Energy Grid-Tie: Smart Technology, Cooling, Modularity and Monitoring

2-Phase Cooled, Modular Power Electronics

ENGINEERING YOUR SUCCESS.

21 July 2014
“Cool and Available” Parker Energy Grid-Tie

- Presented at Energy Storage World Forum
Parker Hannifin Corporation

Parker can be found on and around everything that moves. We manufacture highly engineered components and systems that facilitate motion and the controlled flow of liquids and gases for a wide variety of global markets to increase our customers’ productivity and profitability.

- $13 Billion in Revenue
- 865,000 Products Sold
- 452,000 Customers
- 58,000 Employees
- 13,000 Distribution/MRO Outlets
- 1,100 Markets
- 139 Divisions
- 341 Manufacturing Plants
- 49 Countries
Parker Hannifin – Engineering Your Success

Solving the world’s greatest engineering challenges.

See Our Capabilities Video on the Parker Hannifin Video Channel
Solving the World’s Greatest Engineering Challenges

Our focus on solving some of the world’s greatest engineering challenges sparks our passion for innovation and secures future growth.

Food  Water  Energy  Transportation  Defense  Environment  Infrastructure  Life Sciences
Parker “Smart Technology” PCS

- “Smart” Technology
  - Cooling
  - Modularity
  - Monitoring
- Future Trends
- In-Field Applications Experience
“Smart” Cooling – What is it?

- “Boiling the electronics to keep them cool!”
- 2-Phase evaporative cooling system
  - Refrigerant cold plate technology
  - Simple low pressure refrigerant cooling loop
  - Low energy circulation pump – 10% v. equivalent water cooled system
  - Refrigerant to air or water heat exchanger
“Smart” Cooling – Design

Single phase fluid enters cold plate

Two-phase mixture exits cold plate

Temperature is isothermal across the system

Reduce PCS size by up to 66% vs. conventional air-cooled solutions
“Smart” Cooling – Animation

Two-phase Liquid Cooling

Smart Cooling - Watch on YouTube - http://bit.ly/1jIr3KB
“Smart Cooling” – Two-phase Liquid Cooling
“Smart” Cooling - Advantages

• What are the advantages?
  • Removes 7x more heat than water for the same flow rate
# Heat sink/cold plate performance comparison table

<table>
<thead>
<tr>
<th>Cooling Method</th>
<th>Module Loss (W) for IGBT die 120°C junction temperature. Operating at steady state load.</th>
<th>Temp. spread across heat sink (IGBT – cold plate interface)</th>
<th>Heat sink (cold plate) to fluid thermal resistance °C / W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air cooled</td>
<td>600</td>
<td>23 °C</td>
<td>0.094</td>
</tr>
<tr>
<td>Aluminum, water-cooled, press fit Cu tubing*</td>
<td>736</td>
<td>18 °C</td>
<td>0.051</td>
</tr>
<tr>
<td>Aluminum, water-cooled internal fin passage*</td>
<td>1070</td>
<td>19 °C</td>
<td>0.035</td>
</tr>
<tr>
<td>Water cooled using Copper Cold Plate*</td>
<td>1040</td>
<td>23 °C</td>
<td>0.037</td>
</tr>
<tr>
<td>Evaporative cooling using Cu cold plate (2-phase cooling)</td>
<td>1461</td>
<td>6 °C</td>
<td>0.009</td>
</tr>
</tbody>
</table>

All tests performed at same ambient (40°C)

*Water cooling used 5x the flow rate of Evaporative cooling
2-Phase Cooling System

- Air heat exchanger (evaporator)
- Cold Plates
- Filter/Dryer
- Pump
- Condenser
- Receiver Tank
- Flex Hose

$Q_{\text{in}}$ -> Cold Plates

$Q_{\text{out}}$
“Smart” Cooling – What are the Results?

