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Strengthening PV's Backbone through Inverter Innovation

The competition is fierce in the inverter market. Here's a look at recent trends, technological advancements and how the industry is working to reduce costs.

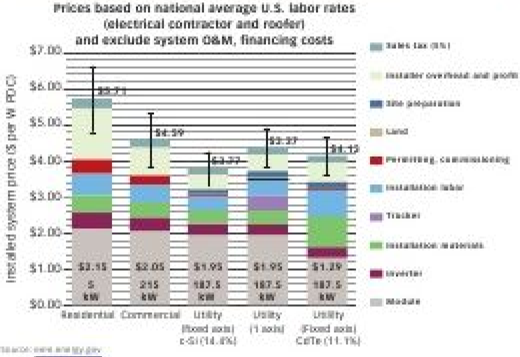
Lindsay Morris, Associate Editor, Power Energineering

In recent years, the photovoltaic market has grown rapidly in North America as a result of falling module prices and federal incentive programs. But at every PV plant, there is a secret behind the panel: a computer that makes it all happen. Throughout the solar industry, the inverter is known as the central nervous system — the backbone of the PV array.

"Integrators and developers are beginning to realize that the inverter's role is not just for converting power, but it is the 'brains' behind the entire system," said Bill Rossi, chief marketing officer for Enphase Energy.

If solar isn't transferred from DC to AC power, it cannot be connected to the grid. The inverter is responsible for the transformation of distributed energy into AC power. If the inverter isn't working, the entire PV system will go down. Not only is it perhaps the most fundamental element of the PV process, but innovations in inverters could result in smarter solar energy processes and easier implementations of solar projects.

Breakdown of PV costs Fig. 1



Source: www.energy.gov

Solar Makes Cents

In recent years, the module portion of the PV market has experienced rapid cost decline as a result of the flood of development in Asia. Panel costs are approximately half of what they were just a few years ago – now pushing $1.25/watt, with predictions that the $1/watt mark may be breached in 2012.

The solar inverter market has historically represented about 8 percent of the overall cost of a solar installation. However, it will be difficult for inverter costs to follow the same downward trend that module costs have experienced because of the "advanced engineering required to design and manufacture the power electronics" in inverters, said Louis Lalonde, vice president of worldwide marketing for Enecsys.

In fact, inverter-specific costs are projected to increase as the PV industry experiences a shift away from measuring cost-per-watt to measuring levelized costs of energy (LCOE), said Charles Dauber, CEO of American Electric Technologies. LCOE analysis considers costs distributed over the project lifetime, measured in cents/kWh of energy produced. This provides a more accurate long-term financial picture that system operators prefer over the simple cost-per-watt calculation often used in the industry, said Ed Heacox, vice president of Advanced Energy Renewables.

Many factors determine LCOE, including performance, system costs and ongoing operations and maintenance. Inverter efficiency, reliability and performance directly impact energy output, Heacox said. "Ensuring the inverters and all PV site equipment remain operational through first-rate O&M affects the amount of energy produced and the long-term return on capital investment."

PV manufacturers recognize that module costs are declining rapidly, but the BOS (Balance of System) cost are seeing much more modest declines, said Paul Bundschuh, vice president of business development for Ideal Power Converters. "BOS costs including the inverter and installation are increasingly the bottleneck to lowering LCOE long-term."

If manufacturers want to lower LCOE long-term, the focus must also be on the BOS costs instead of just module costs, Bundschuh said.

"We've been so successful at addressing the module, but the inverter has a huge effect on installation costs."

Inverter costs could soon comprise 10 to 15 percent of the installed PV system cost, but also strongly impact the installation costs, which are about 40 percent of the installed PV system cost.

"As the penetration of PV on the grid increases, you'll see utilities requesting more advanced features in the inverters that lead to reductions in overall PV system prices," said Bates Marshall, senior manager of strategic marketing for SMA America.

An Advanced Energy PV Powered 100-kW stainless steel inverter is installed at a 787-kW facility at the U.S. Navy Pacific Missile Range Facility (PMRF) in Kekaha, Hawaii. Photo courtesy of Advanced Energy

A production line at SMA America's facility in Niestetal, Germany, where a new circuit board is produced every 30 seconds. Photo courtesy of SMA America.

Reliability Advancements

In the past, inverters have been plagued with reliability issues. Since the inverter is essentially a computer placed in a location that is typically hot, instability has been inherent. In the past, as the percent of PV penetration has increased, unreliability of the inverter has increased. But new inverters are being programmed for low-voltage ride-through, reactive power controls and other features with the capability to maintain a consistent supply of solar power to the grid.

To solve issues on the integration level, some manufacturers, like SMA America and American Electric Technologies, have released "factory integrated" inverters. In the past, EPCs have bought, designed and installed the inverter, transformer and switchgear all separately. Now manufacturers are producing inverters that integrate and connect all three pieces. Marshall said the inverter is shipped on a truck to the plant site, pre-wired and ready to run. "You eliminate the expensive field labor and improve quality," he said. "Instead of integrating the inverter in the hot New Mexico sun, you're doing it in a factory."

Charles Dauber of American Electric Technologies said the factory-integrated inverter method also saves on costs — somewhere between $70,000 and $125,000 per inverter.

While it is the ally of the entire PV process, the sun has in the past been the enemy to the inverter. Since most computers are not constructed to sit under the sun's beams all day, some companies have previously met the challenge by building protective stations around the inverter. But thanks to cooling technologies, modern inverters no longer need to have their own stations — they can be placed on steel platforms.

Some inverter companies, like Advanced Energy, are producing a variation of this concept — what's known as "outdoor ready" inverters. The inverter is placed inside a steel enclosure that guarantees a 20-year lifetime, said Heacox. This helps improve the inverter lifetime, which was previously about 10 years.

