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Component Reliability Standards at 100ºC+ Will Benefit the Alternative Energy Market: Solar & Wind Inverters, Geothermal Drilling and Hybrid Vehicles

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Abstract

This paper presents ongoing work within the Sandia National Laboratories, Geothermal Research Department to create a set of guild lines for reliability testing of high-temperature electronic components and sensors. This effort is directed at new electronic components (SiC, GaN, SOI and SOS) which can reduce energy loss in power electronics by 25 to 50% while operating reliably for many years at elevated temperatures. By operating at elevated temperatures, new power circuits can reduce thermal management concerns and increase energy density. The reduction in thermal management requirements can reduce system size, increase reliability (in some cases) and reduce total operating cost of the final product.

Discussion is given on alternative energy applications needing reliable high-temperature electronics in photovoltaics and geothermal power production. A table is given listing basic the requirement of similar applications with the aircraft, deep natural gas wells and automotive industries. In general, future electronic control systems operating at junction temperatures of 125 to 350ºC are discussed.

Introduction

New electronic devices are taking advantage of Silicon-On-Insulator (SOI) and SiC (Silicon Carbide) technologies to enable reliable high-temperature electronics. These components are opening the doors for higher temperatures control systems and increased efficiency for power hungry applications such as power converters, inverters and motor controls.

However, high-temperature control systems (for example: automotive and aircraft engines controls) require a complete solution utilizing sensors, both active and passive electronic devices and associated packaging. These applications also require proven reliable operation over an extended operating life of years!! This is a major undertaking requiring a community of electronic component manufacturers feeding components and materials into a wide range of applications needed to build market volumes.

An effort within the SAE (Society of Automotive Engineers) has started an HTEP (High-Temperature Electronics Panel) to establish a commend set of high-temperature electronic standards. The table below was created following the 2006, SAE Power Electronics Conference.

Table of General Industry Requirements	Oil and gas wells			Automotive	Electric utility systems	Geothermal wells		Commercial aircraft		AC Photovoltaic Modules
	MWD	Logging tools	Smart wells			MWD	Logging tools	Engine controls	Power electronics	
Operating temp range typ.	30C-175C	30C-175C	+150C	+135C - +180C	-40C - +200C	+225C	+300C	-55C-+225C	-55C - +350C	-20C to +100C
Operating temp range max.	30C-225C	30C-225C	30C-200C			+325C	+325C			-60C to +135C
Survival temp range						+350C	+350C			+150C
Operational vibration	Sine 30g peak, 50 to 800 Hz Random 20g rms, 10 to 500 Hz	Sine 30g peak, 50 to 800 Hz Random 20g rms, 10 to 500 Hz	Ground transportation only			Same as oil & gas	Same as oil & gas			Ground transportation only, none after installation
Operational shock	70C to 225C: 400g, 0.5 msec, half sine -40C to 70C: 1,000g, 0.5 msec, half sine	70C to 225C: 400g, 0.5 msec, half sine -40C to 70C: 1,000g, 0.5 msec, half sine				Same as oil & gas	Same as oil & gas			limited (perhaps +/- 20C/minute at the extreme)
Survival shock	70C to 225C: 1,000g, 0.5 msec, half sine -40C to 70C: 2,000g, 0.5 msec, half sine	70C to 225C: 1,000g, 0.5 msec, half sine -40C to 70C: 2,000g, 0.5 msec, half sine				Same as oil & gas	Same as oil & gas			same
Lifetime	250hrs @ +150C	5yrs @+150C	3-7 years currently	10,000hrs	>10 yrs	1,000hrs @+325	1,000hrs @+325	30,000 to 80,000 hours	5 yrs	>20 yrs
Misc			15-30 yrs for future						Extensive thermal cycling	Cost >= $0.30/W
Notes	1,000 hrs @ +225C will satisfy 98% of the market				Up to 20KV devices			Very high reliability with graceful failures		

Alternative Energy Applications

<u>Photovoltaics</u>

Another application that could benefit from development of high-temperature electronics is power electronics for photovoltaics (PV), particularly so-called "microinverters" that would be installed on the back of PV modules to form an AC module. Improvements in inverter technology are critical to maintaining the downward trend in PV's life-cycle cost of energy (LCOE). Today's inverters are generally one of two types: a central inverter (Figure 1a), in which all of the PV power flows through a single inverter; or a string inverter (Figure 1b), in which each series string of PV modules has its own inverter. There are three significant problems with today's PV inverters.

a.) They require a significant amount of PV expertise during system design, installation and commissioning. Errors in these stages are leading causes of loss of PV energy production in the field.

b.) Central inverters maximize the number of DC components and amount of DC wiring, and require extensive on-site setup, and string inverters do not entirely solve this problem.

c.) Their reliability continues to be too low, especially that of single-phase inverters, although reliability has improved. Shortening of component and assembly lifetimes due to elevated operating temperatures is a key reliability limiting factor.

