

ENVIRONMENTALLY SEALED POWER MODULES

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EXECUTIVE SUMMARY

Modern Electronic Systems are increasingly being applied in outdoor, non-sheltered or semi-sheltered environments. Special measures must be taken in the design and construction of electronic assemblies in these environments to assure optimal reliability. Power conversion equipment presents unique challenges with this regard due to high electrical, thermal and vibration stresses, and the large, irregular shaped components unique to their design.

TDI has developed several alternative equipment design and construction techniques for highly reliable power conversion, compatible with increasing environmental stress levels. The availability of this type of equipment opens up new alternatives for system cost and reliability optimization.

ABOUT THE AUTHORS



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Gary Mulcahy is CEO of Power Products and Programs within TDI. He received his BE-EE from New York University followed by graduate study at the Polytechnic Institute of New York. Mr. Mulcahy is a recognized authority in power conversion technology and the design, development and production of power systems for maximum performance and reliability with minimal life cycle cost of ownership.



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Kelly Atkinson is the Director of Business Development in the US for TDI. He received his BSEE from the New Jersey Institute of Technology. Mr. Atkinson began his career in semiconductor test engineering and has since served in various roles in the power industry, including sales engineering, program management, and business development. Mr. Atkinson has also spent four years as an instructor in the electrical engineering program at Middlesex County College.

INTRODUCTION

Electronic data acquisition, communication, processing and control systems continue to expand their presence in both industrial and day-to-day activities. Along with increasing performance and capability, modern electronic data processing technology has also enabled reductions in size and cost of these systems, and has opened the opportunity for their location in areas normally considered inhospitable to electronic equipment.

It is not unusual to find high-end electronic equipment in non-traditional environments. For example, the advent of WIMAX technology has seen smaller, lighter data transmission and processing equipment at power levels of 500 to 1000 watts located in mast, pole or roof-mounted enclosures. Figure 1 shows a system mounted approximately half way up a communications tower after a winter blizzard.



Figure 1: Communications System in Severe Environment

Electric and hybrid vehicles are also demanding on-board power conversion, energy storage and control equipment, which must function in severe weather and vibration environments. Modern industrial applications require increased bandwidth, data retrieval and processing requirements in severe environmental locations, such as heavy industry factory floors, energy generation platforms, and chemical environments.

CHALLENGES TO POWER CONVERSION CIRCUITS IN UNCONTROLLED ENVIRONMENTS

Power conversion equipment is unique in that it generally absorbs stresses from a number of different factors, such as voltage gradients, high current densities, energy storage, high temperature, and heavy, irregular shaped components. As power conversion equipment operation is moved away from sheltered areas, these factors will combine to reduce reliability, as follows.

INSULATION COMPROMISE

Most modern electronic applications requiring more than a few hundred watts utilize forced air as their preferred cooling mechanism. A typical solid state, switching power supply operating under ideal conditions has its operating life ultimately limited by 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, as illustrated in Figure 2, insulation compromise due to infused dust, debris, and vermin is the number one cause of premature power supply failure.

