MaRS Market Insights

Critical Factors and Opportunities in Solar Power Electronics:
Perspectives from Ontario industry players

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Clemens van Zeyl, CEO and Co-Founder, ARDA Power

Praveen Jain, CEO, SPARQ Systems Inc.

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Introduction

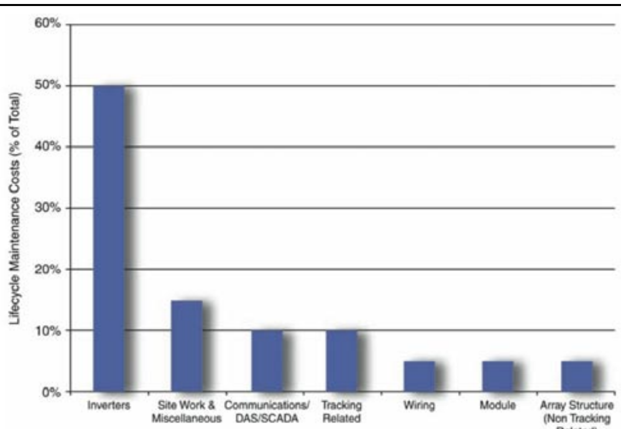
Photovoltaic balance of system (BOS) components are essential to the successful functioning of a photovoltaic (PV) solar power system. Together these components encompass all aspects of the solar power system aside from the PV modules, enabling operations, providing safety, managing storage and optimizing performance.[i]

But although BOS components perform critical roles, they presently account for half of the system costs and most of the system maintenance, and therefore are creating a barrier to the adoption of PV systems. To maintain the successful operation of an installation, project engineers must learn the failure mechanisms of each BOS component, including those of new products now being developed for PV power electronics, which costs their companies valuable time as well as money.

Project developers have identified the inverter as having the most serious reliability issues of all BOS components. In the figure below, SunPower Corporation identifies inverters as the most costly component in the system, and the main cause of unexpected PV plant downtime.[ii]

Figure 1

A breakdown of total lifecycle PV plant maintenance costs for SunPower's managed PV fleet



Source: SunPower Corporation

As the solar energy market evolves, the reliability of PV components will become increasingly important. This paper examines this issue through interviews with PV industry experts, who provide an overview of inverter and other sub-component failures and explain some of the reasons for these problems. They also discuss key performance parameters and opportunities for established and new players to improve system reliability and performance. Lastly, this paper spotlights two Ontario start-ups and the innovations they bring to the sector.

Power electronics performance: A project-developer perspective

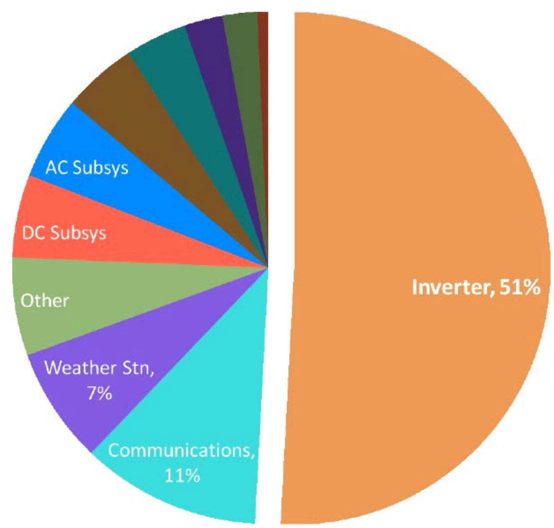
With 450 operational sites to date, solar integrator company SunEdison has a track record of power-systems innovation. The company analyzes their own operational systems with the goal of reducing the delivered cost of electricity and improving their product's reliability. We interviewed Dr. Tassos Golnas, Senior Manager, Energy Analytics, to learn more about opportunities in the power-electronics sector.

Subsystem failures: Root causes and lifecycle costs

SunEdison monitors hundreds of projects that produce more than 230 MWp around the world (USA, Canada, Italy, Spain and India). The following figure illustrates the frequency of failures per affected subsystem that SunEdison reported from 2008 to 2010.

