Volume 13 PV POWER PLANT TECHNOLOGY AND BUSINESS December 2017

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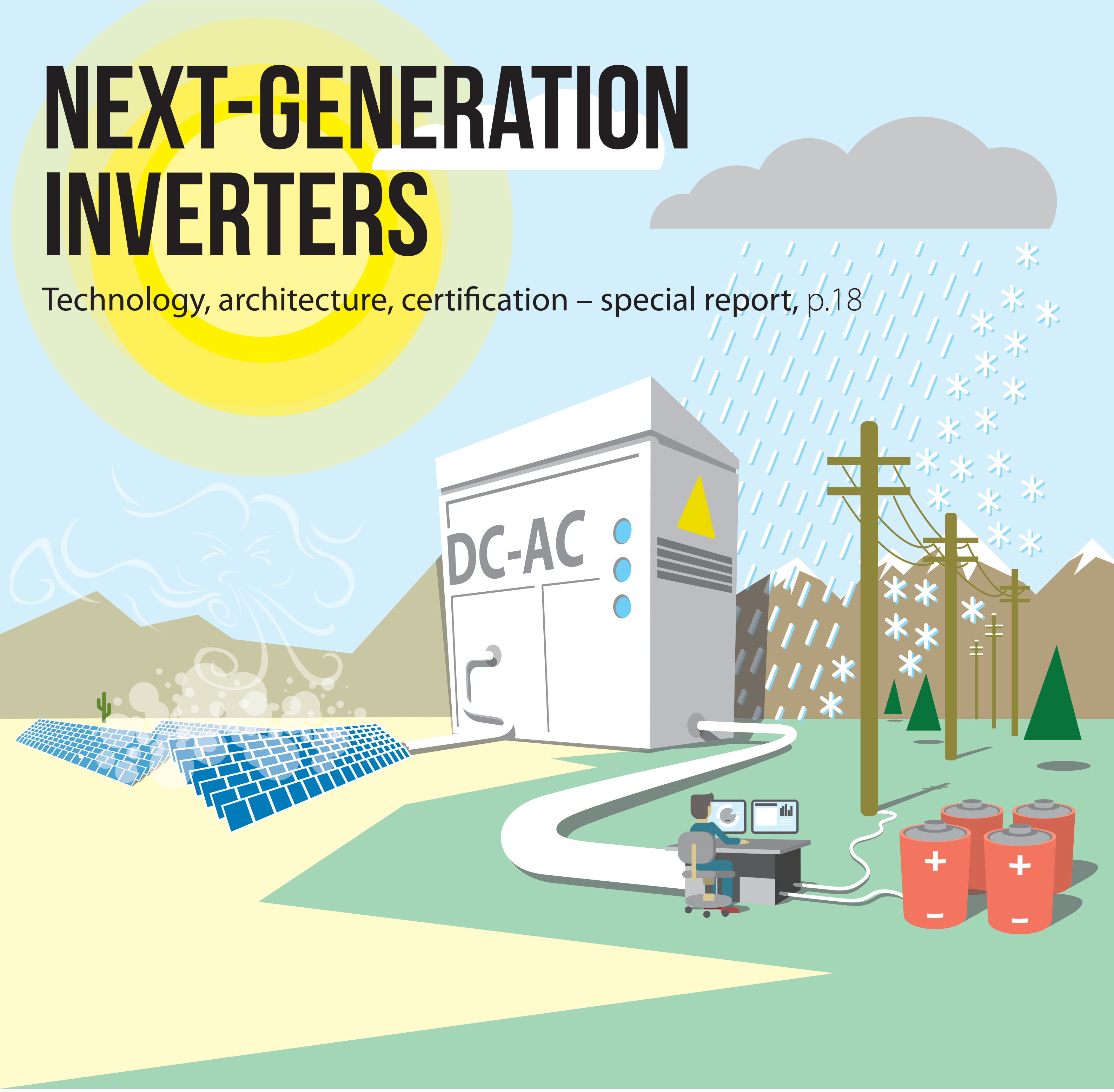

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About LONGi Solar

A world leading mono-crystalline solar module manufacturer for achieving best LCOE (levelized cost of electricity) solutions.

LONGi Solar is a world leading manufacturer of high-efficiency mono-crystalline solar cells and modules. The Company is wholly owned by LONGi Group. LONGi Group (SH601012) is the largest supplier of mono-crystalline silicon wafers in the world, with total assets above $2.7 billion. (2016)

Armed and powered by the advanced technology and long standing experience of LONGi Group in the field of mono-crystalline silicon, LONGi Solar has shipped approximately 2.5GW products in 2016. The Company has its headquarters in Xi'an and branches in Japan, Europe, North America, India and Malaysia.

With Strong focus on R&D, production and sales & marketing of mono-crystalline silicon products, LONGi Solar is committed to providing the best LCOE solutions as well as promoting the worldwide adoption of mono-crystalline technology.

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LONGi Solar

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Introduction

Welcome to Volume 13 of PV Tech Power, unlucky for some perhaps, but we're confident this issue has a stellar line-up owing nothing to good luck.

As always we've put a lot of time into identifying topics that offer real value to you and that delve deeper into the nuts and bolts (literally in some cases) of the solar deployment business.

While module and cell technology draw a lot of attention, inverters are often overlooked. To begin the process of addressing this imbalance we have compiled a three-part inverter special report. Fraunhofer ISE examines the emerging trends in inverter technology (p.18). Sungrow assesses the prospects of 1,500V(DC) architecture and, crucially, what comes next (p.22). Finally, certification body UL acknowledges the rise of smart inverters and presents a roadmap to ensure testing processes keep pace (p.27).

The Middle East has begun delivering meaningful volumes of MWs and is transitioning from hype to delivery. Jordan-based O&M provider MASE lifts the lid on the real-world challenges presented by regional projects and how to address them, including some novel solutions to preventing inverter failure in high temperatures (p.67). We also speak to Sterling & Wilson, the EPC contractor on Abu Dhabi's 1.2GW Sweihan project to learn how it is maximising the LCOE to deliver on a headline grabbing tariff rate (p.72).

First Solar offers some insight to its recycling procedures and how these impact on a project's lifecycle costs.

Liam Stoker reports from the site of the UK's first unsubsidised, large-scale solar plant. The 10MW development is co-located with storage as part of the effort to make the economics stack-up (p.64).

Speaking of energy storage, our Storage and Smart Power section, developed in partnership with our colleagues at *Energy-Storage.News*, offers a superb array of must-read material.

Navigant's Alex Eller explores how energy storage can replace traditional grid infrastructure (p.84) and we have a pair of papers providing alternative views on the role of blockchain in a modern power grid.

Clean power investor Jigar Shah speaks with Andy Colthorpe on life at the leading edge of clean energy finance, not to be missed (p.92).

The team will be at the World Future Energy Summit in Abu Dhabi in January as well as at our own European solar finance event in London (30-31 January, 2018). We look forward to seeing you there.

John Parnell
Head of content

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EUROPE

Post-subsidy

WElink starts constructing 'largest unsubsidised' solar project in Europe

WElink Energy has started construction of a 221MW solar PV plant in Portugal that will not benefit from subsidies. The Solara4 project, located in Vaqueiros, southern Portugal will be the largest unsubsidised solar PV plant in Europe, the company claimed. The project is of major significance to the European industry given the widespread winding down of subsidies over recent years. Only 15 months ago, Portugal's renewables association had said solar cannot work without financial support in the market conditions of that time. The new 221MW project will generate power for the equivalent of 150,000 homes. WElink's long-standing partner China Triumph International Engineering Co. Ltd (CTIEC) was signed up as EPC contractor earlier this year. At the time of the signing, WElink had said construction was expected to start in Q1 this year, so there has been some delay. WElink claimed that it will be able to deliver the project without subsidies due to the increasing competitiveness of PV generation and the two firms' ability to optimise costs. The southern location in Portugal also boasts excellent irradiation levels. Solara4 will include 850,000 solar modules and is expected to employ around 300 people during construction. The project is expected to be grid-connected by mid-2019.

Credit: WElink

WElink claimed PV's general competiveness in the country and ability of it and its EPC partner to optimise costs were the key enablers for the unsubsidised plant.

Hive Energy, Wirsol confirm plans for 'pioneering' 350MW solar farm in the UK

Not to be outdone, developer Hive Energy submitted planning documents for a 350MW plant in the UK that would be built without subsidy. Hive has partnered with EPC firm Wirsol, and the duo has formed the SPV Cleve Hill Solar Park Ltd to advance the project. Should the project complete, Cleve Hill will be almost five times the size of the UK's current largest solar farm; the 70MW DTTC Lyneham array completed in 2015. It will be located between the Kent towns of Faversham and Whitstable in the south of the country. The project, dubbed Cleve Hill Solar Park, will also be designed differently to standard solar farms in the UK to provide the maximum amount of electricity. Panels are to be orientated in an east-to-west fashion, rather than south-facing, and will also be mounted at a shallower angle than usual to produce a more consistent generation curve. Battery storage will also be incorporated into the design to provide grid balancing services.

