PV's plug-in power plants: How modular design is cutting the cost of solar electricity

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ABSTRACT

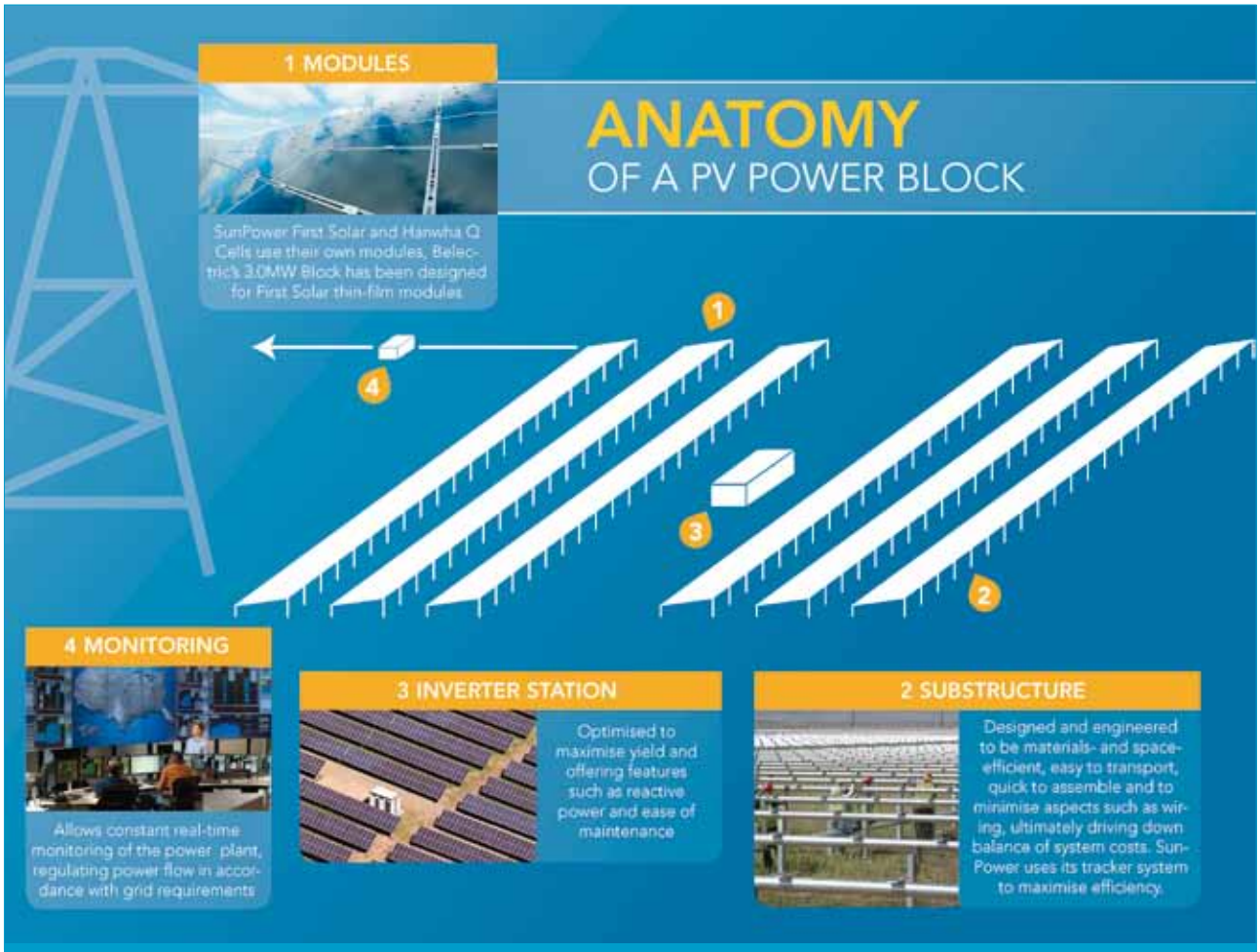
The pioneers of utility-scale PV construction have drawn on methods used in other industries to make power plants more efficient and more competitive. This paper investigates how cutting-edge techniques in modular design are being used to drive down plant costs. The evolution of modular design and its attractiveness to the investor community are discussed.

