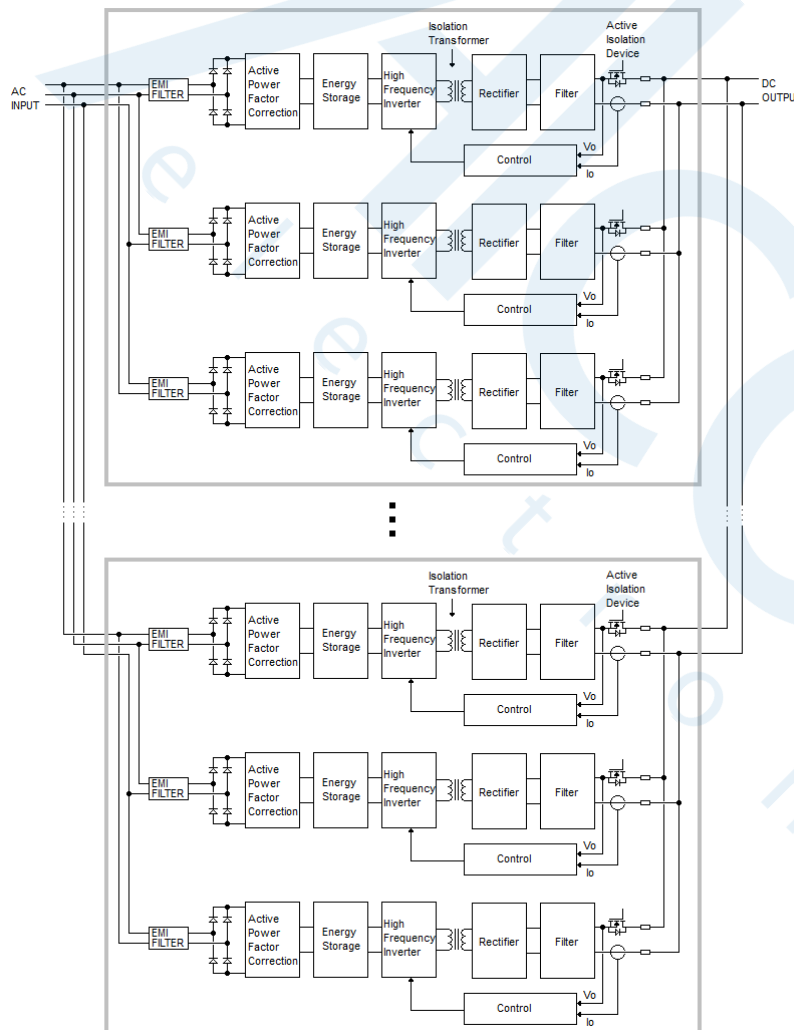


Figure 2 - High Power System with 5.5Kw Power Converter Building Blocks

### Power Converter Modularity Considerations:

Perhaps the most obvious trade-off in connecting multiple 5-6kW converter building blocks in parallel to support high power systems is the greater number of components required. However, as mentioned earlier these components will enable definite system benefits, including active power factor correction, increased control bandwidth for better system speed and accuracy, affordable realization of N+1 redundancy models, and the ability to properly scale the power conversion solution to the size and the economic constraints of the system.

Quite often, while converters with large, monolithic conversion blocks end up utilizing components close to their rated limits of current, voltage and temperature. This can result in compromised MTBF, at or below the values demonstrated in the above example for the moderate power block case.

When looked at from this perspective, Astrodyne TDI believes the trade-off between the number of components and perceived system complexity leans heavily in the direction of lower power conversion building blocks and modularity. This has been a practice successfully employed by high power telecommunication and networking DC power systems for many years.

### Physical Environment Considerations:

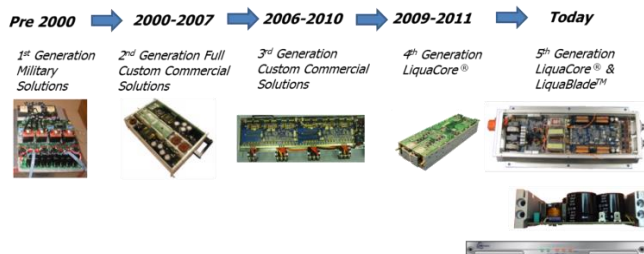
Space available for power conversion equipment is almost always a system constraint and realizing power conversion in a reduced volume is generally looked at as an advantage. Most high power industrial systems in the market today, especially if they require galvanic isolation between utility power and the end application, rely on the line frequency transformers. These are large, heavy and expensive (especially in terms of their copper use).

