Breakthrough technologies lead the solar power industry into the future

Growth continues in the PV panel market

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By any measure, the solar power industry is experiencing explosive growth. In fact, the industry turned a very critical corner without much notice: a recent study found that solar-generated power is profitable without government support in at least 30 countries.

As a result, the global capacity for solar-generated power has reached an all-time high of over 300 GW (**Figure 1**). For photovoltaic (PV) panel manufacturers, the implications are far-reaching.

Manufacturers want to design and bring to market PV panels that are competitively positioned to take full advantage of the growing demand in the market.

This white paper examines the factors and trends contributing to this rapid growth and outlines the essential components to achieve optimal competitive positioning along with the inherent challenges as the industry continues to evolve.

Plummeting cost curves

The costs associated with harvesting electrical power with PV panels have dropped precipitously, enlarging the market by bringing more buyers in, which drives down costs further through economies of scale. The price per watt of solar-generated electricity has dropped to the point where it is economically competitive with the price of electricity generated by coal- and natural gas-fired plants. For example, one study found that in 40 years, the price per watt plummeted by a factor of more than 200, from $77 per watt in 1977 to $0.36 in 2014.

The overall price of solar-generated electricity is affected by the procurement cost of PV panels as well as the costs associated with installing and operating them, including peripheral equipment such as storage batteries and safety devices.

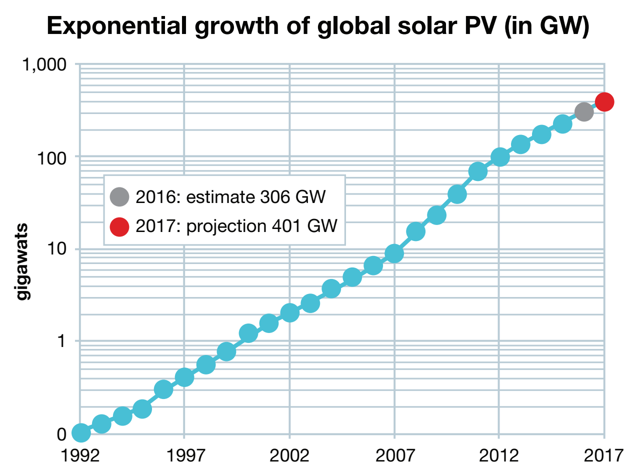

***Figure 1**. Exponential growth-curve on a semi-log scale of worldwide installed photovoltaics in megawatts since1992. (Figures for cumulative nameplate capacity in watt$_{DC}$, watt-peak). [2014 Snapshot of Global PV Markets, IEA International Energy Agency]*

Interestingly, if you take a historical look at manufacturing cost trends, the cost curve for PV panels follows a similar trajectory as other inventions such as the automobile, mobile phone and even electricity. The major factor contributing to the falling procurement cost of PV panels is the cost of manufacturing, which is most affected by materials costs and technical breakthroughs.

Manufacturing costs

Manufacturing costs for solar panels have dropped by 10 percent per year since the 1980s, according to experts at Oxford University. Extrapolating the data, Oxford researchers predicted that solar's share of global electricity would grow to as much as 20 percent by 2027.

Decreasing prices for silicon materials, which are a major component of PV panels, account for a significant portion of this drop in manufacturing cost, but another factor is the increased application of new digital technologies to the power conversion process, as well as the peripheral equipment involved in solar power generation.

Improving Efficiencies

New power-switching technologies can run at higher voltages and temperatures and achieve faster switching speeds, all of which make for a power conversion process that can be as much as 98 percent efficient. In other words, only 2% of the DC power pulled from a solar panel is lost as it is converted to usable AC power.

New digital control technologies, including more powerful and versatile microcontrollers (MCUs), have streamlined the entire harvesting process. A single MCU, for example, might monitor and control the power conversion process while also processing the communications protocols that provide alarms and alerts to ensure the safety of the installation. The efficiencies empowered by digital technology in turn drive down the cost per watt of solar electricity, since fewer or smaller panels are required to generate the same amount of power.

Installation costs

Installation costs play a significant role in the return on investment (ROI) for PV panels and the price competitiveness of solar power. In fact, installation costs have a greater effect on the financial viability of small residential or community PV installations, since these costs account for a greater percentage of the overall cost of small-scale projects than they do for large utility-size solar power sites.

Simplified installation techniques are bringing down costs. For example, in the past, installers would spend a great deal of time putting discrete inverters into place and hard-wiring each one to a group of several PV panels. These string inverters would first take the DC power from a set of panels and convert it to the proper DC level, then convert it again to the standard AC voltage and current levels for use in homes or small businesses.