• Increases power converter efficiency
  • Measured up to 98%

• Reduces power converter size
  • Up to 66% smaller than air-cooled solution

• Higher reliability
  • Fewer moving parts – fans etc.
“Smart” Cooling - Efficiency

<table>
<thead>
<tr>
<th>CEC Efficiency</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>50%</th>
<th>75%</th>
<th>100%</th>
<th>CEC Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmin</td>
<td>585V</td>
<td>97.18%</td>
<td>98.27%</td>
<td>98.47%</td>
<td>98.54%</td>
<td>98.59%</td>
<td>98.26%</td>
</tr>
<tr>
<td>Vnom</td>
<td>650V</td>
<td>97.05%</td>
<td>98.15%</td>
<td>98.38%</td>
<td>98.56%</td>
<td>98.51%</td>
<td>98.22%</td>
</tr>
<tr>
<td>Vmax</td>
<td>820V</td>
<td>94.89%</td>
<td>97.35%</td>
<td>97.90%</td>
<td>98.06%</td>
<td>98.02%</td>
<td>97.87%</td>
</tr>
</tbody>
</table>

Inverter Efficiency vs. Percent Load
Includes cooling system and control power
“Smart” Modularity

• What?
  • Building block approach
  • “Plug and Play” power electronics modules
  • Light weight modules < 25kgs
“Smart” Modularity - Advantages

• Simple manual installation
• Power modules easily freighted to remote locations
Experience

Operating in the Atacama Desert

- Extremely remote locations, minimal population
- Weak electricity grid, frequent variation in grid voltage & frequency
  - Mining operations (demand highest reliability), large load disconnect/connect
  - Single transmission lines to many locations
- Diminished cooling capacity of air at high elevations
- The Atacama is the driest place on the earth

Parker inverter design:

- Minimal maintenance required & no consumables (i.e. air filters)
- IP65 sealed from ambient, no HVAC system, not water cooled (Parker Advanced Cooling System)
- High altitude operation with limited or no de-rating
- Robust controls proven to adapt to rapid fluctuations in DC voltage and AC voltage/frequency
- Provide full power & full VAR capability, sub-cycle response time
- Programmable ramp rate controls real/reactive power & power factor
- Autonomous operation: capable of automatic response real/reactive power in response to grid conditions
- Self contained for rapid deployment, minimal on-site wiring (incl. transformer close coupling design)
“Smart” Modularity - Results

- Increased asset availability or system yield
- Easy on-site Service Technician maintenance
  - < 10 mins module swap-out time
Modular PCS Assembly
“Smart” Monitoring

• What?
  • “It’s like your car”
  • Predictive maintenance schedule
  • Condition monitoring
    • Spot abnormal trends
    • Planned preventative maintenance
  • Parker outdoor rated inverter
    • 100+ temperature measurements
    • Power, Volts, Amps, efficiency etc.
    • Parker patented “HotSpot” monitoring technology
“Smart” Monitoring – Details

- 100+ temperature measurements
- DC Current for each PV String
- Filter Capacitor Current
- Metered Power, kVAR, Power Factor, Voltage, Current
  - Options for THD and Waveform Capture
- Real Time Efficiency
- Fan Speed Indication
- Refrigerant Level Sensor
- Ground Fault Current
- Internal Humidity
- Contactor Aux Contacts
- Fuse Indicators
- All standard inverter parameters
“Smart” Monitoring - Advantages

• No unwanted surprises
• Predictable trouble free operation
• Results?
  • Increases asset availability or system yield
  • Automatic historical operating log
    • 30 days of data at 1s sample rate
    • Trends, dated trip history
  • Remote access via comms
### “Smart” Monitoring