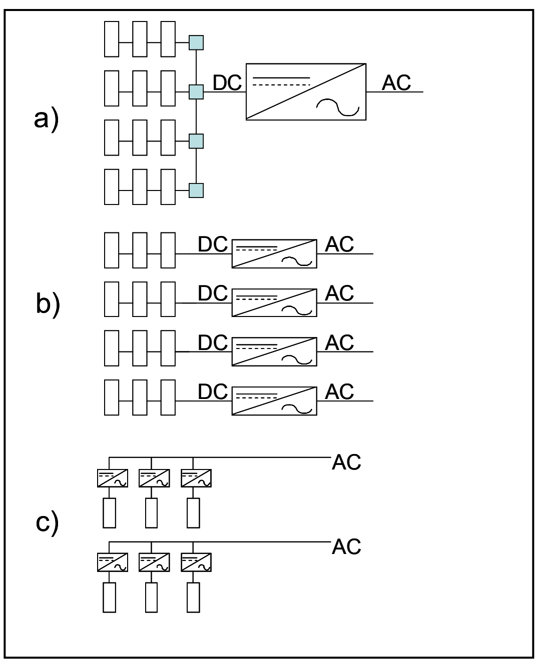

Figure 1: Inverters schemes: A) a central inverter, B) a string inverter, C) a microinverter

The first two problems can be solved entirely by microinverters, which would be integrated into the PV modules to produce AC modules (Figure 1c). There would be no DC wiring, no setup, and no programming on site. Any qualified electrician would be able to install a PV system without errors. There would also be:

- ☐ reduced maximum power point tracking (MPPT) error;
- ☐ reduced power loss due to differential irradiation;

- ☐ greatly enhanced modularity; and
- ☐ potentially, improved reliability through redundancy.

PV microinverters could be installed on rooftops, and will be in close proximity to their modules, all of which results in a high operating temperature environment. Ambient air temperatures of as much as 50^{o}C are possible. PV modules will typically operate at 40^{o}C or so above ambient, and the power electronics could be as much as 20^{o}C above that. Adding some conservative “fudge factors” to account for poor airflow and packaging factors leads to an operating temperature specification of approximately 130^{o}C for microinverters. In addition, PV module lifetimes can be well in excess of 20 years, and thus a 20-year operating lifetime for the microinverter is desired.

In order to achieve the desired reliability, advanced materials, high-quality packaging and manufacturing, and a reasonably high degree of built-in intelligence will all be required. However, all of this must be achieved at low cost—on the order of $0.30/W. This represents an extreme challenge, and the cost/reliability tradeoff is the reason why previous microinverter efforts have failed to gain a market foothold. It is likely that the only way to simultaneously get improved reliability and capability at reduced cost is through massive standardization, which will allow the reaping the benefits of manufacturing economies of scale. That is achievable with AC modules, in which case the number of inverters made would equal (or exceed, depending on module size) the number of PV modules made. Also, the hardware designed could be used in other applications, including other power applications such as “AC batteries”, or automotive applications.

Geothermal Power

Geothermal is the act of mining the earth’s natural energy. In general, the earth has a molten center with a rock outer layer. The most common form of geothermal is taking advantage of underground natural reservoirs where ground water is being heated by very high earth temperature gradients found near earth faults. Today approximate 4% of California and Nevada electric power comes from discovered natural geothermal resources.

Figure 2. A geothermal test well under testing.

Potentially, geothermal reservoirs could be man made! Due to the natural earth temperature gradients, geothermal temperatures (+180C) can be reached between 17,000 and 35,000 ft. At these depths water can be critically heated enabling electrical power plant operation. In this case, the water could be injected within man made factures utilizing a common hydraulic fracturing process developed by the fossil energy industry to increase oil or natural gas production. These man made fractures can extend 1000s of feet outward from the well.