The Netherlands

Capital Stage acquires two planned solar parks in the Netherlands

Independent European PV power plant operator Capital Stage has entered the Netherlands market for the first time with the acquisition of two solar parks that are expected to be completed in 2018. Recently, GTM Research reported that the Netherlands has seen strong annual growth since 2011, primarily from the residential rooftop market, driven by the 'Stimulation of Sustainable Generation' scheme in the country, and would for the first time become a 1GW market in 2018. Capital Stage said that the two solar parks Melissant (10MW) and Ooltgensplaat (37.6MW) will provide a total generation capacity of 47.6MW with an investment of €44.5 million. The projects are expected to be completed and be grid connected in October 2018.

First Solar to provide 19MW in PV modules for two projects in Netherlands

First Solar will provide its thin-film PV modules to help power two utility-scale PV power plants in the Netherlands, with both installations developed by Denmark's Obton. The company broke ground on the first project, a 13.92MW installation, in November, while the other 4.4MW project is expected to come online in mid-2018. Both installations are located in Stadskanaal and have secured licenses under the country's SDE+ renewable energy programme.

Supply deals

SunPower to supply 291MW in second round of CRE4 French tenders

SunPower announced that it will supply 291MW of its solar panels to projects awarded under the second round of France's CRE tender process. These projects include ground mount, carport and rooftop projects in continental France, along with storage and self-consumption in the country's ZNI (non-interconnected zones). Peter Aschenbrenner, SunPower executive vice president, said: "With these awards, the total capacity of SunPower solar panels supplied to ground, carport and rooftop, and ZNI projects awarded in this year's first and second round tender process is 505MW, more than any other solar panel brand. "SunPower solar panels deliver cost-competitive power and proven long-term reliability, and we are proud to play a significant role in serving France's goals for clean, renewable solar power."

JinkoSolar was panel supplier to Armenia's first utility-scale PV power plant

Leading 'Silicon Module Super League' (SMSL) member JinkoSolar has supplied 3,700 'Eagle' multicrystalline modules to the first 1MW utility-scale PV power plant in Armenia. JinkoSolar said that the opening ceremony took place in November in the city of Talin in collaboration with Staubli, Enerparc and Sungrow and project developer, Arpi Solar. The plant has a PPA for 25 years. In mid-2017, the Armenia Ministry of Energy Infrastructure and Natural Resources announced that it has pre-qualified 10 companies for a 55MW solar tender.

AMERICAS

Companies

First Solar produces first Series 6 model

First Solar reported strong results, a new manufacturing plant in Vietnam and confirmed that the first Series 6 module had been produced. The company realigned its manufacturing strategy to accelerate its focus on the larger format Series 6 panels, which it claims will reduce installed costs per W. Major orders for Series 6, nudging 800MW, were also announced in December.

Tesla loses solar crown

Tesla reported a 38% decline in solar system installations in the third quarter of 2017, compared to the previous quarter, its weakest installation figures since the acquisition of SolarCity in 2016. Tesla said it deployed 109MW of energy generation systems in the third quarter, down from 176MW in the second quarter and 170MW in the prior year period. The company is losing major market share in the process, with GTM Research reporting that Sunrun was set to eclipse Tesla/SolarCity as the top residential solar provider.

Central America and Caribbean

World Bank approves US$35 million for renewables and energy access in Haiti

The World Bank has approved two grants of US$35 million in total to improve access to electricity for more than two million Haitians, and to scale-up investments in renewable energy. The bank noted that more than five million people could be reached through solar PV, adding that only one in three Haitians has access to electricity and access is limited in rural areas. Anabela Abreu, World Bank's country director for Haiti, said: "Haiti has significant untapped sources of renewable energy. The country is taking an important step in creating the enabling environment for private investors and in boosting access to electricity.

Enel begins 8MW solar PV plant for Nestle in Panama

Construction is underway on an 8MW solar PV plant in Panama by Enel Green Power (EGP) for Swiss company Nestle. Project Estrella will receive US$8 million for construction from Enel which expects the project to be completed by June 2018. The project is estimated to produce 12GWh annually, covering 9.8 hectares and containing around 21,600 solar panels.

South America

Celsia makes pact with indigenous peoples over 100MW Colombia solar project

Celsia, the energy arm of Colombian conglomerate Grupo Argos, has moved forward with its development of a 100MW solar farm in Colombia by reaching an agreement with the indigenous people of the Sierra Nevada de Santa Marta in the Andes mountains. The Valledupar farm, to be spread across 197 hectares in the village of La Mesa, will be able to generate 187GWh of electricity each year, to power the equivalent of 105,000 homes. It is now expected to start operations in the first half of 2019.

EDF, Canadian Solar commission 284MW PV pipeline in Brazil

Canadian Solar and renewable energy company EDF Energies Nouvelles have commissioned the 191.5MW Pirapora I and the 92.5MW Pirapora III solar energy projects in Brazil, with the two projects boasting a combined generation capacity of 284MW. Both sites were commissioned in November 2017. The Pirapora I and III solar projects, located in the Brazilian state of Minas Gerais, were each awarded a 20-year power purchase agreement following the second and first Reserve Energy Auctions, respectively. The two projects, powered by 600,000 solar panels and 290,000 Canadian Solar modules, will generate 392 GWh and 186 GWh of clean, renewable energy.

Section 201

US trade case handed over to President Trump

The US International Trade Commission (ITC) recommended duties and quotas in the section 201 case that fall some way short of those requested by the petitioners. None of the four commissioners recommended absolute value tariffs, instead opting for percentages over a set value. None of the four commissioners exceeded 35% with most at or below 30%. The suggestions will be passed to the White House with President Trump making the final ruling before the end of January. In late September, the petitioners in the case, Suniva and Solarworld Americas, lowered their requested remedies. Suniva lowered its floorprice from US$0.78 for modules with foreign cells to US$0.74. SolarWorld suggested a quota of 0.22GW for cells and 5.7GW for modules in 2018 instead of a floor price. Both insisted any remedy must include a tariff with a rate of US$0.25/W for cells and US$0.32/W for modules and protested that the proposed rates were too lenient. According to ROTH Capital, a 30% tariff would mean c-Si module ASP of around US$0.49/W. In a follow-up investor note, ROTH Capital said that further industry checks suggested a post-tariff c-Si module ASP of US$0.42/W.

Credit: Flickr/White House

Trump will make the final decision by the end of January.

MIDDLE EAST & AFRICA

Unique Plants

Jordan connects 12.9MW PV project in refugee camp

Jordan has officially switched on the largest PV project ever to be developed in a refugee camp, with the 12.9MW project set to provide renewable energy to nearly 80,000 Syrians. The PV project was developed at the Zaatari refugee camp on the border of Jordan and Syria, with the power generated at the installation allowing families to run a fridge, TV, fans and lights in their shelters. The US$17.5 million project, which was funded by the German government, will provide electricity in the Zaatari camp for up to 14 hours a day.

Dubai utility awards floating solar contract

Etihad Esco is set to develop and install floating solar PV systems after being awarded a contract by Dubai Electricity Water Authority (DEWA). Ali Al Jassim, CEO of Etihad Esco, said: "The installation of solar PV systems at DEWA water reservoirs comes under the implementation of the vision of the Vice President, Prime Minister and Ruler of Dubai, HH Sheikh Mohammed bin Rashid Al Maktoum, to transform Dubai into one of the most sustainable cities in the world." Esco said the installation of systems on DEWA's water reservoir will add to Dubai's solar power energy mix and reduce the emirate's carbon footprint.

Politics and finance

IFC-led consortium finalises 'largest private sector financing package' for solar in MENA region

The International Finance Corporation (IFC) has finalised a US$653

Saudi Arabia

Bids in 300MW Saudi solar tender breach two cents

Credit: Getty

Saudi Arabia's 300MW solar tender saw opening bids go lower than two US dollar cents per unit, setting the tone for a new global solar power tariff record if awarded. Abu Dhabi Future Energy Company (Masdar) bid for 300MW capacity with a tariff of SAR0.0669736/kWh (US$1.786 cents). Saudi Arabia's new Renewable Energy Project Development Office (REPDO) revealed the eight companies that had made it through to this stage, having had 27 companies shortlisted originally in April. These bids will be evaluated for compliance with the requirements of the RfP. The project will be awarded to the winning consortium on 27 January 2018, backed by a 25-year power purchase agreement (PPA). The financial closing date will be 28 February 2018 and the commissioning date is expected during 2019. In April, analysis firm GTM Research forecast that this tender, for capacity located at Sakaka in Northern Saudi Arabia, was the most likely contender for solar to break 2 US cents in 2017.

million debt package for 13 solar projects at the Benban Solar Park, near Aswan in Egypt. This is the largest private sector financing package for a solar PV facility in the Middle East and North Africa (MENA) regions. The 13 plants will have a combined capacity of 752MW. There have been a number of announcements regarding financing of the various PV projects at Benban in recent months, with multiple finance institutions including the European Bank for Reconstruction and Development (EBRD) and developers confirming progress.

Zimbabwe utility plans first 300MW of solar

Zimbabwe state-owned power company Zimbabwe Power Company (ZPC) has applied to develop three solar PV plants with the Zimbabwe Energy Regulatory Authority (ZERA). This is the firm's first foray into solar energy. The three 100MW projects would be based at Gwanda, Munyati and Insukamini, and are expected to take two years to construct at an estimated cost of US$570 million. Feasibility studies have been carried out and EPC contracts signed. The company now awaits approval of its application from ZERA. However, Robert Mugabe's "resignation" after 37 years in power has created both political uncertainty and new possibilities for Zimbabwe's solar market. Solar has begun to emerge in Zimbabwe, but remains undeveloped due to the political uncertainty of recent years.