<table>
<thead>
<tr>
<th>Action</th>
<th>Component</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>EPO Operation</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>CB2 Main Disconnect Circuit Breaker</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Coolant system for damage</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Enclosure for leaks / damage / corrosion</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Inspect AC connections (Enclosure to Isolation Transformer)</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Inspect DC connections (Solar Arrays to Enclosure)</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Enclosure Internal Damage, Corrosion, Cleanliness</td>
<td>Annually</td>
</tr>
<tr>
<td>Review</td>
<td>Coolant system level (via SCADA)</td>
<td>Annually</td>
</tr>
<tr>
<td>Review</td>
<td>SCADA Temperature Data Trends</td>
<td>Annually</td>
</tr>
<tr>
<td>Inspect</td>
<td>Enclosure Damage, Corrosion</td>
<td>6 Months</td>
</tr>
<tr>
<td>Test</td>
<td>GFI Duplex Receptacles</td>
<td>6 Months</td>
</tr>
<tr>
<td>Test</td>
<td>Ground Fault</td>
<td>6 Months</td>
</tr>
<tr>
<td>Clean</td>
<td>Heat Exchanger Fins</td>
<td>6 Months</td>
</tr>
<tr>
<td>Inspect</td>
<td>Solar Panel Input Connections Corrosion,</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Replace</td>
<td>Coolant Pumps</td>
<td>10 years</td>
</tr>
<tr>
<td>Replace</td>
<td>Condenser Fans</td>
<td>8 years</td>
</tr>
<tr>
<td>Replace</td>
<td>Internal Fans</td>
<td>10 years</td>
</tr>
<tr>
<td>Replace</td>
<td>Control Power Supplies</td>
<td>10 years</td>
</tr>
</tbody>
</table>

![Monitoring Interface](image.png)

[Link to Parker's website](http://www.parker.com)
Future Trends – Power Converter Systems

• Lower **cost**
• Higher **power density**
• Higher **efficiency**
• Higher **availability** and **yield**
• Easier to maintain
  • “Plug and Play” power modules
  • Predictive and preventative maintenance
• Long service life, 20 years
• “As reliable as transformer”
Future Trends

• Partnerships
• AB 2514

1.3GW of grid energy storage in CA by 2020
Latest News from California ...

Energy Storage Target of 1.3GW by 2020

After years of wrangling, California’s energy storage future starts to take shape.

JEFF ST. JOHN: JUNE 11, 2013

California has just taken a big step forward in making grid-scale energy storage on a truly massive scale a reality. On Monday, the California Public Utilities Commission released a proposal (PDF) that would call for the state’s big three investor-owned utilities to procure 1.3 gigawatts of energy storage by decade’s end, along with market mechanisms to start the procurement process as early as next year.

The assigned commissioner ruling from CPUC Commissioner Carla J. Peterman is the result of a process that started in 2010 with the passage of California Assembly Bill 2514, the first state law calling for grid-scale energy storage. Last year, the CPUC took up the challenge of figuring out the true costs, incentives, deployment, and benefits of such a massive scale and scope of installations.

“California has just taken a big step forward in making grid-scale energy storage on a truly massive scale a reality. CPUC released a proposal that would call for the state’s big three investor-owned utilities to procure 1.3 gigawatts of energy storage by decade’s end, along with market mechanisms to start the procurement process as early as next year.”

Table 1: Initial Proposed Energy Storage Procurement Targets (in MW)

<table>
<thead>
<tr>
<th>Use case category, by utility</th>
<th>2014</th>
<th>2016</th>
<th>2018</th>
<th>2020</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern California Edison</td>
<td>50</td>
<td>65</td>
<td>85</td>
<td>110</td>
<td>310</td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>65</td>
<td>185</td>
</tr>
<tr>
<td>Customer</td>
<td>10</td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>85</td>
</tr>
<tr>
<td>Subtotal SCE</td>
<td>90</td>
<td>120</td>
<td>160</td>
<td>210</td>
<td>580</td>
</tr>
<tr>
<td>Pacific Gas and Electric</td>
<td>50</td>
<td>65</td>
<td>85</td>
<td>110</td>
<td>310</td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>65</td>
<td>185</td>
</tr>
<tr>
<td>Customer</td>
<td>10</td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>85</td>
</tr>
<tr>
<td>Subtotal PG&amp;E</td>
<td>90</td>
<td>120</td>
<td>160</td>
<td>210</td>
<td>580</td>
</tr>
<tr>
<td>San Diego Gas &amp; Electric</td>
<td>10</td>
<td>15</td>
<td>22</td>
<td>33</td>
<td>80</td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>7</td>
<td>10</td>
<td>15</td>
<td>23</td>
<td>55</td>
</tr>
<tr>
<td>Customer</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>Subtotal SDG&amp;E</td>
<td>20</td>
<td>30</td>
<td>45</td>
<td>70</td>
<td>165</td>
</tr>
<tr>
<td>Total - all 3 utilities</td>
<td>200</td>
<td>270</td>
<td>365</td>
<td>490</td>
<td>1,325</td>
</tr>
</tbody>
</table>

1) First, in terms of total megawatts, the CPUC’s proposal goes pretty far in establishing the state as a leader in energy storage for the grid – and sets some pretty quick deadlines to meet as well. As the chart below indicates, the CPUC wants the state’s big three utilities to start procuring storage resources next year, and then keep increasing that amount by roughly one-third every two years, to meet its 2020 goals.