Figure 2

Frequency of failures per affected subsystem, SunEdison, 2008–2010



Source: SunEdison. (2011, January). *Owner/Operator Perspective on Reliability Customer Needs and Field Data.*

Golnas, speaking about the reasons for such failures and the impact potential downtime had on their lifecycle costs, says, *"51% of the failures manifested at the inverter—they were not necessarily caused by the inverter."* He emphasizes that inverter problems can be either hardware- or software-based. While software issues and some hardware issues can usually be fixed within 24 hours, certain hardware failures require replacement parts to be shipped and then installed, resulting in a longer period of downtime. Golnas observes that tighter quality controls across the supply chain and more realistic testing methodologies can help avert these types of hardware failures, but that, in his opinion, reducing software failures will require a more rigorous approach to software development and testing.

Concerning the impact of inverter failures and lifecycle costs, Golnas explains that *"Inverter failures can lead to downtime in the system where no energy can be produced. Aside from the loss in output, we also incur the service cost of the repairs. In a case where a component fails after the warranty expiration, there is the additional cost of replacing the component. As such, the value of a proper operations and maintenance system cannot be overstated in helping to alleviate the downtime caused by these kinds of inverter failures."*

He stresses that *"Knowing how your solar system is operating is really critical to achieving maximum system performance."*

Inverters: Key performance parameters

For its report, *"Shorting Out the Myths of Solar Power Electronics: What Fits and What Fails,"* Lux Research asked prominent installers and project developers around the world for their opinions of various power electronic technologies. The experts Lux interviewed identify inverters as the main point of system failures, which underscores the importance of their reliability and lifetime.[iii]

Golnas lists SunEdison's key performance parameters for inverters used in climates such as Ontario's:

- **Efficiency** — the percentage of energy from the PV modules that gets converted into grid-ready electricity
- **Reliability** — the mean time to failure or mean time between failures
- **Accessibility** — the ability to easily access the relevant inverter compartments during installation and service
- **Temperature ranges** — the maximum and minimum temperatures between which an inverter can operate at full power
- **Voltage ranges** — the maximum and minimum DC voltages between which the inverter can operate

Golnas notes that in Ontario's cooler climate, inverters have a slightly higher effective efficiency than they will in California, for example, where they will spend more time operating at their maximum range. (At the upper end of their power range, inverters lose a small amount of efficiency.) Inverters in Ontario must also be able to operate in very cold weather. The flip side, of course, is that there is no need to install cooling systems inside inverters in cool climates.

Reliability versus costs: Is there a perfect balance?

According to Golnas, *"The perfect balance of reliability and costs is the one that affords the lowest levelized cost of energy* (LCOE)*."* He explains: *"If the system is designed to 'never fail,' but is offered at a multiple of its 'standard' cost, then it is probably not worth it—reliability at any cost is not the answer because the system will not be financially viable. The total cost of ownership is the real cost to minimize and is the main driver for LCOE. So, for example, the operational costs of a system over its lifetime need to be considered. The total cost of ownership is the metric which uses as the numerator both the upfront cost and the maintenance and puts in as the denominator the energy a system produces during its lifetime. Together they provide a more accurate reflection of the system's value."*

> "The LCOE equation is an evaluation of the lifecycle energy cost and lifecycle energy production. It allows alternative technologies to be compared when different scales of operation, investment or operating time periods exist. For example, the LCOE could be used to compare the cost of energy generated by a PV power plant with that of a fossil fuel-generating unit or another renewable technology."
>
> **Source:**
> Short, W., Packey, G., & Holt, T. (1995, March). *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies*. National Renewable Energy Laboratory.

Golnas uses the metaphor of the lifecycle cost of a house to illustrate his point. When purchasing a house, a prospective buyer needs to examine the initial costs as well as the upkeep to assess the overall outlay. While a house with a lower price tag may seem appealing, if it needs more maintenance, then accurate estimates of those costs will be needed to gauge the total price. Similarly, for a PV system, one must consider the balance between upfront costs and reliability.

The question remains: how to reflect reliability in LCOE calculations? Golnas admits that it is not easy to assess how an inverter will perform beyond the laboratory, in the real world. *"If you can't take into account data based on its reliability, then you are forced to make your decision on the system's capital cost alone. Ideally you would like a system manufacturer with a very large installed base. Data from the field provides the best description of real-life reliability. If you are looking at a new manufacturer without data or installed base, then [a purchase] is difficult to justify based on equivalent lab performance.*

Thankfully, SunEdison has a large fleet of systems that use inverter equipment from various manufacturers. Through our monitoring system we collect real-time system data which provides a good basis for the future selection of inverter technology for most types of installations."

