Energy Storage System Cooling

Laird Thermal Systems Application Note
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THERMAL SYSTEMS

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Background

Energy storage systems (ESS) have the power to impart flexibility to the electric grid and offer a back-up power source. Energy storage systems are vital when municipalities experience blackouts, states-of-emergency, and infrastructure failures that lead to power outages. ESS technology is having a significant impact on a wide range of markets, including data centers that utilize uninterrupted power supplies (UPS) and telecom base stations that utilize battery back-up systems. Telecom base stations require energy storage systems to ensure that cloud data and communication systems stay online during a crisis like a natural disaster. A power outage that restricts or interrupts access to data and communications can cause significant challenges for first responders and others called into action to support citizens and restore essential infrastructure.

Battery back-up systems must be efficiently and effectively cooled to ensure proper operation. Heat can degrade the performance, safety and operating life of battery back-up systems. Traditionally, battery back-up systems used custom compressor-based air conditioners. However, thermoelectrics are becoming more popular because they offer a lower cost of ownership option compared to other cooling techniques. Thermoelectric cooler assemblies not only eliminate the need for a custom solution to reduce the product development time, but also to simplify installation. Thermoelectric cooler assemblies offer improved thermal control relative to compressor-based air conditioners, maintaining temperature to within 0.5°C of the set point temperature. They provide thermal control in environments where the ambient temperature may be either above or below the battery temperature limits, simply by reversing the direction of the current flow. Thermoelectric cooler assemblies optimize temperature stabilization to ensure sensitive battery back-up systems operate at maximum efficiency — all in a smaller package compared to other cooling systems.

Battery back-up system used for the Telecom Industry.

Application Overview

A battery back-up system consists of a series of power inverters, charge controllers/rectifier, and storage batteries. According to FCC order 07-177, when the power to a cellular antenna tower goes out, emergency batteries must provide back-up power for at least 8 hours. Many base stations are located in remote places with harsh environments, including cold mountainous areas or open desert areas with high temperatures and high winds. These base stations can see temperature extremes ranging from very cold to very hot. Long life battery operation is required to minimize replacement as many of these systems are not easy to access.

Batteries used in cellular base stations are typically located in cabinets that are vented to protect the vital equipment from the fumes and corrosive chemicals found in the wet cell batteries, which are often lead–acid or valve regulated lead-acid (VRLA). Several lead acid batteries are wired together in a series circuit, forming a group providing DC electric power. The more batteries that are wired together, the greater the amount of heat generated within the cabinet. Usually, there are two or more groups of series-connected batteries. These groups of batteries are connected in a parallel circuit, allowing one battery group to be taken offline for repair or replacement without removing the availability of back-up power. Typically, the larger the battery cabinet's electrical capacity, the larger the size of each individual battery and the higher the room's DC voltage.

Depending on the location of the base station, temperatures may range from a high of 50°C to a low of -30°C. The heat generated within the battery cabinet can vary depending on the ambient temperature. For reliable operation and maximum useful battery life, the enclosure must be maintained between +10°C to +30°C.

Batteries used in cellular base stations are usually placed in cabinets to protect the equipment.

Challenges

No battery lasts forever. Back-up batteries usually show a slow degradation of capacity until they reach around 80-85 percent of their initial rating. This is followed by a more rapid failure rate.

The rated capacity of a battery is based on an ambient temperature of 25°C (77°F). Any disparity from this operating temperature can significantly alter the performance of the battery and shorten its expected life. To help determine battery life in relation to temperature, one can assume that for every 8.3°C (15°F) average annual temperature above 25°C (77°F), the life of a sealed lead acid battery is reduced by 50%. This means that a VRLA battery specified to last for 10 years at 25°C (77°F) would only last 5 years if continuously exposed to 33°C (92°F) and 30 months if kept at a constant desert temperature of 41°C (106°F). Once the battery is damaged by heat, the capacity cannot be restored.

In battery back-up systems, heat and overcharging are two of the most important factors that lead to battery degradation, lower performance and even thermal runaway. Controlling and stabilizing the ambient temperature seen by the back-up battery is critical to battery performance and lifetime. Battery charging voltages need to be adjusted based on the battery temperature.