Introduction

Large-scale solar PV power plants hold the promise of providing PV-generated electricity at the lowest levelized cost of electricity (LCOE) and therefore becoming the first among PV end-market sectors to reach real-world grid parity and beyond. Production scale in upstream PV manufacturing has been a major factor in solar installation cost reductions over the last decade, and now the drive to scale in the downstream ground-mounted PV power plant sector is generating further overall cost reductions. In less than a decade, PV power plants have gone from the 1MW scale milestone to recent plans to achieve combined/adjoining projects of 500MW and above.

But the rapid development of PV power plants has also resulted in the need to move away from bespoke construction techniques and apply industrial manufacturing methodologies to PV power plants. As projects in the multi-megawatt range have increased, economies of scale have enabled PV power plant pioneers to not only look at scaling benefits simply from a component purchasing perspective but also take a holistic approach to all phases of construction, from pre-planning through to power plant monitoring.

Matt Campbell, Senior Director of US manufacturer SunPower, explains how it treated every project as different and unique when the company first



Infographic: Viki Hämmerle, Solar Media.

Figure 1. The main elements of a modular PV power block.

got involved in PV plant construction. "When we thought about scaling this business to tens of megawatts and hundreds of megawatts, which had always been part of our mission, we thought we needed to cookie-cutter this," Campbell says. "We had to really reduce costs both in the product [panels] and in the field with installations and to standardize."

Modular platform evolution

SunPower is one of a number of leading players in PV manufacturing and large-scale plant construction which are increasingly taking a modular, standardized approach to plant design in a bid to drive down LCOE. This approach has its roots in other forms of complex, high-volume manufacturing, such as automotive assembly, which is well known to have adopted standardized production techniques to reduce overall costs.

The main components of a PV power plant are the solar PV panels, fixed mounting (or tracking) systems, cabling, inverters, transformers, grid connection and plant monitoring. Bringing disparate components to a single site, often with major components such as the panels and central inverters shipped from different continents, involves a high level of complexity, but, because of the scale, also provides significant opportunities to drive down costs.

It is no coincidence that several leading PV cell/module manufacturers – such as First Solar, SunPower and Hanwha Q CELLS – have been quick to take a lead in PV power plant design, bringing their high-volume upstream manufacturing methodologies to PV power plant design. The move downstream is now being widely adopted, not just by other PV module manufacturers but also by enterprises in supply sectors further upstream, such as polysilicon producers like SunEdison, formerly MEMC, and GCL-Poly.

"First Solar strategically vertically integrated in order to reduce the cost of solar electricity and expand into markets without feed-in-tariff policy structures in place," notes Tom Kuster, Senior Vice President, Product Management and Systems Solutions at First Solar.

"By gaining engineering, procurement and construction capabilities, project development and finance capabilities, numerous balance-of-system technologies and industry-leading operations and maintenance expertise, First Solar became a vertically integrated turnkey PV power plant provider."

SunPower cut its teeth developing high-efficiency crystalline silicon cells, but is now a major provider of modular PV power plants, building its first megawatt system back in 2006. According to Campbell, after its revelation about taking a "cookie cutter" approach to plant design, SunPower developed its first branded modular system. "In standardizing we called it 'a power plant in a box', like buying furniture from Ikea. It went from being called a 'power block' to 'Oasis'," he says.

Meanwhile, although not a manufacturer per se, Germany-based EPC firm BELECTRIC is another pioneer of the modular approach, having realized early on that PV power plants needed to evolve beyond the individual customized approach. "With the reduction in the feed-in tariff and the pressure on costs we needed a different approach to serve the utility solar power plant sector," says Chief Executive Bernhard Beck.