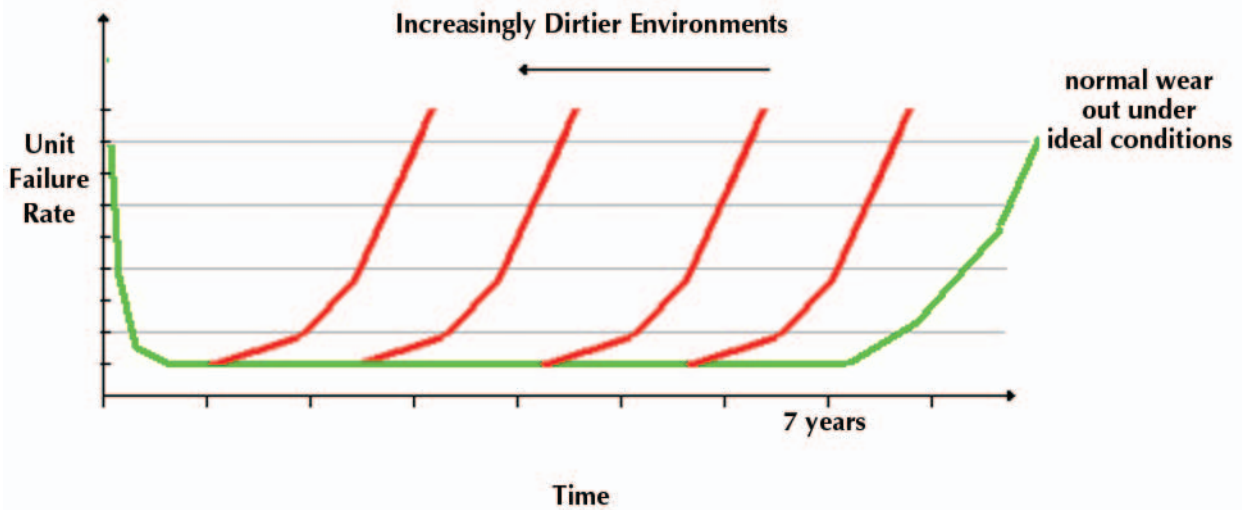


Figure 2: Effects of Infused Material on Operating Life

Even in relatively clean and climate-controlled environments, dust and other potentially conductive debris will be infused into the unit over time. Figure 3 illustrates this phenomenon, showing a unit that was returned for service after approximately two years of operation in a dusty computer room environment.

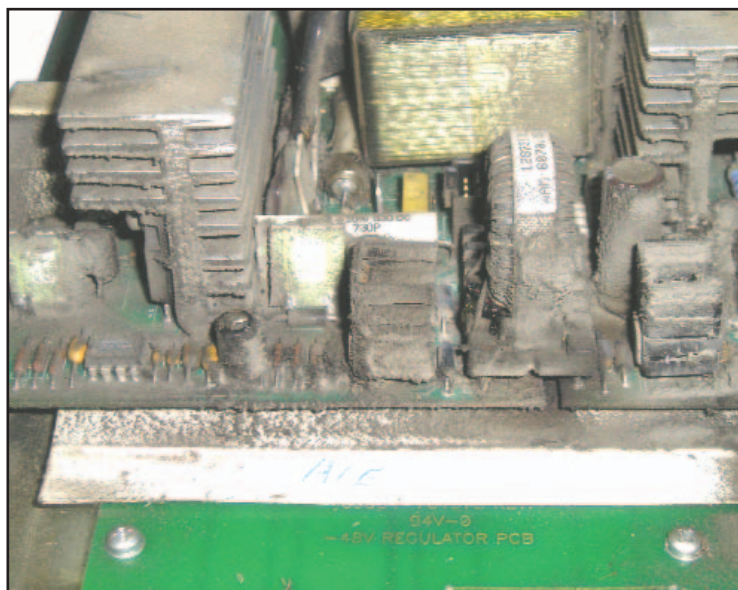


Figure 3: Dust build up in data processing application

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 contaminants 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 4 shows a photograph of a dendrite growing between two PC board traces.