Big plants

Huge Iranian projects in the pipeline

Norwegian firm Saga Energy has signed a preliminary agreement with Iranian state-run firm Amin Energy Developers to build solar plants requiring investment of €2.5 billion investment (US$2.9 billion) in Iran. The plans for 2GW of PV capacity are still reliant on finalising guarantees from Iran's capital Tehran in order to proceed. Meanwhile, Quercus will build a 600MW solar plant in Iran as part of an agreement with the country's energy ministry. Quercus will take a lead on development and operation of the plant, which will be built at a rate of 100MW every six months for three years.

The company has signed a PPA for the project at a "comparable" rate to other large PV sites in the region.

Belectric to build Israel's 'largest' PV plant

Belectric has won the engineering, procurement and construction (EPC) contract for a 120MW project in Israel. Belectric will work with local engineering firm Solel Boneh on what they claim to be the country's largest project. Work is expected to commence within the next few months with commissioning in 2019. "Zeélim is the largest single PV project in our company history outside of Germany," said Ingo Alphéus, CEO, Belectric Solar & Battery GmbH. "We are very proud that this EPC contract has been awarded to us. This is in line with our strategy to significantly grow our business in key solar markets like Israel." Belectric will also take on the O&M contract for the plant after completion, adding to its existing portfolio of 1.3GW.

Record deal

Equis Energy bought by GIP for US$5 billion in record renewable energy deal

US-based investment fund Global Infrastructure Partners (GIP) and co-investors have acquired Singapore-headquartered Equis Energy, the largest renewable energy IPP in the Asia Pacific region, for US$5 billion along with assumed liabilities of US$1.3 billion. This is the largest renewable energy acquisition ever, with GIP set to take over 180 assets with a combined capacity of 11,135MW in operation, construction and development across Australia, Japan, India, Indonesia, the Philippines and Thailand. The transaction is subject to customary regulatory approvals and is expected to close in the first quarter of 2018. David Russell, cheif executive of Equis and chairman of Equis Energy, said: "The investment by GIP and its partners is exciting news for the development of renewable energy in the Asia-Pacific. GIP has a strong track record of managing and growing utility-scale infrastructure businesses, and the combination of experience and knowledge across GIP and the existing management team will allow Equis Energy to continue expanding competitively across its target markets." In August, Equis said it would build a 1GW solar project in Queensland that would be the largest in Australia.

ASIA-PACIFIC

Far East

Seoul-ar City: South Korean capital investing US$1.5bn for 1GW of PV

South Korean capital Seoul plans to invest US$1.55 billion in a solar plan, which aims to install 1GW of PV generation capacity by 2022. "Solar City Seoul" will involve the undertaking of seven initiatives then subdivided into 59 separate projects. One key element of the plan is to oversee the increase of miniature solar generators on household rooftops and verandas from around 30,000 up to one million.

Influential think tank recommends 200GW solar target for China

The Chinese government should increase its 2020 solar target from 110 to 200GW, according to the China National Renewable Energy Centre (CNREC). The think tank is the main advisor to the government's National Energy Administration (NEA), which would be ultimately responsible for acting on the recommendation. In August, the continuing boom of installations saw the country edge past its existing 2020 target. Frank Haugwitz, of the Asia Europe Clean Energy Advisory (AECEA), which highlighted the recommendation in a briefing note, considers the target to be achievable. "The recommended 'new' solar PV target in AECEA's opinion will be realised, if not exceeded by approx. 15-20%," he wrote.

Southeast Asia

Masdar and Indonesian power giant to build world's largest floating solar plant

Indonesian power company PT Pembangkitan Jawa-Bali (PT PJB), a subsidiary of state utility PLN, and the UAE's Masdar have signed an agreement to develop the world's largest floating solar project with a capacity of 200MW in Indonesia. This would be twice the size of a 100MW floating PV plant planned by Hanwha and five times larger than the current largest project of 40MW built by Sungrow in Anhui Province, China. Sungrow and Chinese firm CECEC are also constructing 150MW and 70MW projects respectively in the same region of China. The plant will be built on the reservoir of an existing 1GW hydropower plant.

Vietnam's final solar PPA still short of bankability

Vietnam's final solar power purchase agreement (PPA) has to a large extent ignored recommended changes from a group of international Chambers of Commerce and therefore its attractiveness to foreign investors remains in doubt. The Ministry of Industry and Trade (MOIT) officially released a Circular including the revised solar PPA acting as a mandatory template for utility-scale and rooftop solar projects. The Vietnam Business Forum (VBF), an umbrella group for multiple international Chambers of Commerce, had expressed a long list of concerns about the original draft PPA back in May.

India and South Asia

India plans 77GW of solar tenders in three years

India has announced plans for an unprecedented solar procurement regime that aims to tender for 20GW in 2017/18, followed by another 30GW in each of the two following years, but analysts have described the policy as "completely unrealistic". The main tendering in the current fiscal year would follow the timeline below:

- 3GW in December 2017
- 3GW in January 2018
- 5GW in February 2018
- 6GW in March 2018

Vinay Rustagi, managing director of consultancy firm Bridge to India, said: "There is clearly no detail to how the government is going to actually fulfil or implement such an ambitious roll out and it just seems like this is a simplistic plan - a 'filling the gap' kind of plan rather than something which takes into account the various challenges on the ground and tries to solve them one by one to then achieve the 175GW target."

Indian solar asset sellers getting 'desperate'

Many developers with solar assets in India are looking to sell their portfolios. Some of them have been in the market for a long time and are under pressure from their investors to find an exit. Vinay Rustagi, managing director of Bridge to India, said: "If you look at all the developers in India, most of them are backed by private equity money or corporate capital, which needs to find an exit in the next 2-3 years depending upon the horizon of the individual investors." Rustagi's comments come after a spate of reports suggesting a large number of companies are looking to divest their Indian solar assets, including Ostro Energy, Essel Infra, Orange Power, Shapoorji Pallonji, SkyPower, Fortum and FRV.

Product reviews

Tracker | BIG SUN's iPV Tracker has new bifacial module version to boost yield

Product Outline: BIG SUN Group has combined its dual-axis iPV Tracker with a bifacial module resulting in up to a claimed 100% power generation gain over a conventional fixed-tilt system.

Problem: Bifacial PV modules, which have the ability to significantly increase PV power plant yields, require fixed mount and tracker systems that do not impede scattered light from the rear solar cells as this can limit yield benefits.

Solution: BIG SUN's iPV Tracker has been redesigned to maximise the use of bifacial modules. iPV tracker's unique 360 degree, universal-axis design with a slim cable

drawn driving mechanism, has reduced the shading impact from the linear actuator and slewing drive employed with the conventional dual axis trackers. To eliminate any shading from the module mounting frame, BIG SUN has redesigned the rear supporting frame so as to match exactly to the frame dimension of any module.

Applications: PV power plants.

Platform: The iPV Tracker is tall enough to have the sunlight reflected and absorbed onto the rear side of the bifacial module. These features enable the realisation of the benefits of bifacial modules, especially in snow season regions. Fitted with BIG SUNs energy monitoring system, iPVita, the iPV Trackers can reach > 99.9% availability in field operation.

Availability: Available since September 2017.

Plant control | DNV GL launches world's first control hardware in loop test bench for PV power plants

Product outline: DNV GL has launched the first control hardware in loop (CHIL) test facility for renewable energy generation plants. The facility connects physical power plant controllers to a real-time simulator, allowing the controller to be fully tested and validated without the need for an actual generation facility or power grid.

Problem: Since 2016, Germany has updated its medium- and high-voltage grid codes to require certification of all wind farm controllers before the wind farm can start supplying the grid. Similar guidelines are expected to follow elsewhere in the world, both nationally and internationally and include solar PV power plants. Until now, testing controllers meant downtime for the

generation farm and huge effort coordinating many different players. What's more, a failure during testing could have far-reaching and expensive consequences.

Solution: The physical controller is connected to a real-time simulator that emulates the solar farm as well as the grid connection. Furthermore, a communication layer is included for the master SCADA simulating the grid operator. This setup allows the controller's behaviour in any situation to be explored, and any unwanted interactions to be identified.

Applications: PV power plant control hardware can be rigorously tested under real-world conditions without connection to actual generating plants and energy grids.

Platform: The test bench allows complete testing according to the latest revisions of the German grid codes, with the possibility of ISO 17025 accredited measurements. DNV GL will make it available for customers including controller manufacturers, and renewable energy generation site developers and operators through testing and measurement services.

Availability: Available since September 2017.

System design | GCL-SI offers 'Super 2.5MW Solar Block' for modular PV power plants

Product Outline: GCL System Integration Technology (GCL-SI) has launched its first modular PV power plant system, incorporating single-axis tracking and 1,500VDC technologies.

Problem: The use of standardised and modular components developed together provides the opportunity to reduce balance of system (BOS) costs further, shorter installation times and increase reliability, compared to bespoke designs.

Solution: The Super 2.5 MW Solar Block is claimed to be cost-effective and to maximise space efficiency. The design of the block ensures long-term reliable operation, even in extreme environmental conditions, according to GCL-SI. The block

design utilises GCL-SI's in-house developed 96-cell modules with a specially developed horizontal single axis tracker to accommodate the large-area modules but with a reduction in panel fixture and electrical connections to support faster construction times. All components comply with 1,500VDC standards, which ensures lower costs in cabling and power conversion, leading to high system efficiency. The all-in-one PV inverter power container was specially developed with two 1000kW inverters with 1,500 DC System voltage, and one MV transformer, which further reduces on-site electrical and grid connection work. GCL-SI uses a built-in monitoring system for the inverter.