Opportunities in subsystem performance: An inverter-manufacturer perspective

Headquartered in Calgary, Alberta, and with manufacturing facilities in Guelph, Ontario, Sustainable Energy Technologies builds solar inverters. The company exports to the US and Europe and has sold approximately 15 MW worldwide. The company reports that it has about a 10% share in the 10 kW market in Ontario.

Brent Harris is Vice President of Product Development and a co-founder of Sustainable Energy Technologies. When asked about the changes in power electronics that would significantly improve inverter performance, reliability and cost, he says: *"There are continuous improvements to power electronic components that provide incremental performance and cost benefits. I think that with continued growth of the solar industry, the component makers will start to be able to optimize their devices specifically to meet the requirements of the PV industry. At present, the PV industry is primarily using devices made for the telecommunication/IT power supply and variable speed drive industries. Regarding reliability … [it] comes down to volumes. As manufacturing volumes increase, suppliers can afford to conduct more intensive reliability testing and analysis to improve their designs. At these higher volumes, it is also possible that the control circuitry now assembled on to printed circuit boards could be compressed on to application-specific integrated circuits* (ASICs), *providing more reliable devices and likely also decreasing costs in the process."*

The industry needs to grow and rival the size of other power electronics industries and adopt their best practices, Harris concludes. He believes that efficiency, reliability and cost are the key drivers in the technology of power electronics; however, when it comes to a *particular* PV inverter product, then ease of installation matters too, since that is the concern of every installer.

Increasing a component's lifetime: Is it really necessary?

For its 2006 report, *"A Review of PV Inverter Technology Cost and Performance Projections"* (presented to the US National Renewable Energy Laboratory), Navigant Consulting interviewed multiple inverter manufacturers, and asked their opinions about the relevance of increasing a system component's lifetime. Navigant has found that manufacturers believe designing inverters to last longer than 15 years is impractical and unnecessary, and that the key consumer demand is for a lower first cost.[iv]

Manufacturers speak:

Xantrex (Managing Director): "Why make inverters with a longer life when the customer is better off replacing the inverter every 10 years or so anyway? The inverters available in ten years will be better products with higher efficiency."

SMA America (President): "Why focus on higher reliability? Our customers worry only about first cost. In any case, it's more cost-effective to just replace the inverter in 10 years."

Sustainable Energy Technologies (Director of Operations): "A 20-year lifetime for PV inverters is at least 10 years away."

Mitsubishi: "A 20+ year life for inverters is impossible. Some parts of the inverters would need to be replaced over such an extended period."

SMA (Head of Solar): "A 20-year lifetime is not possible."

Fronius (Head of Sales, Germany): "Inverter MTBF may reach 12 years by 2015. A 20-year lifetime can't be achieved."

GE Energy indicates that a 20-year life would not be practical without a significant impact on cost. A 15-year life is more reasonable, and that should be reviewed based on lifecycle costs.

Source:

Navigant Consulting. (2006, January 12). *A Review of PV Inverter Technology Cost and Performance Projections.*

Harris contends that an inverter lifetime of 20 years is achievable but that the main questions should centre on costs and why a lifetime of 20 years is considered an important target. *"How do you measure success? Overall, it is difficult to expect any electronic product to have a 'lifetime' of 20 years, although we know that many of them do last that long. Wear-out of the electrolytic capacitors is often cited as the weak point in inverter design; however, it is easy to design a product using electrolytic capacitors that will last more than 20 years on paper. The reality is that most inverter failures are due to 'events' such as voltage spikes, lightning strikes, et cetera. These are tough to model and the chances of running into one increase over time."*

Emerging technologies and markets

In its report, *"Developing a 'Next Generation' PV Inverter,"* Sandia Laboratories suggests that the objective of manufacturers should be to make reliable inverters available not only for PV, but also for fuel cells, energy storage, microturbines and other distributed energy resources. The report also highlights areas where emerging technologies can foster significant improvements toward higher reliability. These areas include:

- Interconnection
- Modularity
- DSP (digital signal processing)
- Packaging

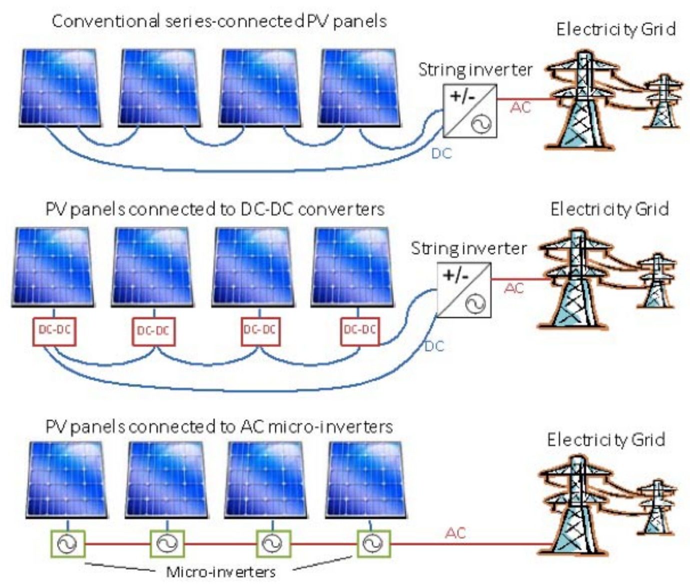
The report concludes that to succeed in developing inverters with high reliability, manufacturers must incorporate mature manufacturing processes with solid design. This would lead to inverters that could be marketed in large quantities, and the design and lessons learned could then be applied in the development of other products.[v]

Distributed power electronics and Ontario's emerging solutions

The field of distributed photovoltaic power electronics is seeing new products enter the market. This category of devices includes DC-DC converters and AC micro-inverters that either replace or work together with traditional central PV inverters, as illustrated in Figure 3.[vi] This paper highlights two such innovative products developed by Ontario companies, ARDA Power and SPARQ Systems Inc.

Figure 3

Schematic of conventional single-string PV system *(top)*, DC-DC converter-equipped PV system *(middle)* and AC micro-inverter-equipped PV system *(bottom)*.



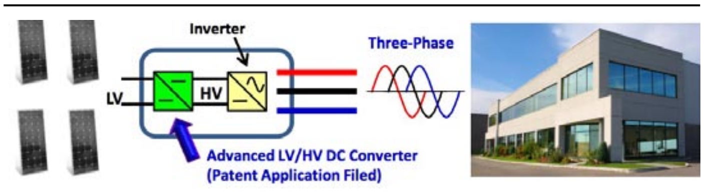
Source: NREL. (2011, January). *A Performance and Economic Analysis of Distributed Power Electronics in Photovoltaic Systems.*

Innovation in DC-DC converters: ARDA Power

ARDA Power has developed a low-cost solution to address the challenges of safety and poor energy harvesting in the commercial market for micro-inverters (miniature voltage converters). Their "Smart-Solar Solution" provides a low-voltage to high-voltage DC converter (Figure 4) that bridges the voltage gap between a low-voltage PV module and the voltage needed to power a standard three-phase inverter at 480 VAC (575 VAC in Ontario). ARDA reports that their product offers safety (due to its low-voltage feature) and increased energy harvesting.

Figure 4

Low-voltage to high-voltage DC converter ("LV/HV converter"), ARDA Power



Source: ARDA Power

DC-DC converter

"A DC-DC converter is one type of distributed power electronics that can provide an improvement in system performance. These devices are also sometimes called power optimizers or power boosters. Rather than replacing a traditional central inverter, DC-DC converters work in conjunction with a central inverter, which is still required to convert DC power to AC grid power."