This adjustment in charging voltage is known as temperature compensation, and is a feature that helps ensure that a battery is neither undercharged nor overcharged regardless of battery temperature. All chemical reactions are affected by temperature. Battery charging is an electrochemical reaction, so it too is affected by temperature. Specifically, cold batteries require a higher charge voltage in order to push current into the battery plates and electrolyte, and warmer batteries require a lower charge voltage to eliminate potential damage to VRLA cells and reduce unnecessary gassing if flooded cells are used.

There are steps to take to maximize battery life and performance, including using advanced cooling systems. However, too many base station cabinets utilize expensive and bulky compressor-based air conditioners rather than alternatives such as thermoelectric cooler assemblies.

Compressor-based Air Conditioner Overview

A conventional compressor-based system contains three fundamental parts: 1) the evaporator, 2) the compressor, and 3) the condenser. The evaporator (cold section) is where the pressurized refrigerant passes through the expansion valve and expands, boils, and evaporates. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor acts as the refrigerant pump and recompresses the gas into a liquid. The condenser expels both the heat absorbed at the evaporator and the heat produced during compression into the ambient environment.

Conventional compressor-based air conditioners are typically AC powered. However, if the AC power goes out, the cooling system would shut down and there would be no cooling provided to maintain the ambient temperature for the back-up battery system. In the event of a brown-out, where the available electrical power is reduced, the batteries may or may not be cooled appropriately. A cooling system that operates on a DC power supply such as a thermoelectric cooler would not be susceptible to black-outs or brown-outs, allowing the ambient temperature of the battery back-up system to be kept constant.

Many battery back-up applications experience environmental conditions that fluctuate throughout the day and over the course of a season. Compressor systems are either entirely “on” or “off”. There is no proportional control, so full power must be applied at all times. Furthermore, the start-up current for a compressor-based system is often three times the steady state operating current, and the circuit must be sized to handle the current. Combining the non-proportionality, repeated on-off control and high-power draw at start-up reduces the efficiency gains at steady-state that compressor-based systems offer relative to other options such as thermoelectric systems.

The compressor-based system relies on moving parts and coolants for operation. Both the compressor and motor are required to move the working fluid through the system, while fans are used to circulate the air through the evaporator. A compressor system’s components will wear out over time due to friction, thermal expansion, and on-off control. There is potential for leakage of the coolant through seals that fatigue from continuous operation. Because of the coolant, a compressor-based system must be kept in a specific orientation during shipping, handling and installation to prevent damage to the system. It can only be mounted in certain orientations, so special units are needed for different installations.

Additionally, compressors are larger and heavier than other options. Compressor-based systems experience vibration that can have a cumulative effect on loosening hardware connections in the cooling unit and electronics in the enclosure. Noise is also a concern due to the various moving parts in these systems. Solid-state systems do not have these issues.

Compressor-based systems are typically designed for operation between 20°C and 55°C. This range is useful for most enclosure applications and operating environments. However, if heating is required, a separate heater and switching circuit must be used or if higher or lower temperatures are desired, a special compressor for that range (with the associated refrigerant and all hardware) must be designed.

All the challenges and issues with respect to compressor-based cooling systems - power, efficiency, reliability, handling and installation, vibration and noise, separate heating and cooling, and temperature control - can be addressed through the use of solid-state devices using thermoelectric cooling.

Thermoelectric Overview

Thermoelectric coolers are solid-state heat pump devices that operate using the Peltier effect. When an electric current is applied to a circuit containing two dissimilar materials, heat is absorbed at one junction (the cold side) and released at the other junction (the hot side). The design of Peltier devices requires the use of both an n-type and a p-type semiconductor. Since heat naturally flows down a temperature gradient from hot to cold, a thermoelectric cooler’s ability to move heat from cold to hot in a solid-state structure is unique. Also, by reversing the polarity of the applied DC current, heating is possible. This feature is especially useful for applications requiring both heating and cooling for precise temperature control.

Thermoelectric coolers provide an excellent alternative to compressor-based cooling systems, although a lack of experience with such devices may cause hesitation in some end users. Thermoelectric-based systems are compact, robust and completely solid state, with no moving parts, fluids or gasses. The basic laws of thermodynamics apply to these devices just as they do to more conventional systems that provide heat transfer.

