Power Systems for Harsh Environments

Modern electronic systems are increasingly being applied in outdoor, non-sheltered or semi-sheltered environments. Power conversion equipment presents unique challenges with this regard due to high electrical, thermal and vibration stresses.

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It is not unusual to find high-end electronic equipment in non-traditional environments such as communications equipment on mast, pole or roof-mounted enclosures. Figure 1 shows a system mounted approximately half way up a communications tower.

Electric and hybrid vehicles are also demanding onboard power conversion, energy storage and control equipment, which must function in severe weather and vibration such as heavy industry factory floors, energy generation platforms and chemical environments.

There are several alternative equipment design and construction techniques for highly reliable power conversion, compatible with increasing environmental stress levels.

Challenges to Power Conversion Circuits in Uncontrolled Environments

Power conversion equipment is often challenged with stresses from a number of different factors, such as voltage gradients, high current densities, energy storage, high temperature and heavy, irregular shaped components. In combination, these factors have a poor effect on the reliability of the power system.

Insulation Compromise

Most modern electronic applications requiring more than a few hundred watts utilize forced air for cooling. A typical switching power supply operating under ideal conditions has its operating life ultimately limited by the dehydration of aluminum-electrolytic capacitors, bearing wear out of cooling fans, and accumulation of dust and debris within the unit. In a well-designed unit, these should provide seven years of continuous operation. However, insulation compromise due to infused dust, debris and vermin reduces the useful life of a power supply.

Even in relatively clean and climate-controlled environments, dust and other potentially conductive debris will be infused into the unit over time. Figure 2 shows a unit that was returned for service after approximately two years of operation in a computer room environment (not generally considered to be a harsh environment).

Infused debris can cause bridging of circuits due to conductive material coming to rest across insulating barriers. Alternately, dust build up acts as a reservoir for ionic contaminates and moisture entrapment from humidity. Over time, these can enable the growth of conductive dendrites that may ultimately bridge insulating barriers.

Dendrites are microscopic conductive paths that are formed when ionic materials, in the presence of moisture and an electric field, disassociate into negatively and positively charged materials. Figure 3 shows a photograph of a dendrite growing between two PC board traces.

Dust accumulation will degrade the performance of heat sinks and air filters that provide cooling for power dissipating elements. As these get clogged, the operating temperature of components will increase, ultimately leading to reduced component life.

One effective approach is to conformal coat printed wiring boards with a thin acrylic coating, such as Chase Specialty Coatings HumiSeal, for computer or control room products.

Infused sand or grit (such as that found adjacent to a construction site or nearby a dirt road) can abrade insulating coatings or barriers, and in extreme cases, components themselves may be abraded.

Humidity and moisture are more pronounced in outdoor environments. Even in air-conditioned cabinets, moisture condensation may occur as temperatures increase and decrease as cabinet doors are opened for service. If equipment is located near the ocean, salt fog penetration will accelerate metal corrosion, as well as provide a rich mixture of ions to promote dendrite growth.

Temperature

Typical outdoor electronic systems must withstand the rigors of the climate they are installed in, with temperature extremes as low as -30°C (-22°F) and as high as 45°C (113°F). Solar loading can increase the effective operating temperature by as much as 20° to 30°C.

Cabinet-level cooling or heating is generally implemented in these environments. An air-to-air heat exchanger is one common (generally reliable) method, however it has modest cooling performance. Traditional compressor-derived air-conditioning has very good cooling performance, however it comes at a greater cost and introduces reliability and maintenance issues.

Strategies to Address Severe Environment Conditions

The most straightforward method used to address severe installation environments is to enclose the system in an environmentally controlled enclosure. Telecommunication systems have been using this method for years, with reasonably good results. However, the advent of smaller systems, such as the WIMAX nodes, has presented new challenges to systems designers in terms of size, cost and reliability.

Some systems utilize environmentally hardened equipment in a semi-sheltered environment that is protected from direct moisture egress, bugs, vermin and solar loading, but unconditioned outside air comes in direct contact with deployed equipment. In these applications, a cost-effective alternative is to use fan-cooled power conversion equipment that is hardened against the effects of humidity, moderate salt-fog, dust and grit. TDI has developed products that utilize a 2 to 3 mm thick coating of Silicon RTV to protect all small electronic components and printed wiring board traces. Larger components and heat sinks take advantage of moving air for cooling purposes, as illustrated in Figure 4.

When the circuit to be powered is located in an air-conditioned and sealed enclosure, an environmentally sealed power module (ESPM) provides an attractive source of external power, since it simultaneously reduces the heat load on the air conditioner and provides additional space for environmentally sensitive equipment.

Battery back up assemblies to provide uninterruptible power to critical systems should also be isolated from the sealed and air-conditioned equipment enclosure to prevent the build up of fumes or corrosive atmospheres. They are often packaged in a separate ventilated enclosure that protects the batteries from the external environment. Temperature regulation of the batteries may be accomplished with highly reliable thermoelectric heating and cooling, which simultaneously assures maximum life and performance.

Environmentally Sealed Power Modules

The ESPMs pictured in Figure 6 are part of an extended life test being performed at TDI, which has been operating continuously for over 14 months, through the environmental extremes of a New Jersey winter and summer season. Note the sunshades over the environmentally sealed power modules.

These environmentally sealed power modules (ESPMs) employ an encapsulating material to carry heat from irregularly shaped internal components to their external heat sink. For lower power units, a thermally conductive silicone RTV potting is used, while higher power units take advantage of environmentally friendly, vegetable-based oil. Encapsulating material for these units has been carefully chosen to provide thermal conduction, component and material compatibility, and the ability to diagnose and repair defective units. Thermally conductive oil is used on higher power units due to its superior heat conduction parameters as temperatures increase, which results from oil's ability to circulate.

The thermal conductivity of a solid encapsulating material is constant and independent of the power it encloses, whereas oil shows increasing thermal conductivity as the enclosed power increases due to convection currents being formed in the oil as it heats up (Figure 7).

Both encapsulating materials provide compatibility with operation in temperature extremes in excess of the -30° to +45° C and maximum internal temperatures expected during full load operation (up to 100° C). They also provide the added benefit of vibration hardening.

A good example of where the elimination of power conversion heat load from system cooling requirements provides significant improvements in cost and reliability is in remotely located DC uninterruptible power nodes.

Many WIMAX nodes require a local battery plant to provide continued operation in the event of a utility power failure. These systems generally require that 200-700 watts of power be maintained for several hours, resulting in a battery plant the size of a suitcase. The charger that maintains these batteries may dissipate up to 70W. Since optimal battery life is achieved when battery temperature is maintained well below 45° C, isolating the power supply from the battery compartment improves battery performance.

With an environmentally sealed rectifier, as shown in Figure 8, power conversion heat can be removed from the battery compartment, leaving only the self-losses of the batteries to be cooled. This allows the use of either typical convection cooling for the battery compartment or highly reliable, solid-state thermoelectric coolers.

The use of a sealed module in this example precludes the need for a 500-1000 BTU air-conditioner, which would typically cost several hundred dollars, reduce reliability and complicate system maintenance.

Environmentally sealed or hardened power modules present the system designer with the opportunity to reduce costs and increase system reliability. New-generation packaging techniques leverage existing high-reliability power circuits, thus enabling optimization of electronic systems targeted toward outdoor and other severe environments.

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