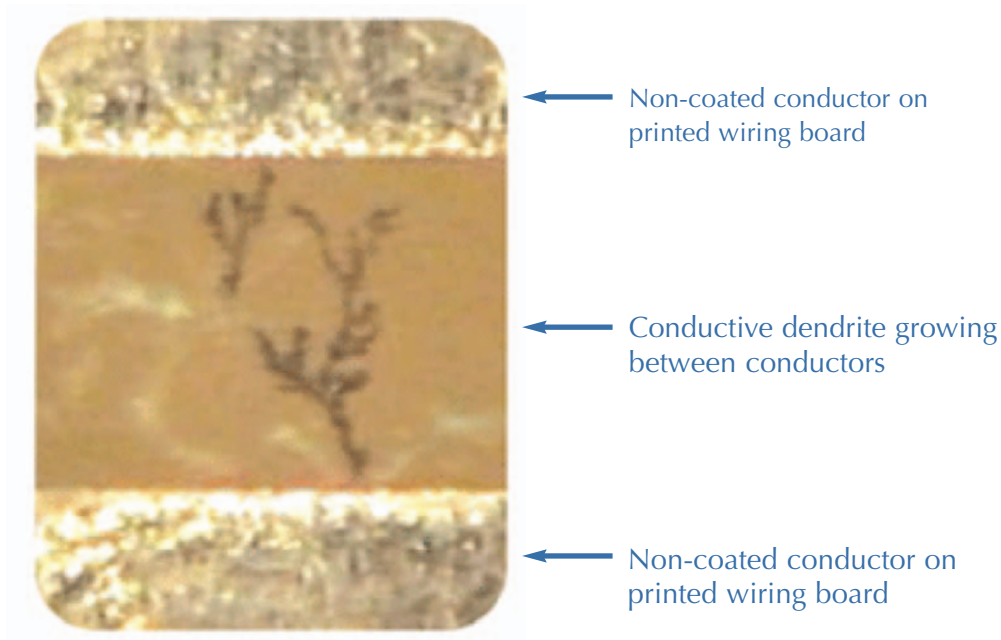


Figure 4: Dendrite (magnified) growing between two traces on PC Board

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.

Transistor Devices has concluded that best practice is to conformal coat printed wiring boards with a thin acrylic coating, such as Chase Specialty Coatings HumiSeal™, for computer or control room products.

As equipment is moved outdoors, atmospheric elements become more stressful. Infused sand or grit (such as 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 nearby the ocean, salt fog penetration will accelerate metal corrosion, as well as provide a rich mixture of ions to promote dendrite growth.

Fan bearings may also be adversely affected by any of these conditions.

TEMPERATURE

A typical computer or control room environment normally provides a temperature-controlled environment in the range of 15-35°C (59-95°F). Under unusual circumstances, such as an air conditioner or heating system failure, ambient operating temperature may be more severe, usually only for a short period of time. Power supplies deployed in this 25°C, nominal, environment are typically rated at 40 to 50°C maximum. Failure rates of electronic equipment typically double for every 10°C of increased operating temperature, and the realized reliability of power equipment is generally two to four times better than if it were running at maximum temperature.

Outdoor equipment, on the other hand, must withstand the rigors of the climate it is installed in, with temperature extremes as low as -30°C (-22°F) and as high as 45°C (113°F). Solar loading effects can increase the effective operating temperature by another 20 to 30°C. Figure 5 presents a typical solar loading test environment, where additional heat is injected into the system's surface via heat lamps.



Figure 5: Solar loading test on system intended for outdoor installation

Cabinet-level cooling or heating is generally provided to electronic systems in these environments. Methods available for cabinet cooling include air-to-air heat exchangers, air-to-liquid heat exchangers, solid-state thermo-electric coolers, and compressor driven air-conditioning.

Air-to-air heat exchangers provide reliable long-term operation, but by definition, the system operating temperature will be higher than the external ambient. Thus, if a system is to be deployed in an ambient of 45°C, and if solar loading is added, it is quite possible to have the ambient in the electronic equipment at 70°C, or above.

Liquid-to-air heat exchangers can remove much more heat, but require a source of cooling liquid to carry the heat away. Thermo-electric coolers also present an attractive method of dissipating heat, but they are generally only practical up to power levels of 100W.

Compressor derived air-conditioning equipment is generally less reliable than solid-state electronics. Experience has shown air conditioners are among the most problematic elements of outdoor systems, and problems increase with the heat load presented to the air conditioner.

Air conditioners generally cycle in a “bang-bang” mode of operation, where their compressor alternately delivers maximum cooling, or is turned off. The resulting ambient temperature presented to the cooled system will cycle about some average, with significant high to low temperature deviations. Competing air streams from the system air conditioner and equipment cooling fans can complicate matters further, with the end effect being decreased reliability of system elements. This is especially true with fan-cooled power modules, as they generally take the form of long, rectangular shaped tubes that are particularly vulnerable to opposing air streams.

When taken all together, it is not unusual for failure rates of fan-cooled power supplies to increase four to eight times from the temperature variations presented in small outdoor systems.

