



Utility-Scale PV Comes of Age

How Innovation is Driving a
Solar Revolution

GE Power

gepowerconversion.com



1. Foreword

The world has an enormous pent-up need for more energy: today, 1.2 billion people still lack access to electricity—that is one in six persons in the world. Lack of reliable access to power is a major obstacle to economic development in many countries: with no reliable access to electricity you cannot develop a manufacturing sector, create jobs, let alone provide health care, or even light a room to read a homework assignment.

By 2030, the global economy will be fifty percent larger than today, and will be home to an additional 1 billion people; both population and economic growth will continue apace in the coming decades, further boosting the need for energy. The International Energy Agency projects that over the same horizon energy demand will rise by about one-fifth and electricity demand by about one-third, based on current policies.

Energy efficiency will continue to improve, allowing us to create more economic growth with less power consumption—but even so, we will need a lot more energy, and we will need to generate more of it in cleaner ways. Climate change and pollution are already top policy priorities. To raise living standards in emerging markets towards advanced economies' levels, and enable continued global economic growth, power generation needs to become much more environmentally sustainable than it is today.

This will require simultaneous progress on several fronts: highly efficient generation from fossil fuels plant, more reliance on nuclear energy, more powerful wind turbines, and improved efficiency in transmission and distribution including through digital technologies. Most importantly, we will need to boost the role of renewable energy: as of 2016, most countries in the world have established renewable energy targets.

Solar generation and energy storage will play a fundamental role. Technological innovation is driving down the cost of solar PV generation faster than expected; and it is enabling higher voltage and greater efficiency in photovoltaic inverters, reducing system losses

and costs. At the same time, advances in energy storage are opening the way for GE's new energy storage solutions : technology solutions that will enable us to generate a much higher share of power from solar, store it and dispatch it efficiently. The energy storage solutions will also enable greater flexibility and grid independence in the delivery of energy, enabling a faster transformation of the whole energy value chain.

Improvements in solar power generation, storage and distribution will enable more flexible and resilient energy supply for manufacturing sites, hospitals and cities. They will support the expected growing adoption of electric vehicles. They will play an essential role in creating a more efficient, resilient and sustainable power generation system to support global economic growth.

This paper discusses some of the most recent innovative solutions that we are developing and deploying to enable this transformation.

2. The Solar Industry & Its Challenges

Something extraordinary is happening in the solar photovoltaic (PV) industry. After years of slow but steady development, it has seen a sudden growth spurt of staggering proportions.

Consider this: we expect to install around 80 GW in 2017 compared to 2.5 GW only 10 years ago.¹

The Global Appetite for Solar

The appetite for solar is clearly strong - and governments use a mix of incentives such as tariffs, auctions and tax exemptions to fuel greater investments. As of 2016, 176 countries have established renewable energy targets.²

At the same time, rapid technological innovation is transforming utility-scale solar PV from a high-cost and relatively risky industry, to a highly efficient one that can finally compete with traditional energy sources - even without government subsidies (e.g. the LCOE of utility-scale solar PV fell by 85 percent between 2009 and 2016³).

This is an exciting phase for the solar PV industry and will be far from short-lived. Indeed, Solar PV's share of global cumulative installed capacity will go up from 5% in 2016 to 32% by 2040⁴.

It's All About LCOE

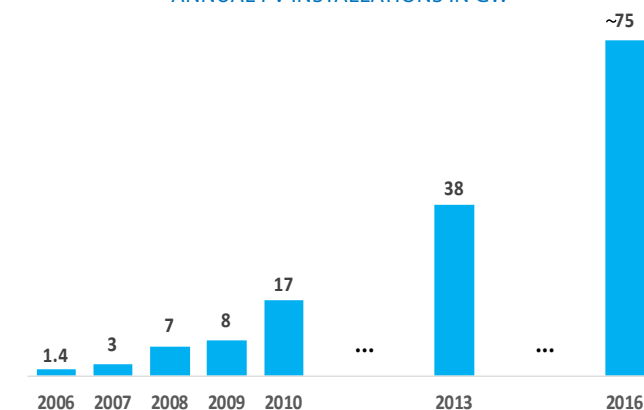
Even with supportive policies, the Levelized Cost of Electricity (LCOE) has historically been very high. Much of the burden features in the up-front costs of installing a solar farm: these include site acquisition and analysis, equipment costs and installations, but also financing costs, which are typically extensive.

Much of the innovation in solar has focused around bringing these costs down - and thus the LCOE. And it's working. The vision of reaching grid parity has become a reality, and we've achieved a point where solar farms are now being installed without any form of government subsidy - even in regions rich in fossil fuel resources.