Source:
National Renewable Energy Laboratory. (2011, January). *A Performance and Economic Analysis of Distributed Power Electronics in Photovoltaic Systems.*

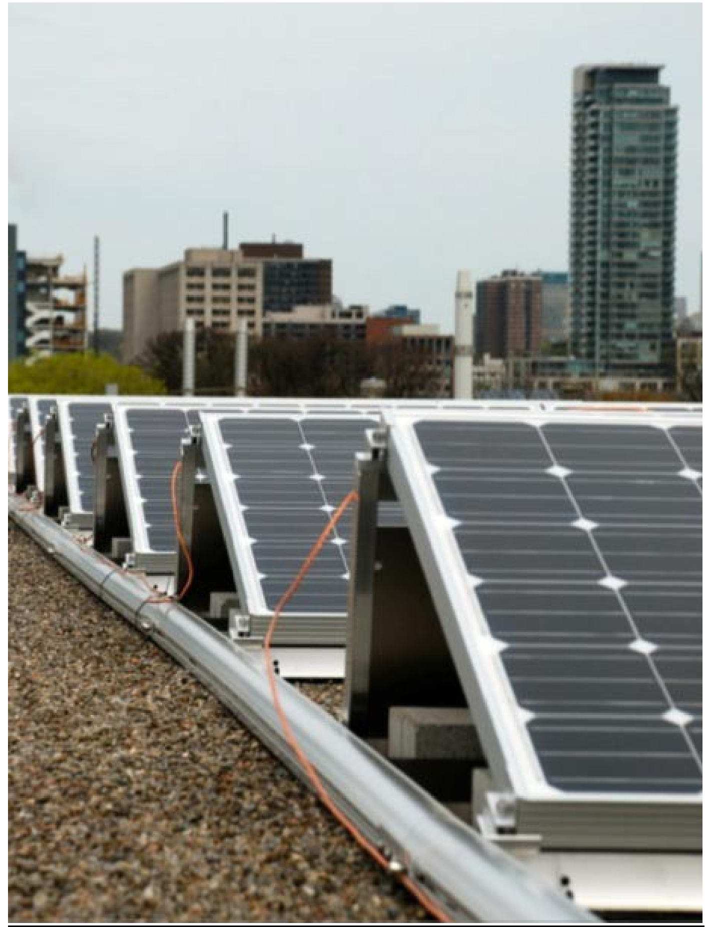
The company has teamed with Celestica to design and manufacture for reliability. Its product will use neither fans nor electrolytic capacitors—a design feature that is expected to enable power electronics to achieve a lifespan of over 20 years. The DC-DC converter was developed to meet critical targets such as optimization of cost versus energy harvesting including maximum power point tracking.

ARDA has also aligned with a strategic partner, Bonfiglioli Photovoltaic, to gain access to key markets. While it foresees little competition for its proprietary "Smart-Solar Solution" (patent pending), ARDA's main competition for commercial solar PV includes companies that produce micro-inverters, three-phase string inverters and central inverters.

Figure 5 illustrates a 4 kW rooftop installation at University of Toronto. At present, ARDA has three field demonstrations lined up (2 x 100 kW and 1 x 30 kW) for commercial rooftops. According to Clemens van Zeyl, CEO and company co-founder, *"The owners of these projects are [primarily] interested in safety, and next, higher project returns."*

Figure 5

Rooftop installation (4 kW, ARDA Power) at University of Toronto



Source: ARDA Power

Innovation in micro-inverters: SPARQ Systems Inc.

Based in Kingston, Ontario, SPARQ Systems Inc. has developednew technologies that boost the lifespan of micro-inverters (to match solar panels—that is, 25 years) and to increase the overall efficiency of solar PV systems.[vii] The company is building micro-inverters (Figure 6) that reduce solar panel size and weight and increase energy harvesting and energy efficiency under normal and partially shaded conditions (e.g., shade from the sun, snow, or dust). According to its CEO, Praveen Jain, SPARQ's patented power electronics *"employ fewer conversion stages, resonant power processing, no electrolytic capacitors, transformer isolation, very high switching frequency (>1 MHz), streamlined control techniques and web-enabled energy management software."*

Micro-inverters

"The current generation of micro-inverter products appears to be achieving greater market penetration through improved efficiency, reduced cost, increased reliability and diagnostic capabilities. AC micro-inverters are installed on each PV module, replacing the use of a central inverter. Each PV panel's DC power is converted directly to AC 120 V or 240 V and grid-tied. The output of each PV panel is therefore effectively in parallel, which eliminates power losses due to module mismatch. Thus the performance improvements that arise from independently peak-power tracking PV modules can be achieved with micro-inverters as well as with DC-DC converters."