VIBRATION

Most office or computer room equipment is designed to withstand operational stress resulting from nearby machinery such as blowers, air conditioners, etc. which generally produce somewhere less than 2 to 3 G's of acceleration at frequencies in the 200 to 2000-Hz range. Outdoor installations may experience significant acceleration at lower frequencies due to the effects of wind, passing traffic, mounting mast movement, etc. As power supplies tend to have fairly heavy components, such as transformers, inductors and relays, special care must be taken to secure these against the effects of long-term vibration stress.

INPUT POWER QUALITY

Power line transients are a source of many equipment reliability issues. These may take the form of very short, high voltage transients (on the order of thousands of volts for hundreds of micro-seconds in duration) resulting from lightning strikes or inductive kicks after the removal of a parallel short circuit. Likewise, longer-term voltage swells (hundreds of volts for hundreds of milliseconds) can result from parallel load transients. Other loads connected in parallel to the subject system may also cause voltage sags (brown out - either momentary or long-term). In addition, power generator or transmission system events can cause power interruptions, which can be a few milliseconds, or in the event of a black out, last for days.

Outdoor equipment usually has little buffering between it and external utility power lines. As such, good practice is to provide peak voltage clamping in the form of surge arrestors (metal-oxide varistors, gas tube surge arrestors, or both) connected near or in the equipment. Power conversion equipment should be designed to handle longer-term swells and brown outs. For example, equipment powered from a 220VAC power line should be qualified to support an operating range of 187 to 300VAC to assure best reliability. Special attention should be paid to any power line fusing since input currents will rise as voltage decreases in most systems.

Many systems must also operate in an uninterruptible fashion, regardless of power line conditions. Energy storage is generally accomplished with lead-acid batteries that are co-located with the electronics equipment. Lead-acid batteries present additional challenges to system reliability regarding temperature control, since their expected life and failure rate are very sensitive to operating and storage temperatures.

Environmentally Sealed Power



Outdoor Cabinet with two 2700W Convection Cooled Environmentally Sealed Power Modules mounted on the side with sunshade.

ENVIRONMENTALLY SEALED POWER MODULES

**Indoor/Outdoor
Convection Cooled,
Watertight, Submersible,
Dust tight, Sleet Resistant,
Corrosion Resistant,
Hazardous Locations Proof**

Modules may be mounted on a telecom tower, a rooftop, or a marine drilling platform or exposed to the sand and dust of the desert with only a sunshade or in the corrosive atmosphere of a chemical factory.

For All Environments



HIGH-POWER, AIRBORNE INVERTER

- Input: 270Vdc (200 – 450Vdc)
- Output: 115Vac, 400Hz, 3 Phase Wye
- Power Rating: 7.5kVA Nominal
(10kVA for 30 Minutes)
- Efficiency: 87% Minimum (Half to Full Load)
- Total Harmonic Distortion: <2%
- Weight: 60 Pounds (27.72 kg)
- Dimensions: Wide x High x Deep
8"(20.32cm) x 13"(33.02cm) x 18"(45.72cm)
- Operating Temperature: -54°C to +71°C
- Qualified to MIL-STD-461E (EMI)
- Qualified to MIL-STD-810F
(Including Rain, Pressure Wash, Blowing Sand)



STRATEGIES TO ADDRESS SEVERE ENVIRONMENT CONDITIONS

As discussed earlier, electronic equipment reliability suffers as its operation environment moves from indoor toward an uncontrolled outdoor environment.

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 utilize fan-cooled power conversion equipment that is hardened against the effects of humidity, moderate salt-fog, dust and grit. Transistor Devices has developed products that utilize a 2 to 3mm 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 6.