Profitability, Growing Installed Base and Grid Stability

On the other hand, pressure on solar plant profitability is high due to reducing tariffs and subsidies impacting investors' return. Cost effective power infrastructure, secure power supply, power quality and grid stability are critical. As more renewable power is being added, efficient solar PV power plants can be a competitive alternative to power generation technologies.

ANNUAL PV INSTALLATIONS IN GW



Source: IEA PVPS report

LCOE
of solar PV fell
85 percent
between 2009 and 2016

Source: Lazard 2016

1 GTM - Global Solar Demand Monitor, IHS PV Demand Market Tracker

2 REN21. 2017. Renewables 2017 Global Status Report

3 Lazard Levelized Cost of Energy Analysis 10.0 - December 2016

4 BNEF New Energy Outlook 2017

3. Innovation is Key

Technology is Driving the Solar LCoE Revolution

Technology innovation is key. In the utility-scale space, there have been huge technology leaps forward in recent years - across all components of a system, from PV modules (materials and cell efficiencies), solar inverters (efficiency, power and voltage ratings), electrical balance of system optimization and stability of grid connection - with game-changing impacts on LCoE.

Take photovoltaic inverters - the means of a solar farm to convert the sun's energy (DC) into electricity for the grid (AC). A solar farm's layout and surface area are prescribed by the kind of inverters it uses - and their capacity. The higher their voltage, the lower the current, which enables more power. The benefits are significant: by gaining a higher energy output per square meter, you need less infrastructure and less land on which to accommodate it. With fewer inverters, solar arrays and cabling, upfront costs go down - as does Operation and Maintenance (O&M) outlay.

The Sprint from 600 V to 1,500 V

The rate of innovation in this area has been breathtaking: it was only six years ago that traditional 600 volt inverters were overtaken by 1 kilovolt counterparts. Then, in 2012, GE developed the world's first 1.5 kV solar inverter. Together with the first 1.5 kV PV modules, this pioneering step has enabled significant savings in system costs of up to 3 percent, and up to 15 percent in operation and maintenance costs—and it even works effectively in regions with suboptimal irradiation.

Today, GE's 1.5kV inverter technology is well proven, with a large installed base of over 4 GW worldwide.

1.5 kV Inverter Technology



1.5 kV Utility Scale Inverter

GE was first to introduce cost-effective 1.5 kV



Higher CEC Efficiency

From 98.5% up to 99% (LV5+)



Robust Air Cooling System

With sediment separators for hot and harsh environments and reduced maintenance



Predix Ready

Predictive maintenance and advanced diagnostics for optimal performance monitoring



Integrated Solution

Available as skid or eHouse solution



How GE's Innovative 1.5 kV Inverter Sets a New Standard for the Global Solar Industry

Breaking the Mold in North America

The North American solar market is relatively mature, with 1 kV inverter technology as the industry norm. Thanks to GE's partnership with a leading U.S. solar PV operator, that is now changing - and fast.

GE is supplying its new 1.5 kV inverters to solar farms across the U.S. The total installed capacity will be over 1GW, and the project marks a turning point in the industry. It is expected to be the fastest and largest deployment of 1.5 kV technology by a single developer in North America, and shows a major shift towards the 1.5 kV plant design.