The primary issue with increasing geothermal power product is the cost of drilling wells. In fact, approximately ¼ or more of the cost of a geothermal power plant is tied up in well construction. Just imagine for a second what drilling with a 6 inch pipe, 5 miles long means.

Twenty thousand feet of pipe is very flexible. The drilling operator can no longer feel the bit cutting the rock. The drilling industry uses MWD (Measurement-While-Drilling) tools, located behind the drill bit, to monitor the drilling activities.

To reduce geothermal drilling costs, electronic systems used by the fossil energy industry need to be converted for operation at geothermal temperatures. In general, geothermal temperatures run from 180C to 325ºC. These tools require new high-temperature electronics and sensors. These tools are placed behind the drilling bit and are subject to high-temperatures, high vibration and high pressures. So the reliability is critical to market success. A failure can cost two days of drilling time as 20,000+ feet of pipe must be removed and reinstalled to replace a failed MWD tool, costing $1000s.

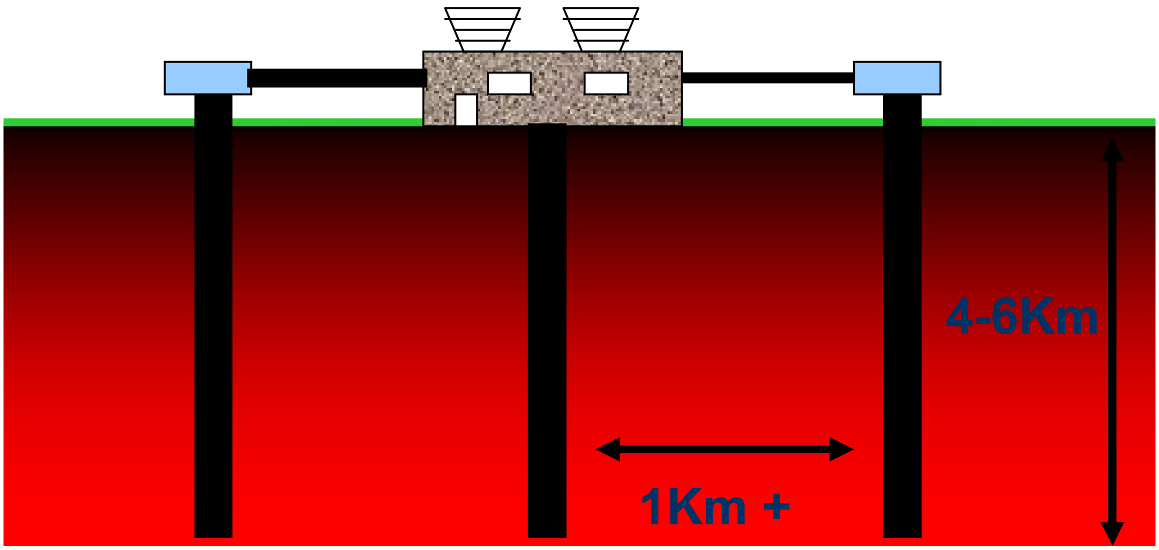

Figure 3. A illustration of a geothermal power plant.

To date, Sandia National Laboratories has demonstrated 300ºC well logging tool electronics and 225ºC well drilling tools. Work is still needed to increase the number of high-temperature SOI and SiC electronic devices and improve electronic packaging for the combination of high-temperatures and vibration / shock.

The only means to increase the number of high-temperature, high reliability electronic components is to grow the market size. Only through research are packaging problems going to be resolved. A common set of industry standards can aid in both of these activities. The component manufacturer needs to understand the future market while the researcher needs to understand the market requirements.

The SAE – AE 7 (Society of Automotive Engineers – Aerospace Electronics 7) has formed a panel called High-Temperature Electronics Panel (HTEP) looking at creating a cross industry standard for reliable HT electronics. The goal is to define a simple set of electronic component requirements to aid in unifying the aircraft, automotive, power inverter/converter and drilling industries to increase the market.

The next meeting of the SAE – AE 7, HTEP meeting is planned for April 24 - 26, 2007, Toulouse, France.

Conclusion

New electronic devices are taking advantage of Silicon-On-Insulator (SOI) and SiC (Silicon Carbide) technologies to enable reliable high-temperature electronics with improved energy efficiencies.

These new devices will enable new energy saving applications; enhance the viability of new solar energy systems and create deep geothermal resources. Sandia is working to demonstrate this new technology and aid in creating testing standards.

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