Today, manufacturers integrate a small inverter into each PV panel. The relatively small cost of integrating this inverter is quickly recovered through reduced installation costs. Panels with integrated inverters, as seen in **Figure 2**, also make a great deal of sense for disjointed sites, where instead of grouping a large number of panels contiguously on a single surface, only a small number of panels can be placed together.

Standard infrastructure

Another aspect of solar power that has brought down costs is the development and deployment of industry standards. Standards offer the industry a unified way to talk about PV technology, measure its performance, and ensure the safety of installed

Figure 2*. Solar panel with integrated microinverter.*

PV products and systems. In addition, conforming to such standards levels the playing the field for PV panel providers and reduces procurement costs.

One of the newest solar power standards, which specifies the communications signal for a rapid shutdown of PV panels, was put together by the SunSpec Alliance, a group of 70 organizations involved in the solar industry. The standard, which supports National Electrical Code (NEC) 2014, NEC 2017 and Underwriters Laboratories (UL) 1741, will roll out in the U.S. in 2019.

The standard is related to the remote powering down of PV panels installed on the roof of a building in the event of an emergency. For example, if a fire erupts in the attic of a home with solar panels on the roof, first responders would want to power down the solar panels before attempting to put out the fire. Solar panel designs compliant with this standard must include a communications channel between the existing power lines running from the inverter to the solar power panels on the roof. (For more information about such an implementation, see the application report, "Interfacing the C2000™ With an AFE030/1: FSK Example." http://www.ti.com/lit/sprac94

Utility incentives

Some governments and electrical utilities have adopted policies and pricing structures to bring down the cost of solar power installations. For example, California, Oregon and several other states adopted the concept of net metering. This strategy originated in Europe and has been promulgated throughout several countries, including Germany and Denmark.

Net metering gives both residential and business customers the ability to sell any excess electricity they generate from a renewable resource back to their utility. Net metering can increase a customer's ROI considerably. For example, a residential solar system only generates power during the daytime, but it's likely that most occupants are not home; instead, peak electrical usage hours are in the evenings after the sun has gone down. With net metering, the excess solar power generated during the day feeds back into the electrical grid and is treated as a credit against electricity the customer purchases from the utility. Without net metering, residential consumers would need a battery-based system to store electricity during the day for consumption at night.

Technology trends

Recent technological breakthroughs – and others not yet discovered – hold great promise to increase even further adoption of solar power, as well as other renewable energy sources.

It should also be noted that materials science has contributed greatly to solar power. The development and deployment of new silicon compounds and films have enhanced the entire process of harvesting energy from the sun.

Digital control technologies

Many of today's MCUs feature multiple processing cores, each very powerful in their own right and often complemented by specialized co-processors or accelerators for real-time applications such as controlling solar power generation. More advanced MCUs and those used in PV panel installations might feature a slew of peripheral capabilities integrated on-chip: functionality like analog-to-digital converters (ADCs) or industrial communications protocols.

Sophisticated MCUs are also essential to effectively and efficiently control the power conversion processes central to solar power generation. PV panels generate DC voltages, but the power grid as well as appliances in homes and machines in businesses use AC voltage. Inverters are needed to convert DC voltages to AC voltages. But before that can happen, the DC power coming from solar panels must be boosted to the proper DC voltage. As a result, solar power generation typically requires two power conversion stages: a DC-to-DC boost converter and another DC-to-AC inverter.

Certain MCUs are particularly good at accurately sampling and controlling the voltages and currents through each conversion process. MCU control of the power switches via pulse-width modulation (PWM) help ensure that power conversion occurs efficiently and accurately. Because of their high operating frequencies, digital MCUs can be very efficient at quickly sensing line load changes and rapidly adjusting the power circuits, which results in much greater power densities compared to analog controllers. Digital power control techniques provide several benefits over analog control, see **Figure 3**.

High-voltage innovations also enable more efficient conversion of electrical power so that less power is lost between the PV panel source and the grid or home load. High-voltage solutions in the semiconductor industry include isolated gate drivers, isolated sensors, wide bandgap technologies and digital controllers, all of which are part of TI's portfolio.

Smart grid

The electrical grid is not what it used to be, but that plays into solar power's favor. Today's smart grid incorporates more intelligence at every level throughout the transmission and distribution network, enabling the inclusion of electricity not generated by traditional power generation plants burning coal or natural gas.

Compared to the predictable supply from fossil fuel plants, renewable energy sources like solar and wind are more variable, which can quickly increase or decrease the amount of electricity they supply to the grid. With solar and wind generation, both supply and demand are variable, creating a more unpredictable and uncertain environment. Greater intelligence in the smart grid helps keep supply and demand in balance.