Source:
National Renewable Energy Laboratory. (2011, January). *A Performance and Economic Analysis of Distributed Power Electronics in Photovoltaic Systems.*

At present, SPARQ is directing its marketing efforts toward the residential (<10 kW) and commercial sectors (<500 kW). The company has engineered a "plug-and-play" solution for residential customers, which will provide homeowners with a simple connection to the power grid. SPARQ plans to start shipping products in July 2011.

Figure 6
SPARQ micro-inverter

Source: SPARQ Systems Inc.

SPARQ faces competition from a number of micro-inverter manufacturers, but remains confident that it holds a competitive advantage. While other players in the market employ either a two-stage solution with an electrolytic capacitor or a three-stage solution without one, SPARQ asserts they achieve the same results using an algorithm-based approach without the need for either an electrolytic capacitor or a third stage. Jain reports their system offers high reliability and a design life of over 25 years, as well as the *"smallest size, lightest weight [and] lower bill of materials."*

Conclusion

Within the solar energy sector, project developers, manufacturers and entrepreneurs have different perspectives concerning the current state and optimum performance of power electronics. However, most agree on the following:

- The most important parameters for developers and manufacturers are reliability and cost.
- Manufacturing practices that incorporate quality-control methods are required.
- Innovations in subcomponents, as well as in packaging and installation, will enable power electronics to penetrate not only the PV sector but also other emerging markets.

We asked two of our industry leaders to identify for researchers and entrepreneurs where they see the greatest market opportunities.

With respect to selecting an Ontario vendor, Dr. Tassos Golnas of SunEdison reaffirms that while the capital cost (including the warranty cost) has traditionally been the deciding factor, the total cost of ownership, which includes the reliability of the inverter, is a more accurate metric (see the LCOE). He cites other major vendor criteria, including:

- Responsiveness
- Having established, quality systems
- Engagement in continuous-improvement procedures
- Flexibility in service agreements
- Support in communications development

When asked what the most valuable new technological alternatives for subsystems or components will be, Golnas says that for inverters, a clear opportunity exists for both component and subcomponent solutions. He explains, *"Subsystem improvement can be realized within the development framework of existing inverter manufacturers; however, disruptive innovations in the component and subcomponent might provide significant cost and/or reliability improvements."*

From the manufacturing side, Brent Harris of Sustainable Energy Technologies believes that with the growth of the small-to-mid-sized commercial rooftop sector, which he thinks will eventually dominate the market, installation costs (and installers' operating costs) will become the major area for competition and differentiation. Says Harris: *"I think the opportunity for entrepreneurs in the solar industry ... [lies] in developing packaged systems and innovative mounting techniques for specific roof types that will reduce installation time and cost. There is a real focus on finance right now as the industry gets bigger and is trying to push into mainstream markets. Once that settles out in the next couple of years, you will be able to get financing from a bank and the control of the industry will shift back to installation/construction companies."*

In conclusion, understanding and examining failures in the field of power electronics helps researchers and manufacturers to design new ways to improve product performance. Thus, collaboration between the solar industry and academia is critical for achieving performance and reliability goals. Initiatives where developers share information about system failures collected from the field and where researchers translate that information into improved methods to test reliability can be already seen with NREL's Photovoltaic Module Field Failure Database. A similar initiative in Canada—one encompassing the performance of the entire system—would boost the development of Ontario's solar industry.

Endnotes

i BCC Research. (2006, November). *Global Market for Photovoltaic Balance of System Components.*

ii Electric Power Research Institute. (2010, July). *Addressing Solar Photovoltaic Operations and Maintenance Challenges.*

iii Lux Research Inc. (2011, February). *Shorting Out the Myths of Solar Power Electronics: What Fits and What Fails.*

iv Navigant Consulting. (2006, January 12). *A Review of PV Inverter Technology Cost and Performance Projections.*

v Bonn, Russell H. (n.d.). *Developing A "Next Generation" PV Inverter.* Sandia National Laboratories. Albuquerque, NM, 87185-0753.

vi National Renewable Energy Laboratory. (2011, January). *A Performance and Economic Analysis of Distributed Power Electronics in Photovoltaic Systems.*

vii SPARQ Systems Inc. (2010). Retrieved June 22, 2011, from http://www.sparqsys.com/.