Applications: Utility-scale PV power plants.

Platform: GCL-SI is offering a global service network as well as remote monitoring, regular inspections as well as a full O&M service.

Availability: Available since October 2017.

Product reviews

Inverter | GoodWe launches the world's first AC-coupled retrofit inverter

Product Outline: GoodWe has launched its new SBP series, which is claimed to be the world's first AC-coupled retrofit solution with UPS function which allows energy storage and uninterruptible power supply to both single- and three-phase inverter systems.

Problem: Due to grid instability and the reduction of solar feed-in tariffs, grid-feed solar systems have become less economical, and an increasing number of users are turning to energy storage and self-consumption as an alternative. However, for those consumers with a conventional grid-connected solar system, replacing their existing grid-tied string inverter with a new hybrid inverter involves an additional costly investment. While there are AC-coupled inverter-charger hybrid systems on the market, none of them are able to offer uninterruptible power supply to prevent the connected loads from experiencing power interruptions.

Solution: GoodWe SPB Series is a cost-efficient, battery backup solution which can work alongside any grid-tied string inverters. Even though GoodWe SBP Series is a single-phase AC retrofit device, it can also work with a three-phase meter to become a three-phase energy storage system. By adding batteries, users can store the energy that the solar array is producing in the daytime and use it at night or even during a power outage. When the grid is down, GoodWe SBP seamlessly begins to invert power from the battery bank to power the critical loads, offering an automatic switchover time of less than 10 milliseconds.

Applications: PV residential rooftop systems.

Platform: GoodWe SBP Series works with any grid-tied string inverter and is compatible with BYD, LG, Pylon and GCL lithium-ion batteries.

Availability: Currently available.

Inverter | GoodWe's new MT series inverters provide greater output power for large DG projects

Product Outline: GoodWe has launched its second generation of MT Series string inverters, GW50K-MT and GW60K-MT, for large-scale commercial rooftops and ground-mounted solar PV systems. Apart from offering a more compact design and competitive price, the new MT Series provide a continuous power boost function to achieve a higher yield and quicker return on investment.

Problem: Conventional inverters are usually able to temporarily boost the AC output power but cannot offer a continuous and cost-effective solution to maximise the output from high-voltage solar modules. Therefore, a larger number of inverters is required to achieve a higher output, leading to a significant increase in capital expenditures and operating costs.

Solution: The new GoodWe MT Series provides a continuous maximum AC output power overload of up to 15%, reducing the total number of inverters to be installed, while minimising labour and installation costs. It also features a more compact design with less than 20% volume and lighter weight compared to other conventional models, which greatly simplifies installation and commissioning. With capacities of 50kW and 60kW, the new transformerless, three-phase GoodWe MT series grid-tied inverters are equipped with four MPPTs ensuring that the outputs of connected modules are able to generate the highest yields even in different PV installation conditions. In addition, it also allows a wireless communication network for monitoring and control of the entire system through smartphone, tablet or laptop.

Applications: Large-scale commercial rooftops and ground-mounted solar PV systems.

Platform: Two different MT Series string inverters, GW50K-MT and GW60K-MT, are available to adapt to different requirements in terms of output power.

Availability: Currently available.

Module | Hanwha Q CELLS launches Q.PEAK DUO modules with half-cut cell technology

Product Outline: Hanwha Q CELLS has introduced its Q.PEAK DUO module series that combines half-cut cell technology, six busbars and the company's proprietary Q.ANTUM (PERC) monocrystalline cell technology to offer efficiencies of close to 20% and power outputs of up to 330Wp from 120 half-cut cells and up to 395Wp from 144 half-cut cells.

Problem: Controlling the various degradation effects such as potential-induced degradation (PID), light-induced degradation (LID) and light and elevated temperature-induced degradation (LeTID), which can appear on multicrystalline or monocrystalline PERC solar cells in early operation stages, is required to mitigate the effects of degradation.

Solution: Q.ANTUM is the proprietary solar cell technology platform of Hanwha Q CELLS and the engine behind its complete portfolio of solar modules. While being based on the rear side passivation of the solar cell (PERC), Hanwha Q CELLs claims Q.ANTUM offers many additional features that differentiate it from conventional PERC technologies – primarily its strengths in controlling PID LID and LeTID.

Applications: Residential and C&I rooftops.

Platform: Hanwha Q CELLS's processes to control degradation are reflected in the performance warranties of all Q.ANTUM products, which guarantee at least 98% of nominal power during the first year, at least 93.1% of nominal power up to 10 years and at least 85% of nominal power up to 25 years. Additionally, Q.ANTUM features Hot-Spot-Protect and Tra.Q laser marking for 100% traceability of any cells produced, as well as strict Q CELLS quality standards.

Availability: Currently available.

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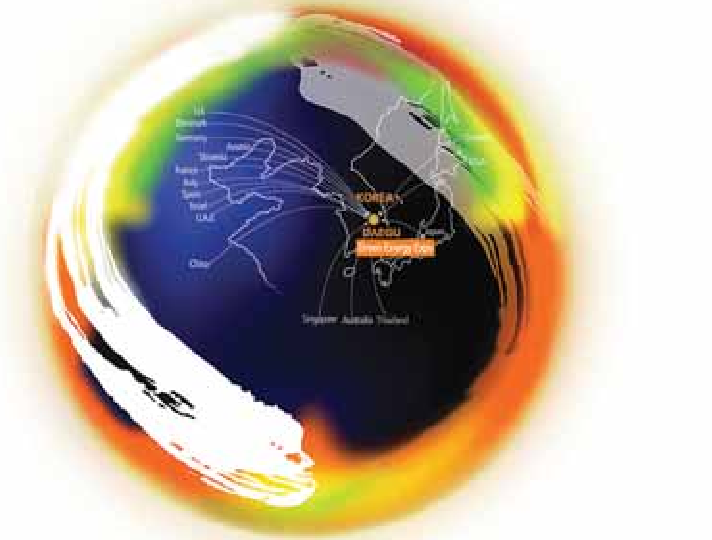

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Product reviews

Inverter | KACO's 'blueplanet 50.0 TL3 RPonly' supports grid stability with reactive power

Product Outline: KACO new energy has launched the blueplanet 50.0 TL3 RPonly inverter, which can feed in reactive power at any time in order to maintain grid voltage in the specified tolerance range – a key contribution to grid management.

Problem: When there is a lot of sunshine, solar parks can feed large amounts of energy into the grid when weather conditions enable high irradiance. However, when there is less irradiance, less electricity is generated resulting in fluctuations and grid impedance. One useful means of compensating for the resulting fluctuations in the grid is to provide what is known as reactive power.

Solution: As a "phase-shifting" device, the blueplanet 50.0 TL3 RPonly can supply any value of reactive power between 0 and 10%, current leading or lagging. The power is not given in watts or volt-amperes but in var. As its name suggests, the inverter can supply up to 50kvar. The correction value applied at the grid connection point is the crucial factor. This is where the park control system 'reads' the measured reactive power. If the measured value deviates from the set-point – which can be set to any value between 100% active and 100% reactive – the inverter will be requested to supply reactive power to the extent that is required to arrive at the target value.

Applications: The application goes beyond solar parks and can be used for reactive power compensation in industrial or other large consumer sites.

Platform: The blueplanet 50.0 TL3 RPonly can be used in new and existing plants, wherever reactive power is required in grid management, perfectly complementing solar inverters from KACO new energy or other manufacturers.

Availability: Currently available.

Module | LG Electronics NeON R solar panel has 365W rating with improved temperature coefficient

Product Outline: LG Electronics' flagship solar PV panel has a 365W rating with improved temperature coefficient and extended product warranty designed with high aesthetics for residential applications.

Problem: Residential solar markets are increasingly demanding higher panel output, to minimise the quantity of panels required for maximum system electricity generation and reduce overall system costs. This is coupled to greater demand for panel aesthetics that better blend with rooftop structures and provide a seamless installation.

Solution: The LG 'NeON R' panel uses n-type monocrystalline cells with back contact electrode technology to minimise problems from the light-induced degradation (LID) and maximise the performance and potential power output for the life of the module.

Applications: Residential rooftops.

Platform: The LG NeON R comes with an extended product warranty, covering labour and delivery. The combined product and performance warranties guarantee the materials, workmanship and performance of the panels for a full 25-year period. In the North American market LG has teamed with SolarEdge Technologies to include SolarEdge inverters with LG NeON R panels, creating one of the most power-dense rooftop solutions on the market. LG is also offering its first AC panel the NeON 2 Ace, coupled with microinverters from Enphase Technologies for the US residential market, which reduces installation time by half, compared with conventional modules, while offering cutting-edge technology.

Availability: Currently available.

Module | Lumeta Solar's 'Lynx' module offers low-profile, zero-penetration installation

Product Outline: Lumeta Solar has introduced the Lumeta 'Lynx' line of solar modules that eliminate racking resulting in faster installation, zero roof penetrations, and improved aesthetics. The low-profile, black-on-black, frameless monocrystalline modules adhere directly to the roof, dramatically reducing module installation time on tile, shingle, and commercial roofs.