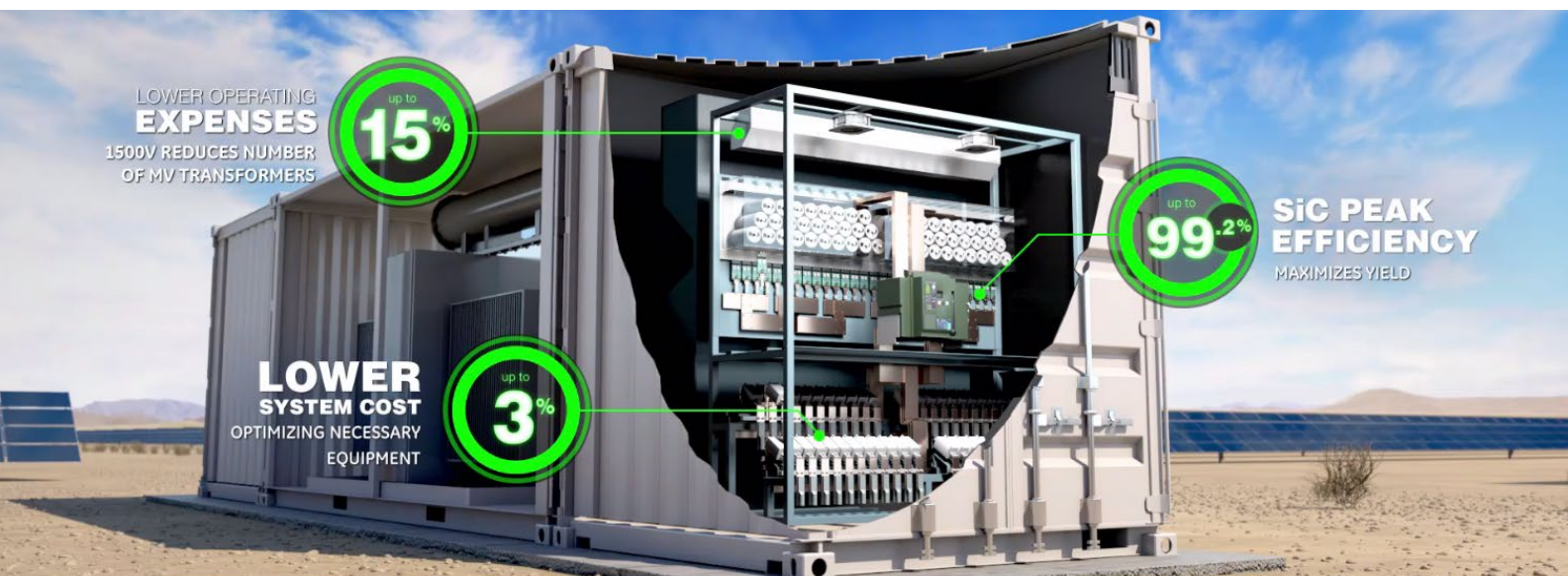
1.5kV Inverter Technology puts Japan Ahead

GE has also partnered with a Japanese solar plant developer to bring 1.5kV solar inverter technology to Japan. In the first pilot project, GE is providing two 1MW, 1.5kV inverters. It is the first step in bringing Japan to the forefront of solar technology, making cheaper, more efficient utility-scale solar the new national standard. With Japan facing a shrinking feed-in tariff, this move towards lower cost couldn't be better timed. The new technology makes for fitter, leaner solar PV, enabling the industry to shift towards greater resilience - both now and into the future.

The Benefits are Significant

The higher voltage doubles the power rating, lowering system losses and plant costs. And because GE's LV5 inverters come with the latest plant controller system, Operation and Maintenance (O&M) is more efficient and grid integration is smoother.

GE's 1.5 kV technology opens up new possibilities for operators to drive costs down, add value and position themselves at the vanguard of a new era for utility scale solar.



4. What's Next?

4.1 Silicon Carbide—A Game-Changer

Over the last ten years, scientists at GE's Research Centers (GRCs) have been developing a revolutionary new power switch using a material that could quickly replace traditional silicon as the standard semiconductor for power conversion. Silicon Carbide (SiC), first discovered in an attempt to produce artificial diamonds, shares many diamond-like properties. Not only is it durable and resilient, and can conduct electricity operating at higher temperatures and with lower losses, it's ideal for use at higher voltages.

GRC has a long and proud history of developing innovative applications that directly meet market needs. In the case of SiC, they applied its properties to create new technologies within the medical and aviation industries—and now, in the very latest, next-generation solar inverters.

GE's new LV5+ SiC solar inverter can achieve up to twice the power density and half the losses compared to silicon designs. Since it generates less heat, it only requires an air-cooled system, so the overall design can be simpler and more reliable. This alone can generate approximately U.S. \$300,000 in opex savings over a 100 MW power plant's lifetime.*

Just One Percent Makes a Big Difference

Many of today's solar inverters are 98 percent efficient, based on the EU 'weighted' efficiency calculation standard. GE's SiC solar inverter breaks this ceiling to hit 99 percent efficiency – another industry first. If that doesn't sound like much, consider this: if a 100MW plant were 1 percent more efficient, it could generate power equalling up to US\$2.5* million over the plant's lifetime.

4.2 The Future is Digital

Predix-based apps are unleashing new levels of performance with over \$50B assets predicted to be connected to the internet by 2020. The Industrial Internet is helping industrial companies reach new levels of productivity and gain a competitive edge.

Predix, GE's cloud-based platform (PaaS) for Industrial Internet applications delivers the industrial intelligence needed to transform industrial operations. It combines people, machines, big data and analytics.