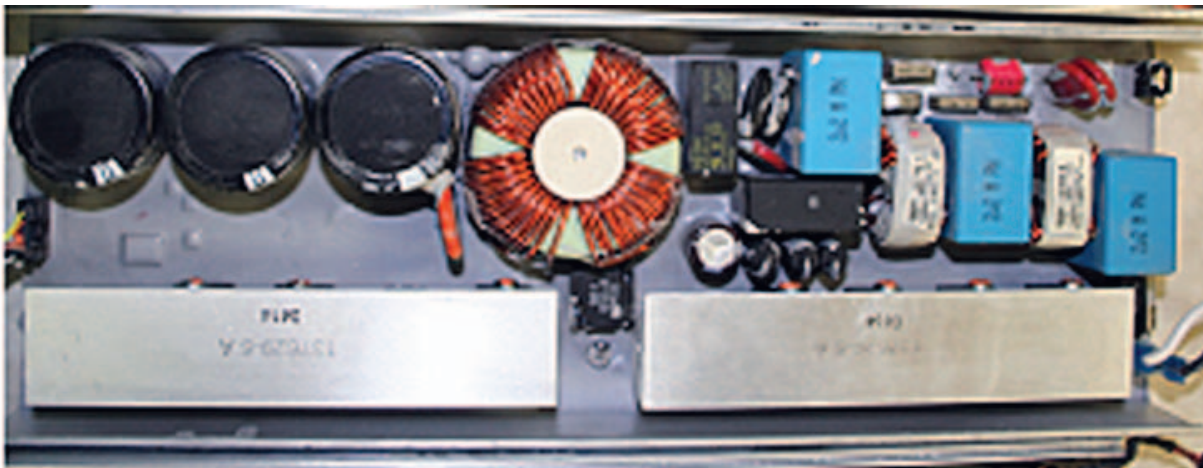


Figure 6: Environmentally hardened air-cooled power supply sub-assembly

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 thermo-electric heating and cooling which, simultaneously assures maximum life and performance.

ENVIRONMENTALLY SEALED POWER MODULES

Figure 7 presents members of a series of environmentally sealed power modules that TDI has developed.

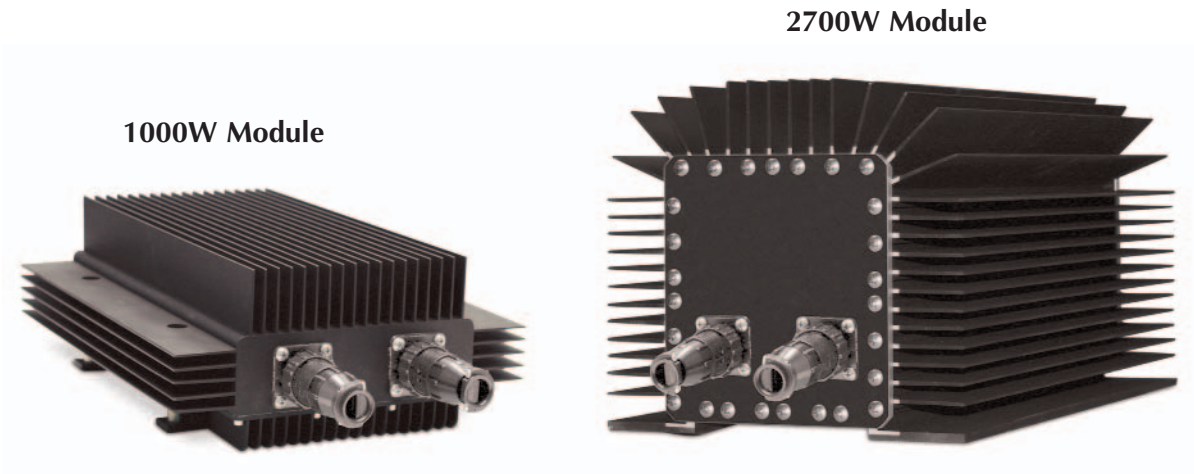


Figure 7: Environmentally sealed, natural convection cooled power modules

The ESPM modules pictured in Figure 8 are part of an extended life test being performed at TDI which have been operating continuously for over 14 months, through the environmental extremes of a New Jersey winter and summer season. Please note the sunshades over the environmentally sealed power modules.