More widespread adoption of PV panels reduces variability, because spreading solar generation over a wider area reduces the aggregate solar-supply variability over that area. In other words, chances that the sun will be shining somewhere in a certain geographic area improves as the size of the area increases.

Another challenge for the grid is the distributed nature of power generation with renewable sources. Unlike the old grid infrastructure, which relied heavily on fossil fuel or hydroelectric-based power plants, a new smart grid will have a magnitude more in line with small-scale "power plants" with the addition of more solar panels on roofs and wind farms to

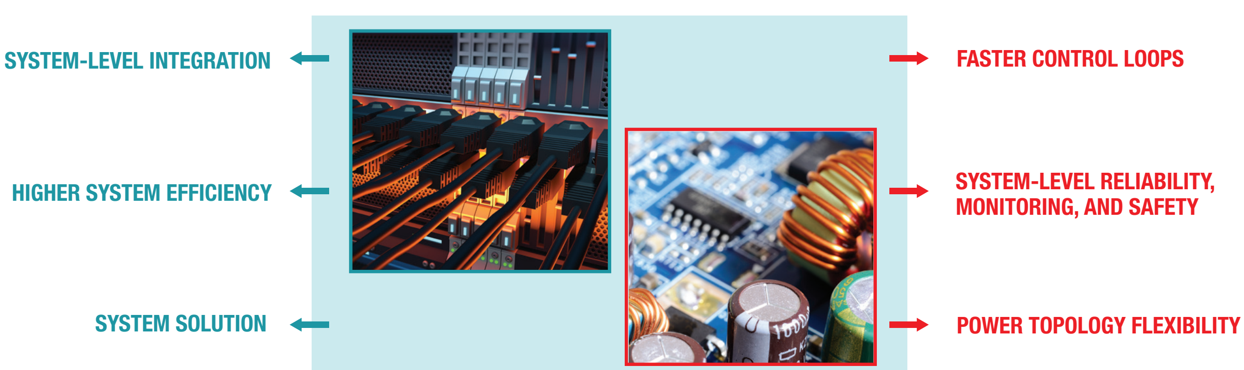

***Figure 3**. Digital power benefits.*

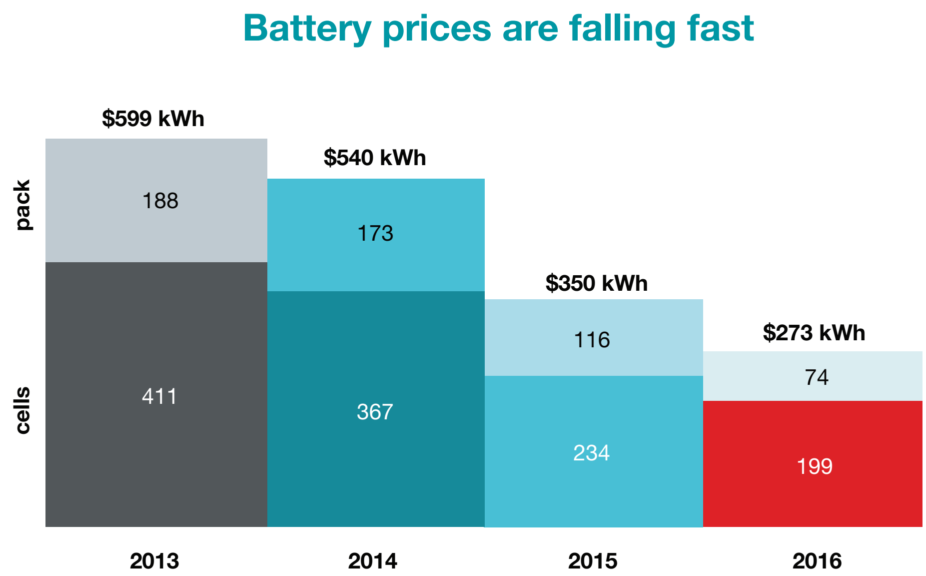

Figure 4. *Battery prices are falling fast. *Battery surveys include electric vehicles.*

the landscape. Again, the intelligence of the smart grid will be critical. Instrumentation and digital control equipment throughout the grid will give utility operators and consumers real-time awareness of fluctuations in supply and demand, and the ability to respond accordingly.

Battery storage

Fossil fuels have an advantage over solar and other renewable energy sources when stored. For coal and natural gas, energy is stored in the fuel until it is burned. But renewable electricity must be stored after it is harvested or it simply dissipates.