Source: BELECTRIC.

Figure 2. BELECTRIC's '3.0 MegaWattBlock' is an example of how modular design is being used in utility-scale PV plants.

Modular PV power plant methodology

As well as car manufacturing, PV power plant pioneers looked to the wind turbine industry for a route to standardization. According to Campbell, SunPower created an integrated cost-reduction roadmap that took inspiration from both the automotive industry and the wind turbine sector. He notes that the 1.5MW wind turbine has been the workhorse of the wind industry for ten years; once the sector had standardized on a 1.5MW unit, the costs of the system were dramatically reduced.

Beck also highlights the influence of the wind industry. "The wind turbine is a defined product and as a project developer you would go around and find the right location for this product," he explains. "This is very logical and has been the practice in the wind industry for around ten years, and the solar industry had to adopt the same approach.

This approach was very clear as it didn't make sense to adapt a piece of high technology to a piece of land. We needed to turn this around and find the right piece of land for the technology, the same way the wind power sector does.

"Although cost reduction was a key driver for the modular block approach, lifetime expectations in the field could not be compromised. A standardized power block had to retain high levels of component quality and overall system quality."

Hanwha Q CELLS, via its former project developer arm, Q-Cells International, was another pioneer of the modular approach.

"We created our EPC business in 2007, underpinned by the pursuit of high quality from our manufacturing," says Frank Danielzik, vice president of EPC at Hanwha Q CELLS. "Quality, quality, quality was at the core of the approach as we had to guarantee to the power plant for 20 years. Right from the start we adopted a modular approach to every aspect of the project business. This included standardized documentation and procedures throughout."

According to SunPower's Campbell and others, the key to driving down costs through the modular block approach is 'pre-optimization' of all elements of the system.

"A power plant block is a complex engineering problem, as you are trying to optimize your manufacturing supply chain logistics, delivery of material, construction sequencing, material utilization, which could be the steel structures and the cabling, and then putting the kit together. Therefore the whole sequence has to be optimized, and when you standardize you can pre-design everything to work together as a seamless system; it becomes the most efficient way to build the system."

BELECTRIC takes this idea to its

extreme, designing every component in its power block as part of an overall system. Beck says: "Systems are designed as one thing. So, we do not use components we suddenly find on the market and combine them in a product; we design a product. That differentiates us from all the other players in the market; we design a product and then we produce the components needed for that product. Anyone else offering power blocks uses available components and brings them together in a product definition. The main difference is that we engineer the full thing."

LCOE motivations

Combining cost reductions and providing the system performance, while maintaining overall lifetime requirements, ultimately all come back to LCOE. The continued adoption of PV power plants will depend on this metric, as will the success of the modular block approach.

"We optimize the unit for the lowest LCOE and that includes the quality requirements for the unit to last the necessary 20–25 years. We know all the parameters and we focus on reducing the kilowatt hour cost. I am pretty sure that our 3.0 MegaWattBlock is the industry benchmark," says Beck, referring to BELECTRIC's flagship modular power plant product.

SunPower's Campbell claims: "Our modular approach is different in that it really is LCOE driven as opposed to cost driven. It's interesting that in the PV industry there has been a shift in the last three to four years from talking about cost per watt to LCOE. Yet we do see people revert back to cost per watt; it's a reflection of the complexity of LCOE. But we see it as important that customers really understand LCOE, which we are pleased our sophisticated customers do and see the long-term picture, and that's the theme of our modular approach."

First Solar's Kuster, meanwhile, says his company can deliver a LCOE that is cost competitive with conventional generation sources today. There is no question that for modular power plant pioneers the bragging rights to the lowest LCOE is hotly debated. However, is not the focus of this paper to directly compare and analyse which company and technology holds the lowest cost mantle. Rather, the focus is to understand how the modular block approach to PV power plant design provides the future of electricity generation.