Figure 8: Environmentally sealed modules deployed as part of a system

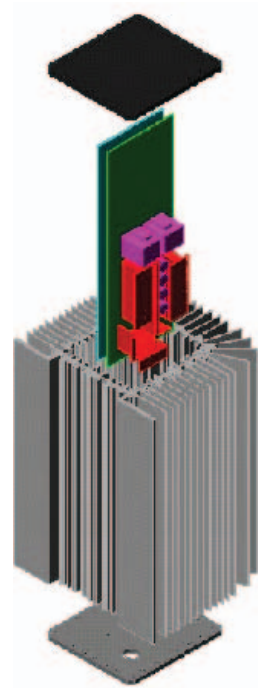


Figure 9: Environmentally sealed unit exploded assembly view

These environmentally sealed power modules (ESPM) 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 utilized, while environmentally friendly, vegetable based oil is utilized on higher power units. Figure 9 presents a typical assembly breakout for these units.

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.

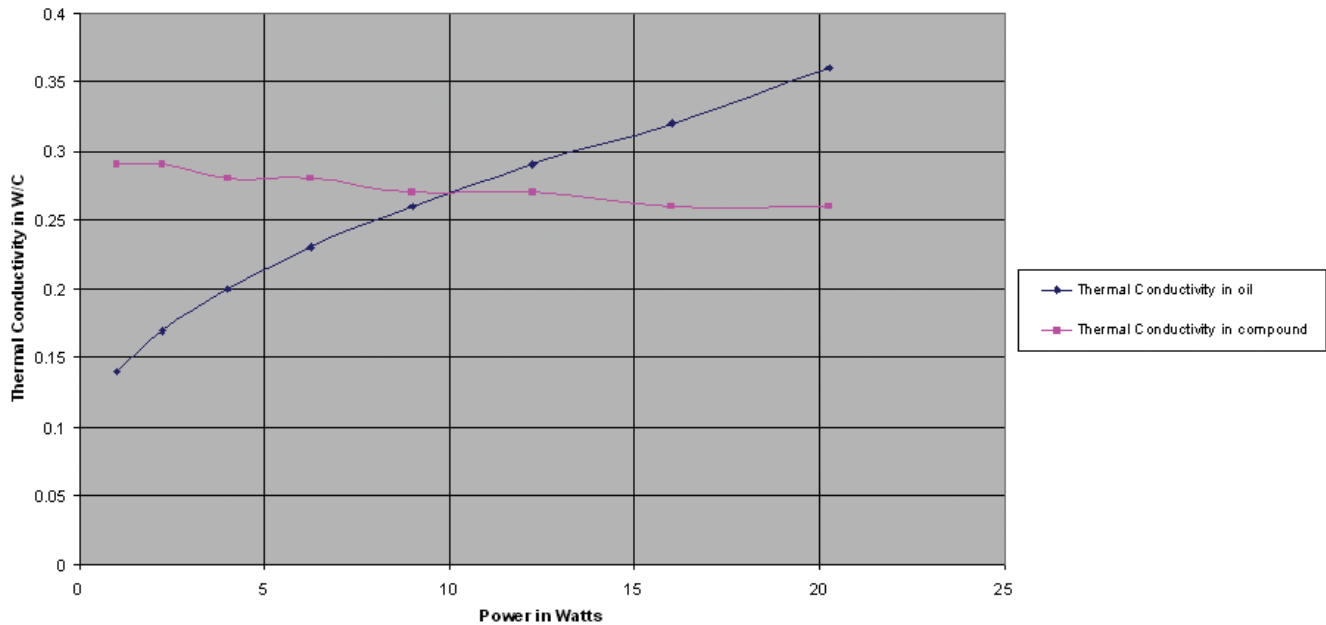


Figure 10: Comparison of thermal conductivity of RTV versus Oil

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 (see Figure 10).

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

A good example where 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 500-1000 watts of power be maintained for several hours, resulting in a battery plant the size of a suitcase. The battery charger that maintains these batteries will dissipate somewhere around 50 to 100W. Optimal battery life is achieved when battery temperature is maintained to be well below 45°C. Thus, if a forced-air cooled power supply normally intended for a sheltered environment is co-located in the battery compartment; a significant cooling challenge will be presented.

With an environmentally sealed rectifier, power conversion heat can be isolated from the battery compartment, leaving only the self-losses of the batteries to be cooled (well under 100W). This allows the use of either normal convection cooling for the battery compartment (if the external ambient is not too severe), or the use of highly reliable, solid-state thermo-electric coolers. Figure 11 shows a remote DC uninterruptible power system that utilizes an environmentally sealed rectifier.

