

A Modular Power Conditioning System for Energy Storage

The right design provides scalability and flexibility

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As power grids across the globe continue to suffer from the effects of high peak demands, instability, and the unpredictable nature of newly added renewable sources, more utilities are turning to energy storage systems as a means to mitigate these issues. A critical component of such systems is the Power Conditioning System, or “PCS”. The PCS is used in a variety of storage systems, and is the intermediary device between the storage element, typically large banks of batteries of various chemistries, and the power grid.

The PCS is a bidirectional power conversion device, enabling grid power to be converted to DC, charging the batteries in a controlled manner, or enabling battery power to be “inverted” to AC to feed the grid.



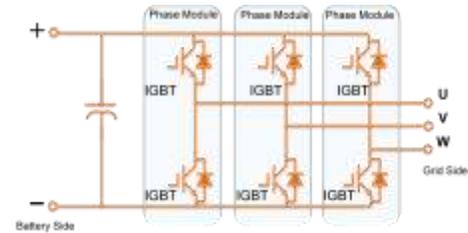
Given the nature of the semiconductor devices that rapidly switch on and off to create alternating current, a big part of the design includes measures to reduce harmonics, resulting in a pure sine wave output. The PCS must be able to synchronize with the grid frequency and zero crossings and provide a stable output – appearing to the grid to be a synchronous generator. It must be capable of a smooth mode transition when the system is used as a power backup or “black start” system. And lastly, in many applications, the PCS must have the capability to control power factor by supplying the grid with the right amount of real or reactive power on demand, over a wide range.

The heart of the PCS is one or more bidirectional grid-tie inverters, containing an array of power semiconductors called IGBTs (Insulated Gate Bipolar Transistors), arranged for DC to AC conversion, capable of switching high power at high speeds. The inverters used are similar to those used to harvest renewable energy from sources like solar fields, wind farms, and wave generators, and share a common pedigree with well established high power industrial motor controls. Inside the inverter, the power semiconductors are told when to switch on and off by sequenced gate drivers which are coordinated by an internal algorithm, driven by inputs from a supervisory system. Other items that comprise a PCS are responsible for physically connecting to the grid and storage element, as well as for protection, detection, power quality, and safety. Given

that the PCS is usually operational 24/7, and in a range of potentially extreme environmental conditions, a good thermal management system is required – both for the inverters and for the ancillary components.

Modular Approach

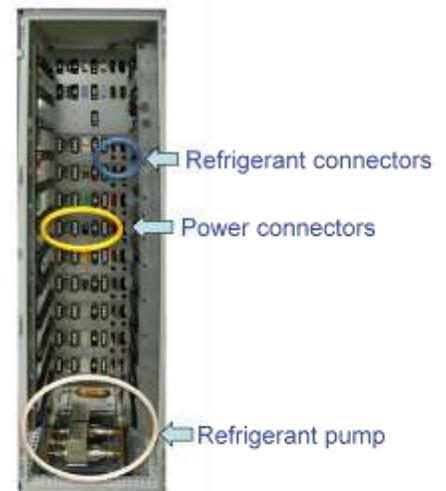
Parker SSD has a unique PCS design, in which modularity is taken to the component level. Each of the three phases coming from the PCS requires a pair of IGBTs as shown in the illustration. These IGBT pairs form the first element of modularity. In this design, the IGBT pair, along with gate drivers, onboard diagnostics, communications, and cold plate heatsinks, are packaged in a compact rackable module. Each phase module is self contained, and identical to any other phase module in the system. The phase module weighs under 40 pounds, and is easily



Phase Module – Front View

handled by one person without requiring ramps or rigging. One module is used for each phase, so the modules are always used in multiples of three. Depending on the power transfer rating required by the PCS, one, two, or three sets of identical phase modules can be used in parallel connection.

To support the phase modules, control module, and capacitor modules, a rack arrangement is used. The function of the rack is not only to hold the phase modules, but also to provide a self-contained refrigerant cooling system for all of the modules that are installed. Power connectors and refrigerant connectors are located in the rear of the rack, and connections to both are made when the module is slid into the rack. The rack is designed so that the modules can be removed or installed through the front cabinet door without the need to manipulate any power wiring. By virtue of the refrigerant cooling system, one compact rack can handle over a megawatt of continuous power transfer. Each phase module includes



Phase Module – Rear View

no-leak refrigerant connectors on the back, along with power connectors. Modules slide in, and are tightened with cap screws. Change-out requires no removal of power wiring, compression lugs, or access panels. The main benefit of the rack and module design is that MTTR is under 10 minutes for module replacement!

This megawatt power stack can be combined with additional stacks to build multi-megawatt systems.

Parker Advanced Cooling

The modular PCS incorporates a unique and highly efficient cooling system that was developed by Parker Precision Cooling division. A major concern of any storage installation is efficiency. Running 24/7, low efficiency can mean wasted energy that could otherwise be sold, and fractions of efficiency points can make a big difference long term.