Storing excess renewable energy requires batteries, located either at the point of generation or somewhere in the grid, but they're expensive and require careful control to ensure their safety.

Fortunately, the advent of electric vehicles has benefited the solar power industry, given the great deal of research into new technologies and materials to develop better automotive batteries. Advancements in automotive batteries can be transferred to renewable energy.

Currently, lithium-ion batteries dominate automotive and renewable energy applications. Lithium-ion battery manufacturers have had to ramp up to keep pace with the increased demand for electric vehicles; as a result, battery costs have dropped by almost half since 2014, according to *Bloomberg* (see **Figure 4**). Although the energy density of a lithium-ion battery cell is nearing its physical limit, researchers expect lithium-ion batteries to dominate the market through 2020. Beyond that point, new battery technologies like solid-state and lithium-air cells may take over.

Another important consideration with regards to energy storage is safety, especially as the energy density of battery cells reaches the limits of the laws of physics. Here again, MCUs and other digital control technologies will play a major role in monitoring, managing and controlling both large-scale energy storage facilities on the grid and smaller residential or commercial battery storage systems.

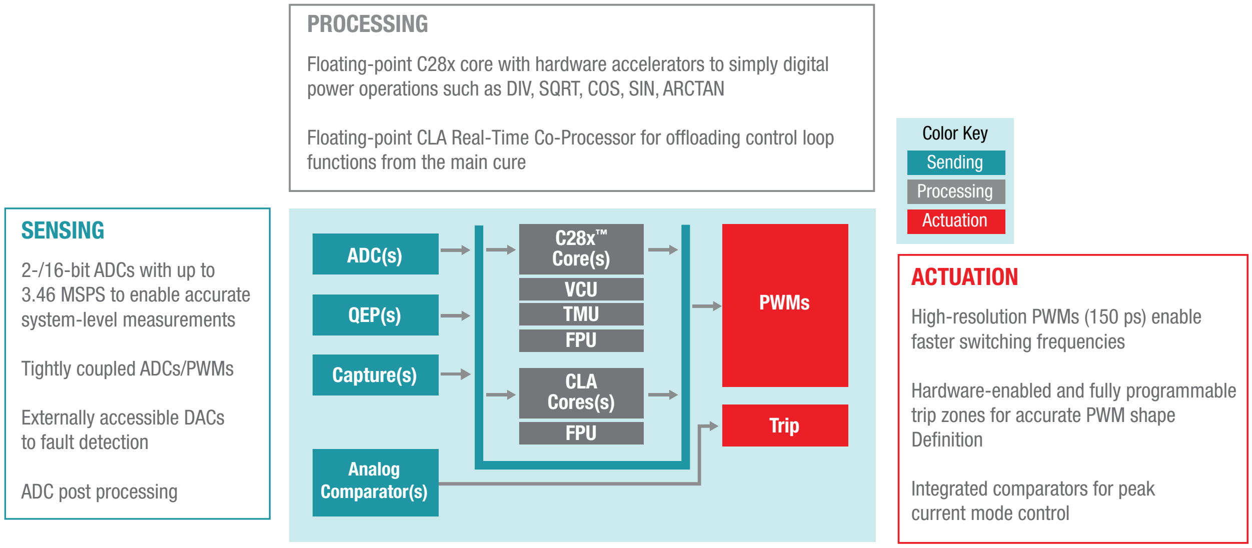

***Figure 5**. TI's C2000™ MCUs integrate key system features for solar inverters.*

Solar reference designs: Applied technology saves development costs

To facilitate fast time to market for new solar system designs, TI has developed several reference designs based on its 32-bit C2000™ MCU family. TI offers a number of software and peripheral tools to support these reference designs, simplifying some of the challenges so that developers can concentrate on the features and functionality to differentiate their products.

For example, the Single-Phase Inverter Reference Design with Voltage Source and Grid Connected Modes is a comprehensive kit for developing a single-phase DC-to-AC inverter with peak power efficiencies of up to 98% and a low total harmonic distortion (THD) of the injected grid current of less than 1%. A C2000 MCU controls the inverter design, which is supported by a suite of tools under the powerSUITE framework including a solution adapter, compensation designer and software frequency response analyzer. These tools simplify the design and tuning of control loops in order to achieve optimal system performance.

Conclusion

The phenomenal growth of the solar power industry can be attributed to a wide range of societal, technical and economic forces. And yet, the momentum that is undeniably present now will only accelerate with new innovations in PV panel designs.

Breakthrough technologies like TI's C2000 MCUs, see **Figure 5**, and the solar tools that support them are giving PV panel designers and solar system developers a new baseline of capabilities from which they can more effectively lead the solar industry into the future.

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