Running a solar farm is driven by LCoE and maximizing the annual energy production. After the initial installation comes the ongoing performance monitoring and maintenance of every piece of kit across the farm, which can extend to the size of a small city. The aim is zero downtime, as just one faulty part can take hours or even days to identify, locate and replace—which can have a heavy impact on output. All this potential risk inevitably contributes to pushing up maintenance costs.

Typical concerns about the critical performance of solar equipment can result in a high contingency reserve of up to five percent, overspend on data-blind O&M contracts of up to eight percent of revenue and/or loss of kWhs in the range of between one and three percent of revenue.

This is why the industry is so enthusiastic about digitization—in other words, acquiring automated, real-time performance data from the installation and analyzing it to gain crucial insights. Digitization done well can predict faults before they occur, and identify degradation before it causes faults.

Solar farms are able to switch from scheduled to predictive maintenance, minimizing the risk of downtime and reducing labor costs in the process.

* All values undiscounted cashflow, 30-year project life with 2,500 MWh AEP baseline

Real Time Insights = Real Time Benefits

GE solutions use a combination of physics based and machine learning models to predict equipment health, therefore improving maintenance schedules and minimize maintenance cost. Predictive maintenance allows optimized onsite visits with intelligent GE solutions which helps to reduce total maintenance cost by up to 30%.

Predictive analytics identify areas of downtime risk quantified against financial impact. Recommended actions are relayed to the field service engineer which can enable up to 80% reduction in losses due to downtime.

Optimized Spare Parts Management is an integrated solution, enabling the alignment of spare parts stock and usage, site location and an automated shipping processes allowing up to 100% just in time parts delivery.

These are compelling benefits—but what is perhaps even more exciting is what digitization can do for the perceived risk profile of the entire sector.

Utility-scale solar is still a young industry: only five percent of total global capacity has been operating for more than five years. Indeed, most of the world's solar farms are so new, they are still under warranty. The technology has transformed exponentially in the last few years alone, and continues to evolve at high speed. While this may attract the bold, it deters the risk-averse. With innovation, comes uncertainty: how do you accurately predict performance over a solar farm's lifetime, when most, if not all, of its infrastructure has never been applied for that long?

This is why digital solutions will play a key role in the future viability of utility-scale solar. Through analyzing data drawn from the infrastructure, we will be able to accelerate the learning curve of applying new technology and, in doing so, reduce the perceived risk. This, in turn, will help reduce the costs of financing and set the industry on a far better footing to evolve in the future.

Driving the Solar Revolution

GE is partnering with its customers to help power the world's solar farms. GE is breathing life into the Japanese solar market by providing its inverter skids to Pacifico Energy to build one of the largest solar plants in Japan. Upon completion, the plant is expected to power up to 30,000 households and reduce CO2 emissions by 68,200 tons per year.

The landmark project Mohammed bin Rashid Al Maktoum Solar Park broke the unsubsidized world record low price at the time, then US\$5.84cents/kWh (2016), making solar power economical enough to compete with fossil fuels in the Gulf countries. The second stage of the project, which uses GE technology, is now generating 200MW of electricity, enough to offset 250,000 tons of carbon dioxide every year.

GE is also starting the first and biggest LV5 solar inverter deployment in India. Partnering with Solairedirect, a subsidiary of Engie, GE will provide 140MW inverters and a 25-year long-term service agreement.

Most recently, GE has been chosen by Invenergy, North America's largest, independent, privately-held renewable energy company, to deploy GE's solar asset performance management (APM) software, powered by Predix, to a 20 megawatt (MW) solar farm, anticipating to achieve over 99 percent plant availability.

5. The Power of Integrated Systems

As the solar PV market is rapidly growing, developers, investors, owners and operators focus on predictability and reliability of operations and annual energy production to minimize risk and get the best return.

With fast global expansion and rapid scaling up of solar farm sizes, the whole process becomes increasingly complex: from initial planning, financing, design, and engineering, through installation, reliable operation and grid integration up to maintaining a plant over the complete up to 20+ years project lifecycle.

So far, we have seen how innovation is driving down the LCoE for solar, yet a volatile economic environment drives the desire for sustainable investments with predictable returns. How can developers and other stakeholders ensure they extract the most benefit from the technology available, while mitigating risk? This is where we believe drawing on trusted, proven expertise is crucial. To minimize the risk from interfaces, and to allow focus on own business operations such as selling power, the need for reliable and sustainable partnerships arises.

5.1 Partnership Matters

GE interacts across the utility scale solar PV ecosystem as one counterpart for developers, investors, owners and operators spanning the full project cycle.