Problem: A module that slashes installation time and almost erases the chance of roof leaks is a benefit for solar contractors' bottom line. A lighter weight system with fewer components is intended to increase operational efficiency for distributors and contractors alike.

Solution: The Lumeta Lynx 60-cell module is a 300W 18.1% efficient module that is designed for both tile roofs, where it is installed using inserts that create a level surface, and composition shingle roofs. The Lumeta Lynx 72-cell module is a 360W 18.3% efficient module designed for installation on almost all commercial roof systems. An industrial-strength butyl adhesive, commonly used in the roofing industry, secures the module for the system's lifetime and enables removal if ever required. The module was tested to NREL's demanding Qualification Plus standard and passed a Black & Veatch-developed reliability and robustness testing protocol that ensures the module withstands the rigors of real-life handling.

Applications: Residential and C&I rooftops.

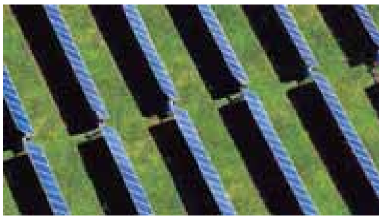
Platform: The Lynx series modules use Dupont's ETFE (ethylene tetrafluoroethylene) sheet that replaces the glass front sheet and enables heat dissipation. The high efficiency black monocrystalline silicon cells with industry-standard EVA encapsulation is intended to provide decades of reliable energy production. A FRP (fibre-reinforced polymer) semi-rigid back sheet protects the cells and a tapered edge seal replaces the frame, removing the need for grounding and reducing soiling.

Availability: Lumeta Lynx will begin shipping to select partners in Q4 2017 and be available throughout the United States in Q1 2018.

Tracker | Mecasolar 'Hyperion-SR' horizontal tracker designed for flexibility and cost competitiveness

Product Outline: Mecasolar's Hyperion-SR' is touted to be the most advanced single-row horizontal tracker on the market. Main features are minimum number of piles per MW, self-powered operation, wireless communications, extended slope tolerances and sophisticated optimisation.

Problem: Providing flexibility in the design of ground-mounted PV power plants, while enabling higher land use density to maximise yield are required to reduce the plant balance of system costs. However, trackers need to provide higher uptime, fast installation and accurate tracking to deliver the highest returns. Increased adoption of 1,500VDC technology also requires longer module rows, and trackers that enable this are being demanded.



Solution: The 'Hyperion-SR' tracking system is claimed to increase PV power plant output by up to 27% compared to fixed structure systems while its dimensions can be extended to to 90 modules per row for 1,500VDC systems. Each row integrates an advanced controller equipped with electrical devices such as UPS, inclinometer and motor current monitor sending its data through a wireless mesh network. Raising the system voltage to 1,500 volts allows for 50% longer strings thus reducing the number of strings for the same amount of power and eliminating almost 30% of the related cabling and combiner boxes permitting fewer inverters per project.

Applications: Utility-scale PV power plants.

Platform: The weight of the structure has been significantly reduced while the optimised design allows wider rotation angles (+/- 55 degrees). In case of severe weather conditions, the tracker automatically moves to stowing position in less than three minutes. The entire tracker can be assembled with fastening devices, therefore on-site welding is not required, reducing workforce cost and mounting time.

Availability: Currently available.

Module | Solaria provides 'PowerVision' series of customised architectural glass modules

Product Outline: Solaria Corporation's 'PowerVision' series of customised architectural solar (BIPV), power generating glass solutions for building facades can be widely used in nearly every aspect of a building envelope beyond the rooftop to generate electricity.

Problem: There is increased demand to evolve building designs to incorporate more solar solutions, and construct, when possible, high performance, net zero energy structures. Buildings currently account for 40% of global energy use.

Solution: Solaria PowerVision-150 is an architecturally beautiful vision glass that can be used in locations not typically associated with solar panels. Building owners and occupants accrue many benefits as solar-outfitted windows mitigate the sunlight's effect on a building. When combined with high-efficiency solar PV modules, together they offer a seamless strategy to unlock the full power potential of buildings with technologies that boost energy generation, providing high yield at a low cost.

Applications: A wide range of BIPV and BAPV applications such as building facades, skylights, canopies and sloped glazing roofs as well as other structural components.

Platform: PowerVision-150 is endorsed by leading glass and fabrication companies including Pilkington, AGC, and Walters & Wolf. Recently, Linel, a fabricator of customized architectural glass and metal products has also endorsed the technology for BIPV sloped glazing systems.

Availability: Currently available.

Storage | Tabuchi's smart inverter and battery package future-proofs residential solar-plus-energy

Product Outline: Tabuchi America has launched its next-generation Eco-Intelligent Battery System (EIBS). The all-in-one system is compliant with the UL 9540 certification requirements, which provides third-party validation of safety, reliability and efficient energy management for hybrid solar-plus-storage systems.

Problem: While there are many efforts to develop and apply safety standards for the rapidly evolving energy storage industry, the UL 9540 certification compliance is limited to a relatively small number of energy storage manufacturers. Attention to safety regulations is more important than ever, not just to protect the safety of residential home owners and property, but also to expedite the permitting process.

Solution: The system is designed for adaptability and ease of installation with a DC-coupled battery. This maximises the amount of solar energy used by the system and safely provides solar power to the grid and to residential customers during power outages. Consumers get more out of their system because both the battery's bi-directional converter and the solar inverter are DC-coupled. This allows the energy generated by the solar panels to directly charge the batteries without first converting to alternating current (AC) like most storage systems. This also leads to higher system efficiency through one less DC-AC inversion.

Applications: In tandem with residential roof top PV systems.

Platform: The increased storage capacity can help retain critical electrical loads operational longer during a blackout. Added surge capability enables the EIBS system to power motor-driven loads such as water pumps, which have a higher starting load, allowing greater integration within the home.

Availability: Currently available.

Technical trends in next-generation solar inverters

Inverter technology | Inverters are the subject of intensive ongoing innovation as the range of roles they are expected to play in PV power plant operation continues to grow. Stephan Liese of Fraunhofer ISE scopes out some of the key areas for further technological advancement in the next generation of solar inverters

Towards a global CO2-neutral energy supply, renewable energy sources are becoming increasingly important worldwide. In particular, photovoltaics will take a key role in this context. In recent years, the levelised cost of electricity for PV has dropped massively compared with conventional energy sources [1]. As the key element of a photovoltaic system, irrespective of the power range, the efficiency and reliability of solar power generation are essentially determined by the properties of the PV inverters. As a result of increasing cost pressures, new generations of PV inverters are required, in which not only technical innovations and reliability but also cost optimisation and intelligence play a central role.

Power density

Power density and power-to-weight ratio already played a major role in inverters at the beginning of their development in the early 1990s. Major technological advances have been made over the last few decades by eliminating circuit topologies with transformers and adding new semiconductor technologies. Not only could the efficiency therefore be brought close to the theoretical limit of 99% [2], but also the power density and power-to-weight ratio could be increased significantly.

The introduction of the latest semiconductor technology has led to a significant increase in power density, particularly in the field of photovoltaic inverters. The introduction of silicon carbide semiconductors has led to higher switching frequencies being realised, thus allowing the passive components, such as inductors, to be reduced (Figure 1).

Due to the increasing market penetration of wide bandgap semiconductors, SiC-MOSFETs are increasingly being used in PV inverters. Wide bandgap semiconductors permit devices to operate at much higher voltages, frequencies and temperatures than conventional silico-based semiconductors. The combination of silicon IGBTs and SiC Schottky diodes, in so-called hybrid power modules, has already become state of the art in commercially available inverters. Due to the increasing electrification of the transport sector and the resulting volume market for semiconductors in addition to photovoltaics (Figure 2), it can be assumed that prices for SiC semiconductors will continue to fall in the coming years. In the transport sector, power density or power-to-weight ratio is even more important than in the field of photovoltaics. Each additional kilogram of weight saved can increase the range of electric vehicles. As a result, silicon carbide technology within photovoltaic inverters will become state of the art within the next few years. The first manufacturers in the field of PV inverters have already announced devices that are completely based on silicon carbide technology.

Credit Fraunhofer ISE

Figure 1. Example of weight/volume reduction of inductors

Semiconductor technologies such as gallium nitride, which are still predominantly used in consumer electronics today, are becoming increasingly interesting for applications in power electronics. By increasing the switching frequency in the megahertz range, weight and volume as well as the associated material costs can be further reduced. In contrast to SiC semiconductors, which are commercially available up to a reverse voltage of 1,700V, commercially available GaN semiconductors are only available up to a reverse voltage of 650V and with a maximum current carrying capacity of 60A, which adversely affects the scalability of the power classes. Due to the high price and low reverse voltage, GaN semiconductors are still mainly used for research purposes in smaller power electronics devices (<5kW). One of the future challenges will be to improve GaN semiconductors for parallel connection

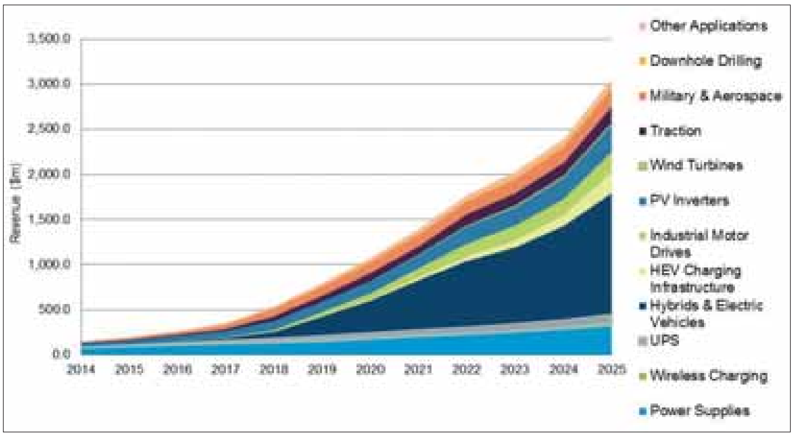


Figure 2. The SiC power semiconductor market. Source: IHS

to cover higher power ranges. The high switching frequencies associated with GaN semiconductors will require additional innovative, internal and external EMC device concepts that comply with current standards.