Thermoelectric Cooler Assembly Technology Evaluation

Thermoelectric cooler assemblies, which mate heat transfer mechanisms to thermoelectric coolers, are compact, efficient units that can control the temperature of base stations. Thermoelectric coolers serve a cooling capacity spectrum from approximately 10 to 400 Watts, and can cool by removing heat from control sources through convection, conduction, or liquid means.

Thermoelectric devices operate using DC power, leaving them less vulnerable to the black-outs and brown-outs that can impact other types of cooling systems. Using DC power allows thermoelectric cooler assemblies to remove heat at a rate proportional to the power applied, so when cooling needs are low, less energy is used to maintain temperature control. This compares favorably relative to the “on”/“off” operation of compressor-based systems.

Also, the ability to provide both cooling and heating with the same thermoelectric device, simply by reversing the direction of the current flow, means that the rapid cycling from thermal overshooting between competing cooling and heating devices can be avoided. Thermoelectric cooler assemblies offer a high degree of thermal control, increased energy efficiency, and improved reliability over other cooling systems.

Thermoelectric cooler assemblies offer several additional advantages over other cooling technologies. For example, conventional fan trays do not cool to below ambient and require an air exchange with the outside environment. Thermoelectric cooler assemblies can cool to well below ambient and protect electronics inside enclosures from outside contaminants, and prevent exposure from the outside environment. Thermoelectric cooler assemblies also provide precise temperature control with accuracies up to 0.01˚C of the set point temperature, due to their proportional type control system.

The operating range for a typical thermoelectric cooler is -40˚C to +65˚C for most systems. For compressor-based systems, the typical operating range is +20˚C to +55˚C, allowing thermoelectric coolers to operate in a much larger environmental area.

Thermoelectric cooler assemblies feature a solid-state construction, so they do not have compressors or motors. Therefore, they offer a more compact form factor and lower weight than conventional compressor-based systems. The only moving parts in thermoelectric cooler assemblies are fans on the hot and cold sides, which circulate the air after heat is absorbed in the cabinet and dissipated to the environment. This means that they have much lower noise and vibration and a longer life cycle compared to competing technologies.

Thermoelectric cooler assemblies do not use any type of coolant, meaning that they are mountable in multiple orientations without any impact to performance or reliability. Since no CFCs are used, they are environmentally friendly and unrestricted in terms of government ozone depleting regulations. As a result, thermoelectric cooler assemblies have a low to no field maintenance requirement, which lowers the total cost of ownership.

The following table shows a scenario of how thermoelectric devices can be applied compared to compressor-based systems:

Comparison Chart

	Thermoelectric Based	Compressor Based	Comments
Power Usage	Best with proportional control in cooling mode and heating mode.	No proportional control; affects overall efficiency.	Thermoelectric cooler assembly is more efficient over wider range of temperatures.
Reliability	> 70,000 hours	Unpublished	Fan is only moving part in thermoelectric cooler assembly.
Power Input	DC required	AC required	DC more flexible to accommodate multiple geographic regions.
Reliability	Solid-state heat pumping; proportional control; fan is only moving part.	Mechanical pump, refrigerants, fans. On-off switching duty cycle.	Fan is only moving part in thermoelectric cooler assembly.
Handling and Installation	Can be shipped, stored, and installed in any orientation (top, vertical, horizontal)	Refrigerant (R134a) requires unique orientation.	Condensation control may dictate some design-orientation in thermoelectric cooler assembly.
Noise / Vibration	< 61 dB(A)/ none	< 61 dB(A) / mechanical	Fan is only moving part in thermoelectric cooler assembly with option to speed control
Maintenance	No disassembly needed. Periodic compressed air over heat sinks.	Disassembly required to access coils and chambers. Compressed air, replenishment of refrigerant.	Thermoelectric cooler assembly has low total cost of ownership.
Temperature Control	<0.01°C	≥2°C	Thermoelectric controller accuracy to < 0.01°C, if required, using PID
Size	0.0127m3	0.0273m3	Thermoelectric cooler assembly takes up less volume than compressor-based system.
Weight	7kg	17kg	Thermoelectric cooler assembly weighs less than compressor based system.