High frequency switch mode power conversion building blocks provide the advantage drastically reducing the size and volume of the isolating transformer element. Along with this the previously mentioned benefits of active power factor correction, increased operational bandwidth and redundancy can be realized. Compared with line frequency transformer based systems, high frequency switch mode typically provides volume savings on the order of greater than 300%, with weight savings of up to 70%.

Modularized, moderate-power converter building blocks also offer the opportunity to ease system maintenance and repair. If something goes wrong in a large monolithic converter, it generally requires a skilled technician and many hours of down time to troubleshoot and repair the system. On the other hands, a modularized system can be maintained by less skilled personnel in a fraction of the time.

### Managing Component Temperatures:

Perhaps the most significant compromise with 1st generation designs is, while they can be effective at capturing heat from major dissipating components, significant amounts of heat may not be well coupled to the cold plate. This results in excessive internal air temperatures within a chassis enclosure. Even with coolant temperatures on the order of 35°C, this can easily result in internal chassis temperatures exceeding 95°C, to a point where low power passive component reliability is compromised.



## Figure 4 - Evolution of ATDI Liquid Cooled Designs

As liquid-cooled designs evolved, they gravitated toward highly customized, extruded aluminum cold plate shapes that are both more economical than copper tube/aluminum plate designs, and provide effective cooling for both regularly shaped components (such as power semiconductors), and irregularly shaped components (such as magnetic parts). Moreover, these designs provided opportunity to control internal air temperatures by providing an effective cooling path to chassis side walls, providing a convection path for internal components that are not directly connected to the cold plate.

As demonstrated in Figure 2: 2nd and 3rd generation examples, these designs were successful in terms of thermal management and providing effective product solutions for specific applications, but being so specific they proved difficult to migrate to other applications. This ultimately led to the strategy shown as 4<sup>th</sup> generation, or what was branded as Astrodyne TDI “LiquaCore®”

LiquaCore® was conceived as a modularized, scalable solution for liquid-cooled applications. As shown in Figure 5, it developed a standard extruded cold plate in the shape of a U, into which a power conversion PCB assembly can be placed.

### **System- Level Considerations for Liquid Cooling:**

Liquid-cooled solutions also need to be reviewed as to what happens if there's a leak or condensation. As mentioned earlier, LiquaBlade power supplies are carefully designed and manufactured to prevent coolant leaks. However, as with any system parameter, the possibility of leaks should be considered. The best way to protect against coolant leakage either inside or outside the LiquaBlade module is to monitor the system for liquid accumulation at some point toward the bottom of the system. If liquid is detected then coolant flow to the system should be terminated, and input power removed from the system.

Likewise, condensation due to humid air coming on contact with cool components is another area of concern. When selecting coolant temperature it is important to take into consideration the Ambient Air Dew Point to prevent condensation, ensuring the temperature of the coolant is sufficiently higher than the ambient air dew point. All PC board assemblies within LiquaBlade are conformal coated to help prevent insulation compromise due to small to moderate amounts of condensing humidity. However, if the power system is to be operated in areas where condensing humidity is a genuine concern, a power system controller that monitors humidity is a genuine concern, a power system controller that monitors humidity and coolant temperature is available. This will limit coolant flow to the LiquaBlade modules while they warm up so as to prevent the possibility of condensation.

### **Conclusion:**

Learning achieved from years of experience has resulted in Astrodyne TDI's LiquaCore and LiquaBlade designs. These provide unique levels of thermal management, design flexibility, maintainability, and cost effectiveness. LiquaBlade opens the opportunity to leverage high frequency switch mode conversion in high power DC systems that traditionally have been the exclusive domain of line frequency based solutions, providing significant benefits in terms of size, flexibility, performance and system availability.