Photovoltaic inverters can basically be divided into two categories. On the one hand there are string inverters in the range up to around 125kW and on the other hand there are central inverters starting with several hundred kilowatts of power up to the megawatt range. In string inverters, multi-level topologies have established themselves as state of the art. The related introduction of a large number of voltage levels leads to an additional reduction of the passive components in the output filter, in addition to the increase of the switching frequency by new semiconductors. However, multilevel topologies with an increasing number of voltage levels have the disadvantage that their operation is associated with a considerable additional effort of circuit and control technology. The so-called three-level topologies offer a good compromise in terms of complexity and power density. The combination of multi-level topology and the latest semiconductor generations in combination with high switching frequencies will not only continue in the field of string inverters, but will also increasingly find its way into the field of central inverters. In the case of central inverters, the trends are clearly moving in the direction of even higher power and input voltages. Research projects are already being undertaken that significantly reduce the size of central inverters due to semiconductor technologies and innovative design concepts (Figure 3) [3].

Increasing the power to weight ratio

The cost breakdown of PV inverters shows that the actual power electronics with their semiconductors and their control contribute only about one third of the total costs. The vast majority of the costs, up to 70%, are associated with the mechanical and electromechanical components. The mechanical components include the housing, which consists mainly of die-cast aluminum or sheet metal, depending on the performance class, the aluminum heat sinks, which are partly integrated into the housing structures, and the supporting structures. The inductors, PCBs and connectors can be assigned to the electromechanical components. With the exception of inductors, which are becoming increasingly small due to higher switching frequencies in conjunction with new semiconductors, only a few technological innovations have been produced in all other areas, which make a significant contribution to costs.

A small number of inverter manufacturers, for example, are already using the first polycarbonate housings, which reduce the use of materials and contribute to cost reduction. New material combinations with regard to the housings and adapted production processes can thus meet EMC requirements on the one hand and on the other hand, these innovations also promise considerable cost-cutting potential in the future.

As far as cooling is concerned, the so-called concept of the "hot core" has recently been investigated experimentally within the research project "PV-Pack" [4]. The aim of the project is clear from its name: "PV Pack: Optimised cooling, packaging and assembly technologies for efficient, fast-switching and highly integrated PV inverters in the 10 to 40 kW power range." To achieve this, a highly qualified consortium was formed, comprising SMA Solar Technology, Fraunhofer Institute for Manufacturing and Applied Materials Research (IFAM), Phoenix Contact and Fraunhofer ISE. Due to the thermal insulation of the heat sink, increased temperature levels can be achieved, which, especially in conjunction with SiC semiconductors and their operating temperatures of up to 200°C, allow a more efficient use of the heat sinks and semiconductors. The use of composite materials can further reduce the material costs of the heat sink and thus increase the power-to-weight ratio. Furthermore, different temperature zones have been introduced in the concept, which means that electronic and electromechanical components with lower temperature requirements can be used, which in turn has an impact on costs (Figure 4).

The connection of cooling and housing is state-of-the-art in the field of string inverters and at the same time includes the supporting structure of the inverter. Within the above-mentioned research project, these two components were completely decoupled from each other, which in turn allowed the support structures to be viewed separately. In the future, multi-functional lightweight construction concepts could be used here, for example with integrated heat transfer mechanisms or with partial

Figure 3. Demonstrator system of a modular, highly compact 1MW battery inverter using SiC-MOSFET's

Figure 4. PV-Pack 70kVA PV inverter with new cooling concept

electrical conductivities, which would allow a more effective use of the installation space.

Considering the costs and the associated use of materials, there is still considerable potential for optimisation in this area to bring further innovation. Here the emerging mass market for electromobility could have a massive impact on cost-cutting potential too. To increase the power-to-weight ratio, however, it is not enough to focus solely on the above-mentioned points. PV inverters and the associated power electronics also require a number of additional components, which are usually purchased separately. For example, EMC filters, capacitors and a whole range of circuit breakers can fall under this range. In the future, these components should also be investigated more intensively to determine to what degree an increase in the power-to-weight ratio can be achieved and how this can also contribute to cost optimisation. Particularly with the introduction of 1,500V technology in the field of string inverters (>50 kW) and for some time already in the field of central inverters, it can be seen that a considerable number of parts and components are not yet commercially available for the increased voltage resistances, especially for string inverters, and that they have to be developed partly on request.

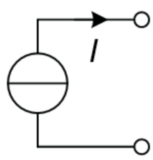
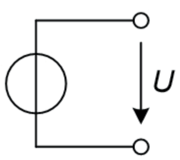
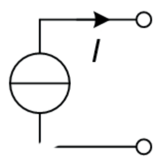
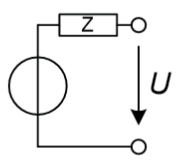
Reliability and intelligence

The main failure causes of PV inverters in terms of power electronics are nowadays either the power semiconductors or the capacitors. In the future, it must be ensured that either the reliability of these two components is increased or the power electronics is empowered to make intelligent statements about state of health of the inverter or these two components. Fault-tolerant PV inverters can also help to ensure system services by, for example, only operating at reduced power, depending on the fault. In the age of industry 4.0, a whole series of innovations are still needed at this point regarding monitoring, in order to increase the internal intelligence of PV inverters. One look at some wind turbine manufacturers, which are already a considerable step further along this particular line, is enough.

Photovoltaic inverters are normally dimensioned for a lifetime of 20 years, although it must be taken into account that this calculation "only" takes the hours of sunshine into account. In recent years, however, the devices have increasingly been taking over various system services that are otherwise provided by conventional generators; in order to be able to provide such services on a permanent basis, the devices must also be dimensioned for night-time operation. As a rule, the ancillary services are grid-supporting methods, such as frequency support via active power or voltage maintenance via reactive power.

Due to the implemented control technology, most inverters can only function as current sources and thus

Table 1. Operating modes and behaviour of inverters. Source: Fraunhofer ISE

Operation Mode	*Grid-feeding*	*Grid-forming*	*Grid-supporting*	*Grid-sustaining*
Grid	interconnected grid	island grid	interconnected grid	*interconnected grid or island grid*
Application	grid with a high share of rotating generators	grid is formed by one inverter	grid with a high share of inverters	*Inverter-dominated grid / no rotating generators*
Source characteristic at fundamental oscillation (50 Hz)	current source $Z \rightarrow \infty$	voltage source $Z \rightarrow 0$	current source $Z \rightarrow \infty$	*voltage source with virtual impedance* $Z = R + j\omega L$
Equivalent circuit diagram				
Droop Control	no	no	P(f), Q(U)	f(P), U(Q) [grid-compatible]

contribute to the maintenance of the electricity grid only to a limited extent. However, due to the increasing penetration of feed-in inverters into the power grid and the displacement of "conventional" rotating machines such as synchronous generators, it will be necessary in future for the inverters themselves to ensure the maintenance of the grid.

Typically, PV inverters operate in grid-feeding operation. Due to the increasing multifunctionality of inverters, e. g. with inputs for photovoltaics and connection options for batteries, these devices usually have two operating modes. This includes on the one hand grid-parallel operation and on the other hand island operation. In grid-parallel operation the inverter is synchronised with the grid voltage and grid frequency and feeds a current into the grid. Therefore the source characteristic is a current source. This operation mode is called "grid feeding". In island operation, however, the inverter forms the grid voltage and frequency of the island grid. The source characteristic is a voltage source. The current is determined by the connected loads. This operation mode is called "grid-forming".

With the increasing number of inverters feeding the interconnected grid and the reduction of synchronous generators, the need to control the grid voltage and frequency by the inverters is increasing. The operation mode of inverters that operate in an interconnected grid or island grid is called grid-sustaining. This operation mode demands complex and universal control algorithms which are currently under development and are still being used for research purposes. In the future, this functionality should be implemented as a standard feature in multi-function devices, battery inverters and photovoltaic inverters, so that PV can also contribute to the full supply of renewable energies, even if limited by the available power, to maintaining the grid.

Furthermore, the increasing interconnection and digitalisation of renewable energy plants will become increasingly important, especially with regard to the fluctuating generation of electricity from PV and wind. Often, the electricity generated is not consumed directly on site, but has to be transported where it is needed. The additional expansion of electrical storage facilities will help to bring production and consumption closer together. Precise acquisition and control of power flows is essential. In order to ensure this and not endanger grid stability, the communicative capabilities of the devices will play an increasingly important role in the future, especially with the superordinate grid operators, in order to optimally control the power flows in the grid. ■

References

[1] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf
[2] https://www.ise.fraunhofer.de/content/dam/ise/en/documents/press-releases/2009/press-release-fraunhofer-ise-sets-a-new-world-record.pdf
[3] http://netfficient-project.eu/
[4] https://www.ise.fraunhofer.de/en/press-media/press-releases/2017/photovoltaic-inverter-with-highly-integrated-concept-promises-lower-costs.html

Author

Stephan Liese joined the Fraunhofer ISE in Freiburg in 2011. Starting from the development of software for power electronic devices he has managed several industrial and public projects related to this topic. Since 2015 he has been the head of the "Modelling and Control of Converter Systems" team and since 2016 the head of the "Distributed Generation and Storage" group within the Power Electronics and Grid Technologies department.