Solution

Laird Thermal Systems' Outdoor Cooler Series is an air-to-air thermoelectric cooler assembly that offers dependable, compact performance to cool enclosures in an outdoor environment. Designed to pass harsh environments, the Outdoor Cooler Series combines superior heat pumping capability with form factor, while minimizing power consumption.

The AA-230 Series has a heat pumping capacity of 230W at dT = 0°C, Tambient = 35°C. Heat is absorbed and dissipated through custom designed heat exchangers with high aspect ratio, air-ducted shrouds and high-performance fans. The units are designed for horizontal mount orientation to accommodate shelf space in a cabinet or rack, providing a smaller, more efficient option to cool or heat vital electronics. Instead of cooling the entire cabinet, a single smaller AA-230 cooler protects only the specific electronics that require cooling, which translates to energy cost savings. The AA-230 can run longer with less power than previously designed thermoelectric based cooling units.

The AA-480 Series offers up to 480 Watts of cooling power and achieves a Coefficient of Performance (COP) rating of 1. The AA-480 Series thermoelectric cooler assembly saves nearly 30% of space compared with two standard air-to-air units offered today with similar cooling capacities. This simplifies installation and consumes less space inside the cabinet.

Both products are environmentally friendly, as the solid-state operation eliminates the need for a compressor and CFC refrigerants that are regulated by the government.

In addition, both the AA-230 and AA-480 Series have been designed to pass rigorous Telcordia test requirements, such as earthquake resistance, salt fog, wind-driven rain, high temperature exposure and dust contaminants. This is due to the selection of world class components such as brand-name fans with the highest degree of environmental protection and lifetime guaranteed waterproof connectors, heavy duty anodization on the high-density heat sinks, overheat protection, and double environmental seals for the thermoelectric coolers.

AA-230 Outdoor Cooler

AA-480 Outdoor Cooler

Thermal Control

The temperature control specification for a battery back-up application is typically +/- 2°C or greater. This allows hysteresis to be designed in, reducing cycling between cooling and heating or on/off when the enclosure is at its set point temperature. This range is suitable for thermostatic control, but a tighter tolerance requires a proportional type of control.

A SR-54 thermoelectric-based controller can drive the temperature of an enclosure to within 0.1°C of the set point temperature. This is accomplished with the integrated bi-directional proportional–integral–derivative (PID) control, adjusting the net power to the thermoelectric cooler and allowing fine tuning and rapid response to component or environmentally-induced heat load fluctuations. A bi-directional thermostatic controller can operate in both heating and cooling modes to accommodate the seasons throughout the year. Additional features include alarms to detect a fan, thermistor or thermoelectric cooler failure. External communication can be incorporated to notify the end service provider that it is time for replacement.

Results

The Laird Thermal Systems Outdoor Cooler Series offers a lower cost of ownership by maintaining the appropriate temperature range using less energy than standard air-to-air systems due to its high Coefficient of Performance (COP). Because of its innovative design, the steady state construction requires less maintenance than standard compressor-based air conditioners.

The AA-230 and AA-480 units can operate for much longer with less power consumption than previously designed thermoelectric-based cooling units, ensuring longer lasting battery back-up during power outages.

Conclusion

Laird Thermal Systems' offers the industry's widest selection of thermoelectric cooler assemblies. Our thermoelectric cooler assemblies deliver temperature stabilization that ensures sensitive battery back-up systems operate at maximum efficiency. Coupled with an SR-54 controller offering precise temperature control and accuracy to within 0.1˚C, the AA-230 and AA-480 series offer cooling units designed for harsh environments, making them ideal for battery back-up applications.

About Laird Thermal Systems

Laird Thermal Systems develops thermal management solutions for demanding applications across global medical, industrial, transportation and telecommunications markets. We manufacture one of the most diverse product portfolios in the industry ranging from active thermoelectric coolers and assemblies to temperature controllers and liquid cooling systems. Our engineers use advanced thermal modeling and management techniques to solve complex heat and temperature control problems. By offering a broad range of design, prototyping and in-house testing capabilities, we partner closely with our customers across the entire product development lifecycle to reduce risk and accelerate their time-to-market. Our global manufacturing and support resources help customers maximize productivity, uptime, performance and product quality. Laird Thermal Systems is the optimum choice for standard or custom thermal solutions. Learn more by visiting www.lairdthermal.com

Contact Laird Thermal Systems

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