Another method many manufacturers have introduced to increase reliability is liquid cooling. "Blowing air on a hot computer is not going to work — you have to incorporate liquid cooling," said Dauber. Cooling technology also removes the cost of building a station and the expense of cooling the station itself. Many manufacturers architect their cooling systems around the concept of tareloss — the amount of power lost in order to run the system. This means that the cooling technology is designed to allow the least amount of tareloss possible, resulting in a more cost-effective process.

A 100-kW Enphase Energy inverter at work at a PV plant in Phoenix, Ariz. The system was installed by LE Solar Energy in 2010. Photo courtesy of Enphase Energy

Trends

Inverter trends for the commercial and utility space include advancements in size consolidation, voltage increases and smart features, said Lior Handelsman, vice president of product strategy and business development for SolarEdge Technologies.

Terms like "microinverter" and "mini inverter" have been floating around for residential and commercial-scale solar for a while. Distributed power conversion solutions such as module dedicated microinverters can be attractive in residential applications with partial shading issues, but commercial and utility-scale systems continue to depend on large central inverters due to lower costs. Instead of central inverters getting smaller, some have actually increased in size in an effort to improve efficiency, said Bundschuh of Ideal Power Converters.

"Inverters are becoming bigger and bigger in order to utilize the economy of scale," Handelsman said.

The size, weight and cost of PV inverters are limited by magnetic components such as transformers, reactors and inductors. These components are built from commodity metal materials such as copper wire and ferrite/steel cores. Little opportunity exists for significant cost reduction in PV inverters unless the amount of these materials can be substantially reduced, Bundschuh said. However, some hope exists, as IPC current-modulation topology has reduced the weight of magnetic components by more than 90 percent, he said.

> "Inverters are becoming bigger and bigger in order to utilize the economy of scale"
> — Lior Handelsman

Utility-scale inverters are also increasing in size due to voltage issues. The market is experiencing a shift away from the traditional 600-volt toward 1000-volt, said Laurent Bataille, senior vice president for the renewable energies business at Schneider Electric. "Therefore, inverters are increasing in size, using multiple inverters as building blocks for larger systems."

Dauber said one of the benefits of moving toward the 1000-volt design is a significant cost savings on cabling and the prevention of losses that typically occur with the 600-volt level of architecture. This occurs as a result of more panels per string, Dauber said. "Efficiency goes up; costs go down."

The higher the DC voltage, the higher $/kW gain, Handelsman said. Some regulations are changing to even allow for 1500-volt systems, he said.

In an effort to further voltage-related inverter advancements, the U.S. Department of Energy's National Renewable Energy Laboratory has partnered with Semikron to develop a prototype of a 50-kW inverter. The inverter is the size of a microwave oven and can be used for PV projects, a small wind turbine, a battery charger, a fuel cell or a flywheel. When the inverter is produced in volume, the price is expected to be one-third the cost of other integrated power electronics of the same rating. Funding for the prototype was provided from the California Energy Commission.

In addition to voltage advancements, inverters are also becoming smarter. In the past, inverters have been viewed simply as conversion units. Now inverters

LCOE vs. Cost per watt

LCOE: Cost per kWh

A precise method for determining the net present cost of production for a specific PV installation, or, expressed in terms of key financial aspects:

$$\text{LCOE (cents/kWh)} = \frac{\text{Lifetime expense for capital + financing + installation + O\&M + miscellaneous}}{\text{Lifetime energy production}}$$

Advantage
Encompasses cumulative system costs and total energy production over the system lifetime, levelized to compare with prevailing electricity rates in cents/kWh.

Limitations
Can entail complex analysis; however, online calculators now make LCOE calculations straightforward.

Cost per watt

A simple calculation that estimates the value of your investment at the time of purchase:

$$\text{\$/W} = \frac{\text{Total installation expenses}}{\text{Peak power rating}}$$

Advantage
Quick, simple math for budgeting solar PV projects.

Limitations
Provides no comparison to grid parity and completely ignores critical factors like efficiency, uptime, system architecture and lifetime optimization.

Source: Advanced Energy Industries, Inc.

Solectria Renewables' utility-scale inverters installed at Seabrook Farms in New Jersey. Installer: DCO Energy. Credit: Solectria Renewables & DCO Energy

are being built with features such as reactive power, smart grid interaction and energy storage. "Utilities, especially in Europe, are increasingly pushing for inverters to assist in grid stabilization," said Tom Haddon, a PV research analyst at IMS Research. Because of this push, smart inverters are expected to account for 80 percent of the EMEA market in 2015, according to IMS Research.

While the push for "smart" inverters may be the strongest in Europe, North American inverter manufacturers are also innovating smarter systems. "There is an evolution happening in what we call utility interactive control," said Heacox of Advanced Energy Renewables. These controls are essentially interactive controls that allow the inverter to interact with the grid in a stable way, Heacox said.

In the past, inverters were expected to detach from the grid if zero-, low- or high-voltage situations occurred. Now new smarter inverters, however, can ride through an AC grid disturbance of any kind, at least for a short period of time, Heacox said. Aside from voltage ride-through, other smart features include power factor control (PFC), dynamic power control (DPC), module-level optimization, module-level safety, anti-theft and monitoring.

"By adjusting anti-islanding requirements to allow the inverter to stabilize the grid during brownouts and blackouts, rather than disconnecting, the PV system will become a more valuable generation asset to the utility," said H. Clinton Porter, director of marketing for KACO New Energy.

Inverters are experiencing more innovation than any other part of the PV chain. Hundreds of inverter companies have entered the market over the last three years, hoping to evolve a technology into something that will make the overall PV process more streamlined and less expensive. In the end, when the backbone of the PV system — the inverter — is bolstered, the entire process of creating solar energy will be strengthened.