Beck sums this up when he says: "With the modular approach everything comes together in LCOE comparison. This is where you have to educate the customer, as there are many ways to construct low-cost electricity. There are differences between products available from the few companies able to offer this approach, yet they all have to provide the necessary LCOE levels. Simply compare the products being offered against the LCOE."

Benefits of evolution

The benefit of a modular approach is that once a design is proven in the field across multiple projects, it can be tweaked to incrementally reduce costs further, taking LCOE economics into unchartered waters.

"One of the things that has been interesting has been that we have these operations built into our DNA, as we have built our own factories and our own production lines, and we have used lean principles that help us get waste out; and that's what we have done with our modular power blocks and plants," says Howard Wenger, SunPower's president of regions, who is responsible for the company's global residential, commercial, utilities and power plants business.

Wenger says that working on bigger projects also allows SunPower to make ongoing improvements to what it does. He cites one of the company's largest current projects, the 747MWp Solar Star project in California, which is being built around SunPower's Oasis platform, the brand name for its power block concept.

> "Any time we learn something at any stage it goes back into research and product development for the next developed product."

"With Solar Star we are using our second generation Oasis [platform] and between those generations we made a number of improvements – things like [increasing] the rate at which we can install from 1MW a day to 2–3MW a day, with the ability to go even faster," says Wenger. "The [Solar Star] plant will use around 500 modular Oasis lines, which will even allow for continuous improvements within one project."

BELECTRIC's Beck echoes this point: "Anything we learn from the product goes back into research. This is the difference," he remarks. "If you see a normal, individually built EPC power plant this is not a round ticket thing, rather it's a one-way ticket. Information learnt on an individual project may not therefore be usable on another project, especially when different modules or inverters are used.

"Where is the learning curve, compared to doing the same thing over and over again and getting better each time? Any time we learn something at any stage it goes back into research and product development for the next developed product. This is how we took our 2MW Block to the 3MW Block and the next stage beyond."

"Our modular approach in collaboration with our own R&D and systems department enables us to find room for improvement every year, while retaining the high quality," adds Danielzik from Hanwha Q CELLS.

The learning curve advantages that standardization provides do not necessarily have to be applied post-project. SunPower's Campbell highlights some examples of learning curve dynamics that were actually implemented during individual projects, albeit on some of the largest PV power plants built to date that have longer lead times.

"We have a closed-loop audit process integrated into the programme, especially on the construction side. As we get feedback in the field we loop that back to engineering and project development, and although we take a pretty rigorous approach to standardization there are areas of flexibility to adapt to real-world situations in the field," Campbell explains.

The SunPower Oasis (1.5MW) power block achieved an annual cost reduction (BOS) of 24% in 2013, according to the company in its fourth quarter, 2013 financial conference call. As seen in Fig. 3, which SunPower released in mid-2013, its Oasis cost reductions were projected to fall to the 50% range at the end of 2013. Off-field pre-engineered components – such as tracking and racking systems – have been key cost-reduction drivers. The company remains confident that the complete loop-forward and loop-back revisions strategy to the power block, which takes advantage of both engineering and technological advances, will provide further BOS cost reductions.

First Solar had also published a BOS and LCOE cost-reduction roadmap (see Fig. 4) in early 2013. The holistic approach to integrated system design and implementation of engineering upgrades and new technologies is also a key cost-reduction driver at the company. Improving overall power plant yield with a newly designed tracker system is part of the strategy, and that system also has its own BOS cost-reduction roadmap. First Solar has also been developing new techniques for installing its modules on the racking system in a much faster way than in the past.

Attractiveness to banks, investors and owners

Ultimately, though, the attractiveness of the modular approach has to resonate with the end customer and financial backers.

According to Beck, the market is still not really ready for what he describes as

the "full delivery of solar power generation". What this means is that the ability to take a single modular power plant unit and place the product at a correctly selected site, like that undertaken in the wind sector, has yet to be widely understood by investors and PV power plant owners.