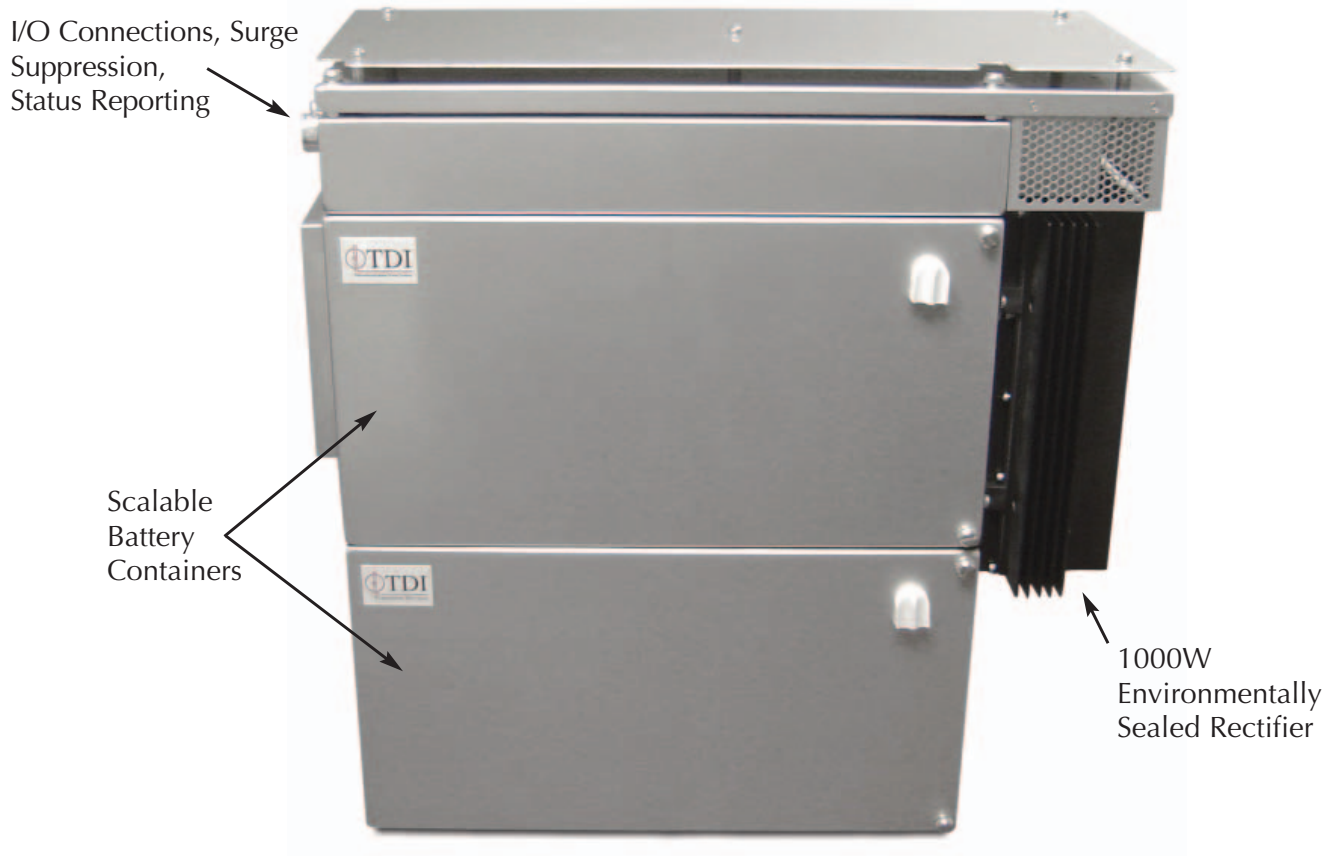


Figure 11: TDI's "Network Edge" Uninterruptible Power System

The use of an environmentally sealed power module in this unit avoided the need for a 1000-BTU air conditioner, which would typically cost several hundred dollars and reduce reliability and life. The environmentally sealed rectifier eliminates the need for an air conditioner, saving hundreds of dollars, and assures reliable, long-term, maintenance-free operation.