With GE, you do not simply acquire a powerful piece of kit—you gain a partner committed to making your venture a success through its entire lifetime. From providing finance to project management and maintenance, we coordinate and combine resources, partnerships and expertise every step of the way—helping our customers reduce risk and make their vision a reality.

5.2 More Than Just Inverters

Building on more than 4+GW of solar inverters shipped worldwide, GE offers the power of full solar system solutions. Providing leading solar inverter technology to drive cost-effective solar PV utility-scale infrastructure based on advanced SiC technology including integrated skid and eHouse solutions.

Our customers benefit directly from the power of GE, and beyond just central inverters, we're able to deliver a full suite of powerful solutions that meet our solar customers' needs:

On demand battery storage & hybrid solutions - Breaking new ground in innovating decentralized energy supply, battery energy storage solutions can enable up to 20% higher energy output. GE's

battery energy storage can be combined with PVs and cogeneration technology to create hybrid power plant solutions for clean, reliable & predictable power.

Electrical Balance of Plant (EBoP) solutions that range from high voltage switchyard equipment to systems hardware and design, and engineering services include system studies, civil, electrical, protection and control engineering, control building and panel assembly and on-site installation and testing.

Digital solutions that increase your asset reliability and availability with customized service agreements across the solar farm lifecycle. Helping you to see failures before they occur with digitally enabled performance guarantees in various partnership models.

GE's Energy Consulting experts provide techno-economic consulting services, planning software tools, and training to help overcome renewable integration challenges, and

GE's Financial Services invests in long-lived and capital intense energy projects, and provides financing & domain expertise to GE and its customers, to help reduce upfront capex with attractive financing models.

5.3 GE as Partner Throughout the Entire Project Lifecycle

GE, as your partner of choice for solar solutions, offers a range of partnership models designed to guarantee performance, and achieve investable returns without compromising on quality. GE's equipment and bankability ensures optimal development costs and can include either technology, bilateral or full turnkey partnership models.

TECHNOLOGY PARTNERSHIP MODEL

- Performance ratio guarantee
- Decision of the PV module technology
- Optimization of the competitive tariff or capital cost or O&M or IRR

BILATERAL PARTNERSHIP MODEL

- Technology partnership model
- Equity investment up to 40%
- Project development expertise
- Lower cost debt financing

TURNKEY PARTNERSHIP MODEL

- Bilateral partnership model
- Construction, civil & installation works
- Project lifecycle partner with single interface

Integrated Solar Solutions



5. Summary

The Future Looks Bright

As we have read, it is clear that there has been huge innovation across the whole solar PV industry. At GE, we see the entire solar industry as an ecosystem in which each piece is inter-connected. By taking an integrated system approach to solar plant management that encompasses the 'best fit' of every piece across the solar energy value chain, we offer customers more reliable solar systems solutions that are less complex, with reduced cost and risk.

Digital solutions such as APM are a critical first step in the journey towards a more cost-effective plant, which optimizes power generation. The industry will not only see immediate improvements, but will also be future proofing for long-term performance gains.

With leading inverter technology, fully integrated systems, services and digital solutions, GE is a bankable partner supporting customers across the entire project lifecycle. Having matured from a component supplier to a complete solar PV solutions partner, GE has the technology, capability and tools to drive utility scale solar PV to the next level.

For solar PV, this innovation across the industry has driven down LCOE to record levels. This drastic reduction has taken the brakes off the industry and accelerated capacity growth. Today, utility-scale PV is fit and mature enough to compete in the global energy market, and together with our customers, we're leading the way towards a bright future.



About GE

GE is the world's Digital Industrial Company, transforming industry with software-defined machines and solutions that are connected, responsive and predictive. GE is organized around a global exchange of knowledge, the 'GE Store', through which each business shares and accesses the same technology, markets, structure and intellect. Each invention further fuels innovation and application across our industrial sectors. Through its people, services, technology and scale, GE delivers better outcomes for customers by speaking the language of industry. To learn more, please visit www.ge.com

About GE Power Conversion

GE's Power Conversion business, a business unit of GE Power, applies the science and systems of power conversion to help drive the electric transformation of the world's energy infrastructure. It does so by designing and delivering advanced motor, drive and control technologies that evolve today's industrial processes for a cleaner, more productive future. Serving specialized sectors such as energy, marine, renewables and industry, through customized solutions and advanced technologies, GE Power Conversion partners with customers to maximize efficiency. For more information, please visit www.gepowerconversion.com/industries/renewables/solar-solutions

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