"However, what we see is the growing interest from the utility sector and the investment sector to invest in standardized solar power plant units," Beck adds. "These provide the certainty from one block to another, regardless of the number of blocks in a project.

"We know in advance what we are going to see in performance and LCOE, and we can provide pricing several years ahead. This all makes it easier when selecting the right site or placement options."

> "Providing a standardized turnkey approach has significant benefits for the end customer and related financial partners."

According to Hanwha Q CELLS' Danielzik, providing a standardized turnkey approach has significant benefits for the end customer and related financial partners. A key benefit is the transparency provided at every stage of the project, backed up by known and bankable high-quality products, processes and certification, which keeps all stakeholders informed and involved.

"The modular approach provides many benefits, but transparency, especially early on in a project, is often crucial," he says. "Standard processes with clear definitions and timetables enable successful project execution with quantifiable gates."

Danielzik also notes that adopting a complete modular approach to all aspects of the project means there are no surprises for customers or financiers and that final acceptance always turns out as planned.

"From an operations point of view there is a need to reduce unknowns so that 95% of issues are clearly answered in using the modular approach. The project-specific adjustments are limited to what is needed by the customer, which accounts for the remaining 5% and they are typically about actual site considerations," says Ron Stephan, head of engineering and construction at Hanwha Q CELLS.

SunPower's Campbell echoes this crucial factor: "One of the advantages of the standardized approach is the power block becomes a known entity to the investor and is all de-risked. It should be so well engineered that it becomes boring. From an investor point of view boring is good."

Figure 3. SunPower Oasis cost-reduction roadmap.

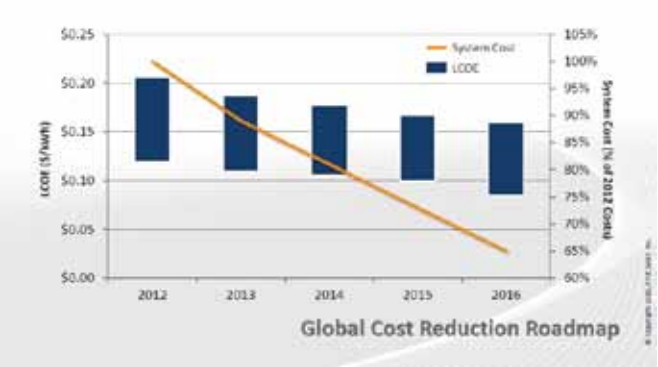


Figure 4. First Solar PV system cost-reduction roadmap.

Global capabilities

First Solar's Kuster adds a further spin on the theme: "The pre-engineered and configurable designs provide local construction partners with flexibility as they adapt the solution to meet local codes and project-specific parameters. The optimized and proven solution also serves to streamline project activities, including development, financing, permitting, installation, and commissioning for a faster time-to-power.

"By streamlining the execution of solar projects and providing local construction and supply chain jobs, this business model provides significant regional value while minimizing the technical risks associated with power plant execution and operation in emerging solar markets."

Certainly, Kuster is hitting on a major attraction of the modular approach that mirrors the overall PV trend of broad-based globalization. Large-scale PV power plants have predominantly been located in a small number of regional locations, such as Europe and the USA. Only in the last couple of years have large-scale projects been built in India, China and, in 2013, South Africa. Japan and Latin America, notably Chile, are now in the large-scale project roll-out phase, supported in many instances by the modular power plant approach and adding to the geographical diversity.

Whatever direction incremental innovations in the modular power block approach may take, the platform is pushing ahead relentlessly and opening markets to utilities, investors and owners that were simply unimaginable only a few years ago.

> "It will be the downstream modular PV power plant that will drive the LCOE model past grid parity with fossil fuels."