Traditional air cooling requires compressor-based air conditioners and large air handlers, inherently not as efficient as a cooling system could be. Comparing to an air cooled system, pumped refrigerant at 0.3 gallons per minute does the same job as 150 CFM of air. And since each rack of modules has its own cooling system, there is inherent system redundancy. A failure of one pump for example, would not require a system shutdown.

Conventional liquid cooling is water-based, which is also not an optimal solution. A substantial volume of chilled water-glycol solution must be pumped through the system, using substantial wattage. There are also concerns about corrosion and the need for filters and other maintenance items, and clearly a water leak inside a cabinet full of live electrical componentry could spell disaster.

Parker's advanced cooling system addresses all of the weaknesses of air and water cooling in that it is a low volume, non-compressor-based system that uses a dielectric, non conductive fluid to take the maximum amount of heat out of the PCS. R134a in a two phase system removes 930 BTU per pound versus 1 BTU per pound of water.

Cooling System Operation

R134A refrigerant in liquid state resides in an accumulator, and is circulated by a constant displacement pump, through a series of cold plates under the IGBTs. As it passes through the cold plates, some of the liquid changes state to vapor, absorbing a tremendous amount of heat when the phase change occurs. The vaporized refrigerant rises to a condenser which also serves as a heat exchanger, while the refrigerant that does not vaporize returns to the accumulator. Cooled, the vapor condenses back to liquid phase and is returned to an accumulator, where it completes the cycle. Note that there is no compression cycle, and the temperature of the refrigerant never goes below the ambient, so condensation on critical components is not an issue.

To get rid of the heat that is removed from the semiconductors, two options can be provided. Refrigerant to air or refrigerant to liquid heat exchangers located outside the PCS cool the vaporized refrigerant, condense it back to liquid state, and return it to the accumulator.

PCS Connectivity

A PCS contains more than the power semiconductors that actually perform the power conversion. To interface safely and securely with the grid and storage element, switchgear and circuit protection are generally specified. These can take the form of AC or DC contactors, circuit breakers, fused disconnects, or a combination of these. For power quality and reduction of harmonics, a tuned filter, consisting of a combination of capacitors and inductors is included.

Of great importance is a complement of monitoring instrumentation. Sensitive localized temperature and current detection can provide an early warning to the system, allowing corrective action to be taken before a potential failure occurs.

A standard communications backbone provides amenities like SCADA control, remote access to operating parameters via internet, and interface to the site dispatch control.

Parker's modular design approach places these devices in AC and DC side cabinets flanking the power stack. The end result is a 1 to 1.5 megawatt functional section. By combining additional sections, a full utility scale installation can be assembled in short order.

Advantages of Modular Design

The design approach chosen by Parker carries many benefits, the two most valuable including scalability and system redundancy. Scalability allows for the expansion of a base system for future state conditions. In some cases, a small trial system has been installed, which is easily expanded once the concept is demonstrated and proven. In others, availability of funding has dictated building in stages. And with the dramatic increase expected in renewable sources over the next decade, and the corresponding increased requirement for stability and VAR support, the capability to add capacity will be a given.

System redundancy ensures maximum uptime and revenue to the user. By virtue of the modular design, one or more sections can be taken off line for maintenance while the system continues to operate. For example, in a typical 4 MW container installation, one 1 MW section can be isolated while 3 MW is still available.



Packaging for Site Deployment

When it comes to packaging the individual megawatt class modules that make up a PCS, there are basically two different schools of thought.

An ISO shipping container is one option that has been used in many existing installations. The advantages include standardized shape and size for initial deployment or later relocation, and ease of transportability. Up to 4 megawatts of capacity will comfortably fit in a 20 foot container, with transformers typically located outboard. The container approach allows “walk-in” personnel access for maintenance or service, and also acts as a shelter from the elements.

Another option is a custom “PCS Powerhouse” design which is all inclusive and compact. This design generally includes multiple exterior access panels, allowing for easy inspection and maintenance, while presenting a smaller footprint relative to power capacity.

Reliability and Longevity

An energy storage system only produces revenue for its user when it is on line and providing its intended function, whether that is frequency regulation, VAR support, power backup, or arbitrage. Lessons learned during the design and development process are always crucial to the release of a reliable final installation. A structured DFMEA (Design Failure Mode Effects Analysis) plan is critical, even with proven sub-systems, and can save a lot of time and energy at product release. Accelerated life testing is invaluable, especially with a system that is to operate for 10, 15 years or longer.

Real-time temperature monitoring at crucial points inside the PCS can provide preemptive notification of thermal issues. A holistic approach to climate control is necessary, including all critical components – both inside the inverter and including other current handling devices as well.

Finally, details of site location, commissioning, and wiring practices can make or break a successful installation. A site location must allow for proper access to entry doors and panels, and for ventilation. A level and rigid mounting surface is very important. And manufacturer’s instructions regarding grounding and other external connections should be meticulously followed. Installed and maintained in accordance with the directions provided will ensure years of profitable operation.

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