1,500V and beyond – where

Interview | Last year Sungrow became the first to market with both a string and central inverter at 1,500V. Geng Tian, director of product and engineering of Sungrow North America, tells Ben Willis how the evolution of inverter technology will help propel the next leap forward in PV plant design

Credit Sungrow

Sungrow's SG125HV was the first 1,500VDC string inverter on the market

When Chinese inverter specialist Sungrow launched the world's first 1,500V(DC)string inverter at Solar Power International in the US last September, the event underlined the extent to which the higher voltage power plant technology was well on its way to becoming industry standard. Previously restricted to central inverters and thus the larger projects for which these are generally used, 1,500V combined with the flexibility of the string inverter format opened up a whole new range of possibilities for the higher voltage architecture and the benefits it offers.

Sungrow North America's director of product and engineering, Geng Tian, was one of the team that developed the company's pioneering 125kW, 1,500V string inverter. He had also worked on the solar industry's very first 1,500V inverter, the LV5 central inverter produced by GE. This gave him a unique perspective on the 1,500V concept, both in terms of its potential possibilities but also its limitations.

One of the limitations, Geng says, is the fact that although 1,500V central inverters are well suited to large utility-scale projects, the reality is that opportunities for such projects are diminishing.

"The reason why we were thinking about a string inverter in the 1,500V range was because in the central inverter market, the power block size is changing from 1MW to 2MW to 3MW to 4MW; if you go outside the US – Mexico, Australia, India – they're looking at 5MW, 7MW and 10MW blocks," he explains. "But in reality the market has started moving away from the super power plants, like Desert Sunlight or Solar Star – those 500, 700MW plants. So a block size of 4MW or 3MW is becoming a limitation for relatively smaller projects.

"If you look at the commercial and industrial (C&I) and small utility market, predominantly over the past couple of years in that market most of the applications there is string inverters – three-

next for inverter technology?

phase, 1,000V string inverters at 20kW, 60kW. These are products targeted at the small commercial/industrial projects, from a couple of hundred kilowatts to 1-3MW. But there is a huge gap in the market, between around 1 and 20MW. And the sites for these are not like a square anymore; and the developers who are normally doing the big utility-scale projects, they have high overheads, they don't have enough justification to go after the 5, 10, 20MW projects anymore. But the smaller developers, who are normally doing the 1MW, 2MW projects, do not have the sophistication to deal with the complexity of utility-scale projects – the 10, 20MW projects. So it's like a hole in the market – there's the demand but no product."

The key attributes of the string inverter – ease of handling, installation and maintenance – made it the ideal product to fill this gap. But to produce it at the higher voltage threw up a number of technical challenges. Chief among these was how to squeeze the higher power into a unit that was still small enough to retain the characteristics of a string inverter.

"It's easy for us to produce a 200 or 300kW string inverter, but the issue is that always we want to make sure this is a string inverter and not a small central inverter, meaning that we can have two people easily carry and install it," Geng explains. "And at the same time we need to increase the power as much as we can, because the higher the power of each block, the less balance of plant components you're going to have to use. So 125kW is an ideal block – it's a trade-off between the higher power, the weight, the cost and other considerations such as manufacturability."

The technological leap that enabled Sungrow to achieve the necessary power density was a shift from the standard three-level topology normally found in inverters to five. What this essentially means is increasing by two the number of power conversion steps the inverter must make, but it had the advantage of enabling the use of smaller, more efficient components.

"We developed our own technology that allowed us to significantly shrink the size of the capacitors and the reactors and other components," Geng explains. "So that's the biggest technological achievement that allowed us to reduce the weight and increase the power density. Sungrow central inverters and older generation string inverters are all using three-level topology. But this 1,500V string inverter introduced a new five-level topology."

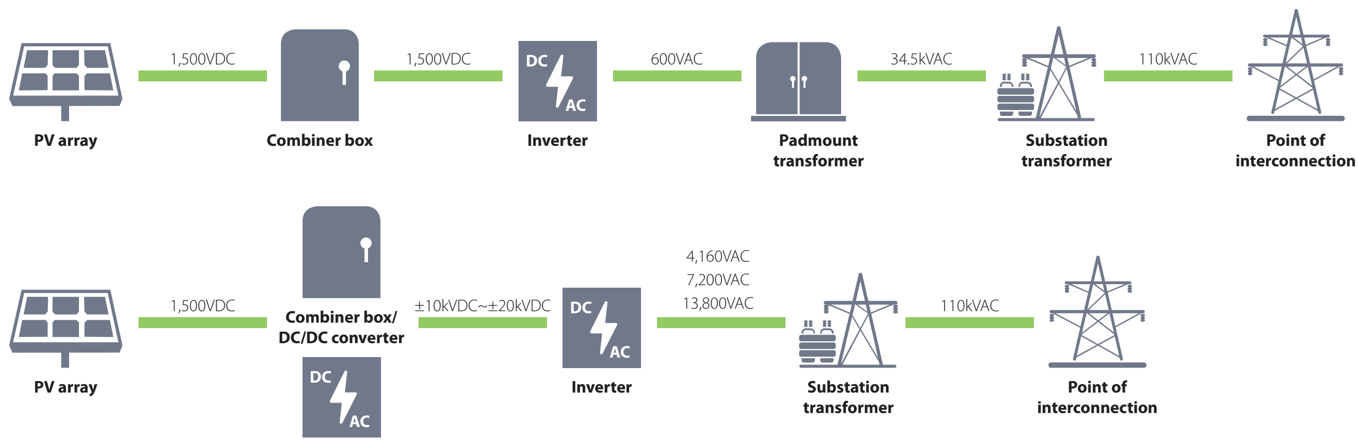
With the 1,500V string technology firmly under its belt, Sungrow is now pushing the concept of the 'virtual central inverter'. What this means is clustering a number of string inverters together in the field to emulate the balance-of-system benefits of a centralised architecture – reduced cabling, better control at the point of interconnection and so forth – but with the flexibility of a string inverter – ease of installation and ease of maintenance to name but two.

Geng says it also gives developers "ultimate flexibility" with their site, overcoming the power block limitations of central inverters. "You can easily put eight or nine inverters per 1MW block; or you can put in 20 inverters for a 2.5MW block," he says. "And the entire balance of plant is essentially like a central inverter – you're running 1,500V cables, you're using the combiner boxes almost in exactly the same way as a central inverter…but still able to capture the benefits of the string inverter and its flexibility. For the people who are developing large-scale utility PV projects, their supply chain and design practices are really built around the central inverters. So this is like a natural transition for those developers – to replace one central inverter with multiple string inverters in the same location."

The next leap forward

The big question is where next for inverters and PV power plant design in general. There has been no shortage of debate about whether the next step is an even higher voltage – 2,000 or even 3,000VDC, which would bring into play medium voltage DC (MVDC) architecture. Such a transition would be a huge leap forward for the PV industry, but it seems a way off yet, as underlined recently when Greentech Media reported that US giant First Solar had indefinitely suspended previously announced plans to shift to MVDC due to what it said was ongoing competition in the inverter market.

Figure 1. The architecture of a typical 1,500VDC PV array (top) and (below) as envisaged by Geng Tian with the 600VAC power conversion stage eliminated



Accurate PV plant data monitoring is essential for low-risk assets

PV Tech undertook an interview with Jürgen Sutterlüti, PV Business Development Manager at Gantner Instruments to understand why accurate real time monitoring and control of PV power plants has become mission critical.

Q: Why do you need to monitor PV power plant assets in real time?
A: Many plant owners have focused on CAPEX optimisation, which is simply reducing PV plant costs. If we take the analogy of driving a car, which includes having to physically monitor your speed. However, to understand the performance aspects such as miles per litre of fuel spent you need the unbiased monitoring capabilities to be as efficient as possible. Without the monitoring, there is no feedback to show your PV performance in that aspect. Gantner has the turnkey tools to do this in the form of the hardware and Software as a Service (SaaS) based solutions, which allows the asset to be operated in the most efficient optimised manner. This becomes even more critical in regions where the lowest CAPEX is applied and efficient O&M is mandatory for maximising profitability over the plants lifetime.

Q: Is limiting CAPEX in monitoring and control therefore a false economy?
A: In a post feed-in tariff world maximising kilowatt hours of electricity is essential to plant economics. Targets vs. actual performance is needed in real time monitoring and with Gantner Instruments you are also in the position to get the expected performance of each component, based on self learning modelling and models, such as the mechanistic performance model (MPM) where we have demonstrated accuracy of +/- 2.5% for each component – in real time.

Q: Clearly, there seems to be a misconception as to what O&M provides other than part of CAPEX cost of the plant?
A: In the CAPEX model you typically have to configure for the right monitoring hardware, data logger, plant controllers and various measurement sensors and instruments to monitor what goes in and what goes out. By reducing the CAPEX on the monitoring hardware side some money is saved, yet the result is almost limited visibility through the OPEX phase of the plants lifetime. What is being missed that we see in our calculations is that the payback in monitoring investment can be only two to three years.