The industry may have projected the expected roadmap to a lower cost per watt from the manufacturing floor, but it will be the downstream modular PV power plant that will drive the LCOE model past grid parity with fossil fuels and ensure global adoption of large-scale, unsubsidized electricity, regardless of technology type.

Modular PV power plants in practice

Hanwha Q CELLS: Q.MEGA

Outline: Hanwha Q CELLS' branded modular plant Q.MEGA is constructed in a 'cascade' format, incorporating 1.4MWp DC output blocks that include 24 modules per string and 6906 modules per block. A completed block can be independently grid connected.
Modules: Hanwha Q CELLS manufactures its own modules in Malaysia and Germany, which means that key components are always available. Options now include sourcing from Hanwha SolarOne, its sister manufacturer in China. Long-term yield security is achieved by Anti PID Technology1, Hot-Spot Protect and Traceable Quality Tra.QTM, as well as being VDE Quality Tested.
Inverters: 1 inverter station 1.3 MVA AC.
Special features: Continuous development of the modular system has led to high levels of optimization, with the benefit of construction times of 1MW per day, compared with 3.9 days for the system in 2009. This flexibility and high degree of system standardization helps keep costs low. The flexibility aspect also allows power blocks up to 3MW in size to be configured.

SunPower: Oasis Power Plant

Outline: The Oasis power block's high-efficiency modules are claimed to deliver higher output per square metre than conventional PV power plants, minimizing project footprint and permitting risk. Pre-engineered in 1.5MW power blocks, they are built with proven components to ensure reliability and lower risk to project investors. SunPower says it controls every step, from tracker and panel manufacturing to grid connectivity.
Modules: SunPower modules have been independently tested, with performance ratios of around 95%. The company launched the industry's first combined warranty that covers both power and product for 25 years.
Inverters: With advanced plant controls, the standardized Oasis inverter features voltage ride-through, curtailment control and dynamic power factor adjustment, enhancing grid interoperability for PV power plants.
Special features: The T0 Tracker with SunPower's 425W module maximizes the solar plant capacity factor and produces up to 30% more energy than fixed-tilt systems. The company also offers the C7 Tracker system, which combines single-axis tracking technology with rows of parabolic mirrors, reflecting light onto 22.8%-efficient 'Maxeon' solar cells.

First Solar: AC Power Block

Outline: First Solar integrates advanced technologies to optimize the entire power plant. The company has also recently developed PV tracking systems to capture more available sunlight.
Modules: First Solar manufactures its own CdTe thin-film modules with better temperature coefficient benefits than conventional c-Si modules.
Inverters: Advanced plant features include the ability to provide accurate energy forecasts, regulate voltage, curtail active power when necessary and react to changes in grid frequency. First Solar has used SMA Solar's utility-scale central inverters for several large-scale projects.
Special features: First Solar claims to have made significant improvements to BOS components in order to optimize the entire PV power plant and reduce life-cycle costs. It uses proprietary data acquisition, plant control and mounting systems to provide reliable and predictable solar energy, increased energy yields and system availabilities, and a lower LCOE.

BELECTRIC: 3.0 MegaWattBlock

Outline: BELECTRIC's new 3.0 MegaWattBlock is claimed to set new standards in solar power production and uses a maximum voltage of 1500V.
Modules: 3.0 MegaWattBlock is designed specifically to operate with First Solar's CdTe thin-film modules. BELECTRIC has also used CIS thin-film modules from Solar Frontier for the system.
Inverters: Developed in cooperation with GE and PADCON, the 1500V inverter system reduces system and maintenance costs. A material-saving design is also built with the highest levels of quality and provides superior surface area efficiency, according to the company. The turnkey system uses an efficient, grid-stabilizing power conditioning unit (PCU) with GE inverter technology, providing a claimed performance ratio of up to 85%.
Special features: The specially developed PCU includes an intelligent power plant controlling system, the inverter system and the transformer. The inverter system was optimized for the use of thin-film module technologies and is characterized by a high level of system efficiency.