CONCLUSION

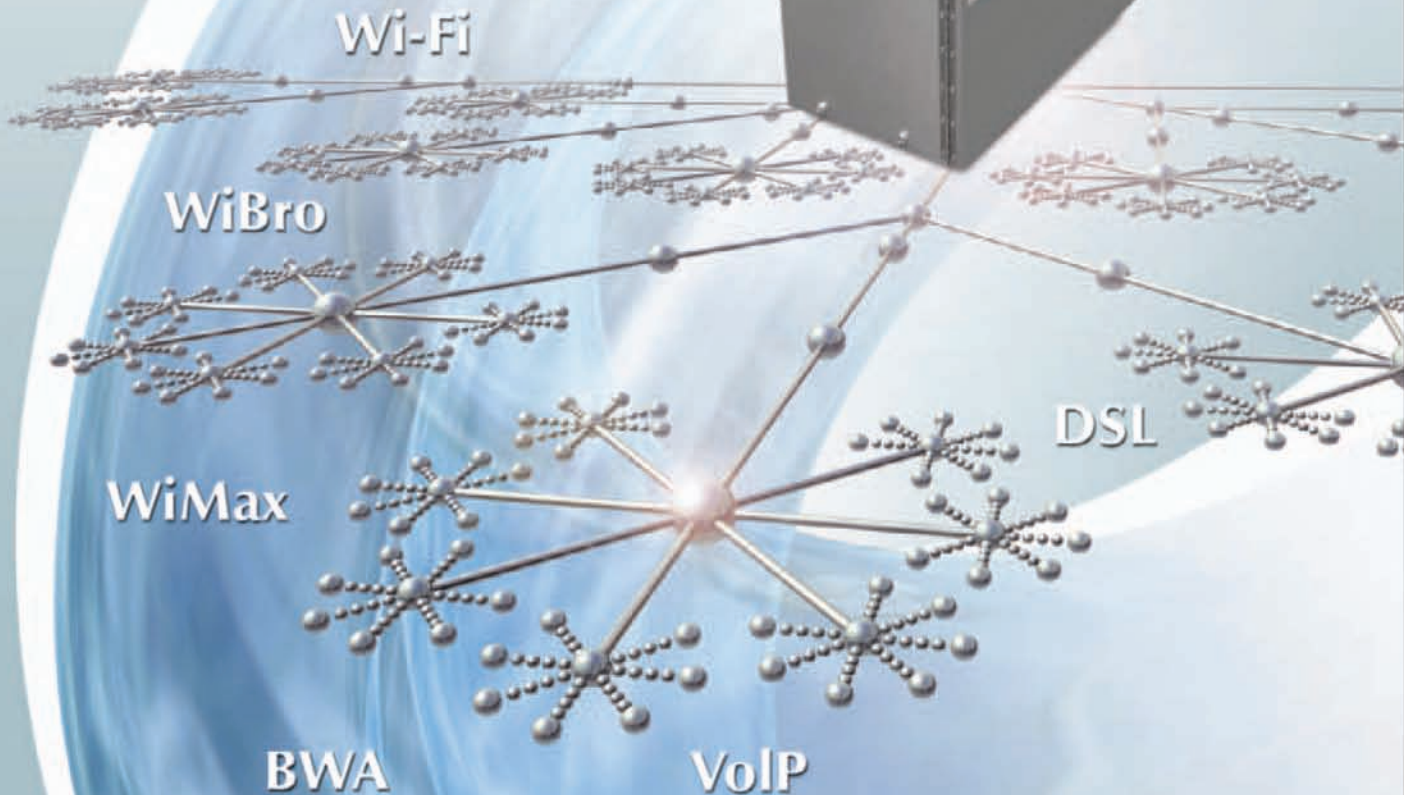
Environmentally sealed or hardened power modules present the system designer with the opportunity to reduce costs and increase system reliability. New generation packaging techniques leverage existing, high-reliability power circuits, thus enabling optimization of electronic systems targeted toward outdoor,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



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