California Assembly Member Nancy Skinner (D-Berkeley), author of AB 2514, originally included a mandate that the state procure enough energy storage by 2020 to meet 5 percent...
In the News - Partnerships

Arlington, Va. – March 6, 2014 – AES Energy Storage today revealed the AES Battery Integration Center, a technology center located in Indianapolis, Ind., that evaluates advanced battery and power conversion technologies for use in AES Advancion™ – a complete battery-based energy storage offering, which is now available to utility buyers and renewable developers in select markets. LG Chem and Parker Hannifin are the first manufacturers to become certified suppliers for Advancion through the development of supplier-specific control modules at the Battery Integration Center. This framework reduces costs and enables increased scale by creating a channel for more battery and power conversion manufacturers to participate in AES customer solutions.

“Through the work at the Battery Integration Center, AES Advancion combines best-in-class battery technology and power conversion equipment with our proven control architecture to offer a comprehensive approach to storage solutions,” said Brett Galura, Vice President, Solution Development, AES Energy Storage. “LG Chem and Parker Hannifin are two leading suppliers that will help us continue to bring the benefits of energy storage innovation to key markets.”

Brett Galura, VP Solution Development AES Energy Storage.
In-Field Applications Experience

• Over 86MW of Parker PCS deployed world wide
• Real life examples of using 2-phase cooling and modular power electronics
AES operates 72MW of Advanced Reserves with five years of established development and operating experience.

World’s Largest Li-Ion project
32 MW of Parker PCS
99+% Uptime!
In the News - Lights on Winter Olympics

EnerDel, Parker supply grid energy storage system for Winter Olympics in Sochi

06 February 2014

US-based EnerDel and the Energy Grid Tie Division of Parker Hannifin have collaborated on two major energy storage projects in Russia, including the backup power capability for the 2014 Winter Olympics in Sochi.

EnerDel, a leader in utility-scale lithium-ion battery energy storage systems, was contracted in 2010 to supply backup power for the substations that support the XXII Olympic Winter Games. The company’s system has been built, delivered, and commissioned well in advance of the start of the Winter Olympics, which begin tomorrow.

Working in partnership with EnerDel, a leader in utility-scale lithium-ion battery energy storage systems, Parker Hannifin’s Energy Grid Tie division supplied one of its highly efficient and compact PCS solutions as part of a 1.5 megawatt, 2.5 megawatt-hour installation connecting large banks of battery energy storage to the grid, smoothing out fluctuations and supplying back-up power for the local substations that will support the games…….
Complete Grid Tie Solutions for Energy Storage

Parker Hannifin Corporation

Complete Grid Tie Solutions for Energy Storage

ENGINNEERING YOUR SUCCESS.

Visit our Grid Tie Solutions Website
Presenter: Dr. David Blood

As the Engineering Manager and Market Manager EMEA for Parker SSD Drives Europe and Energy Grid-Tie, David is based in Littlehampton, West Sussex, England. Originally from Bolton, Lancashire, David was educated at the University of Reading, gaining a 1st class honours degree in Electrical and Electronic Engineering in 1985, followed by a PhD in the control of AC motors in 1989. During his 22 year career with SSD, David has worked in various roles such as motor control firmware development, product leader, project management and finally, departmental manager. David has been involved in the development of nearly every digital AC drive made by SSD over the past 20 years, including the 690 and 890 series, introducing advanced sensor-less speed control to these product families. David is currently part of the team introducing Parker’s new AC30 range of inverter drives to the market.

Phone  d: +44 1903 737 318 or m: +44 77 1350 1928
ENGINEERING YOUR SUCCESS.