Q: Which sector therefore needs to be educated and informed the most about the need for real time monitoring?
A: In the past the EPC's were adding monitoring capabilities, simply because they were specified in the contract and data collected for around 2-years before handing over to the investor-owner sector. Good prices on projects are now impacted by not having a good track record of monitoring. Gantner Instruments is addressing this issue and provides the right asset KPIs to the investors, which is independent and traceable as we have the full solution from hardware (e.g. combiner boxes, weather stations), data logging layer and cloud based services.

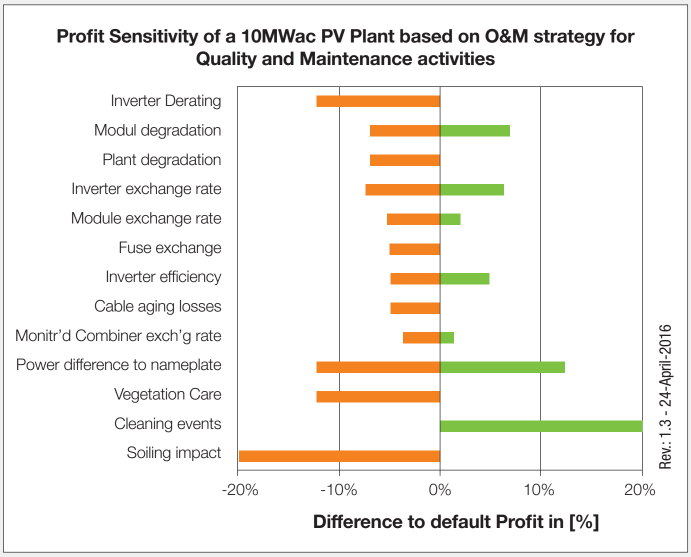
Q: I am getting the impression that not all plant monitoring is created equal, especially for the lifetime of an asset or a portfolio of assets?
A: We have experienced this with owners of large asset portfolio's wanting to build-in uniformity and harmonisation across all of the assets. The driver is to get overheads down and get all the reports in-house. We have the capability to provide the software that can run on clients private servers or our SaaS platform to help support them as Gantner Instruments uses the philosophy of open interface.

Q: You mentioned harmonization, what benefits does this approach give?
A: Bringing as much standardization to the project table really helps such a standardized monitoring and control layer because this allows later on to manage any size of asset portfolio in any part of the world in the same way as you have the same data in the same aggregation and filter level.

Q: When does O&M sensitivity come into play for asset management?
A: Notably in emerging markets where assets are expected to operate for plus 25-years and its energy generation is constant or at an optimized level. Clearly, there is an expectation of hardware malfunction during the lifetime or external factures causing disruption like lightning effects, not least component degradation. All these parameters need to be kept under surveillance so that operations are not drifting from expectation. These parameters can deviate by say 5% and when multiple parameters are deviating, the drift can become significant and sums up to as much as a 50% loss in expected annual profit. This is where O&M sensitivity comes in and monitoring pays off.

Q: I am interested to know that with monitoring of so many things and potential issues, is the data accuracy paramount?
A: When an asset has some monitoring features such as data logging consistency and some advanced features you can run the asset reasonably well. But if you are not feeding in accurate data – visibility into issues takes longer and less quantifiable and actionable. Gantner Instruments data accuracy and traceability is based on real world testing sites and developed performance models from those test means we can detect issues such as PID (Potential Induced Degradation) of the PV panels in a third of time typically seen in the field.

Q: Finally, can you quantify some of LCOE savings from accurate real time monitoring and control?
A: Cost effective monitoring solutions are beneficial as they give direct access to O&M cost which are greater than 24% of the total LCOE. We have seen PV plants with monitoring that can deliver 6.3% better energy yield, which results in over 4% better LCOE and 4% higher profitability. The trend today is that lower system costs now require increased effectiveness at the O&M level that embraces data accuracy and harmonization but will enable reduced LCOE and maximum profit potential.



Geng's view is that this transition, if it happens at all, is a long way off yet. This is due not only to the massive implications it has in terms of component supply chains but also because moving to medium voltage on the DC side of a plant would require specially qualified medium-voltage technicians, significantly pushing up the cost of operations and maintenance.

Over the next two years Geng believes there will be no "fundamental change" in inverter technology, rather a steady lowering of costs and incremental improvements in performance and reliability. He predicts 1,500V will see ongoing geographic expansion beyond Europe and the US into pretty much all the world's growth solar markets – India, Australia, Mexico, MENA.

Beyond that, out to something like five years from now, Geng says it will be a "different story". "The PV inverter we're looking at right now is going to be a lot different in five years," he says.

One major development on the horizon will be the likely shift from silicon to silicon carbide componentry in inverters.

"The shift to five-level topology is using current semiconductor devices and putting a more sophisticated level of topology to improve the power and reduce the cost," Geng says. "But with silicon carbide, it will help simplify the topology because it can switch a lot faster, has much less switching losses. So silicon carbide will help to increase the efficiency as well as reduce the cost, providing that the price of silicon carbide devices will drop low enough."

A shift to high-power silicon carbide technology could also pave the way for innovation on the AC side of power plants, Geng believes. Currently, 1,500VDC inverters step down the output power to a low-voltage 600V (AC), before it is stepped back up by the transformer. Each of those stages result in voltage losses of several percent, so eliminating the low-voltage AC stage of the power conversion process Geng says would be a big breakthrough for the industry.

"You want to be able to break through the 600V (AC) limit so you can step up to 1,500V from the PV array directly to the medium voltage, so you break through the limit of the ideal block size," he says. "You don't need to worry about ok, is it going to be 4MW or 2.5MW, because you don't have to worry about running a 600V [AC] cable all over the place or a 1,500V cable all over the place; instead you can run a 10kV or 20kV DC cable across the field, rather than run a lot of AC cable across in the field. So there's a huge reduction in of cost in the cabling."

"Any breakthrough in any area could lead to a complete architectural change in solar plants"

Figure 1 (previous page) shows a schematic diagram of what such an innovation would look like.

Whether or not that happens depends on numerous factors, many on them based on the appetite at a policy and regulatory level for such a big change to the status quo. But on the technology side, the advent of high-voltage, low-cost silicon carbide could also be a key enabler in driving such an advance, Geng believes.

"Silicon carbide is an enabler for optimising and improving the entire balance of plant," he says. "There's a 10kV silicon carbide device coming into fruition; that single device will help to significantly simplify the topology required to go to a medium voltage type of architecture so you can easily use a 10kV device and traditional two-level topology to create the AC output at around 6.6kV or 7.2kV. If you use a three-level topology with a 10kV device you can easily convert that into a 13.8kV or something in that range. So you don't have to go through the low voltage stage anymore."

Such a progression of course remains within the realm of speculation for now. But as Geng points out, the evolution of PV power plant technology has already surpassed expectation, with many believing that even the previous jump from 600 to 1,000VDC was pushing the envelope, let alone the 1,000V to 1,500V that has since come around. It would be an unwise gambler, therefore, to bet against the next big leap forward being too far ahead.

"No one knows when there will be a unique development," Geng says. "It's not just the inverter manufacturers, it's the developers and EPCs and key component suppliers; it's the whole supply chain all the way from the top down. Any breakthrough in any area could lead to a complete architectural change in solar plants." ■

Credit Sungrow

Advanced testing for smart inverters

Certification | As inverter technology advances in step with the development of the smart grid, so too are testing and certification regimes. Tim Zgonena of UL looks at how standards are evolving to ensure inverters are keeping up with the demands of a rapidly modernising power network

With the advent of today's modernising grid, it becomes imperative that standards, codes and deployment guidelines improve and advance in parallel with the integration of photovoltaic (PV) energy storage systems and the increased levels of distributed generation. In the United States alone, there are several hundred thousand miles of high-voltage transmission lines carrying electricity between the three major power grids: the Eastern Interconnection, the Western Interconnection and the Texas Interconnected system, and additionally there are several million miles of local distribution power lines. To date, the US Department of Energy (DOE) has invested more than US$100 million dollars in an effort to advance the US power grid's resiliency [1]. Though overall improvements were necessary due to aspects such as ageing infrastructure and population growth, many advancements are also the result of PV technology, energy storage systems and increased distributed generation being integrated into the grid.

Naturally, these changes made advanced inverter technology both important and necessary to help ensure continued grid reliability. As always, with many changes come a range of considerations that need to be addressed to effectively understand, align and harmonise protocols, standards and certifications because codes and standards vary internationally and by state or local jurisdiction.

Traditionally, testing and certification regimes tackled inverters from the safety perspective. Most traditional UL equipment safety standards evaluate functionality, electrical hazards, fire hazards, mechanical hazards and verification of electrical ratings. All of these hazards are evaluated and tested under both normal and foreseeable abnormal conditions. Standards, such as UL 1741, offer a means to determine

that inverters and other renewable energy power conversion electronics:

- Are constructed per common industry requirements;
- Can be installed in accordance with US codes;
- Can be operated per industry-specific required ratings;
- Perform safely under rated normal worst-case conditions;
- Perform safely under foreseeable abnormal operating conditions and failure modes.

Inverter testing is becoming increasingly rigorous

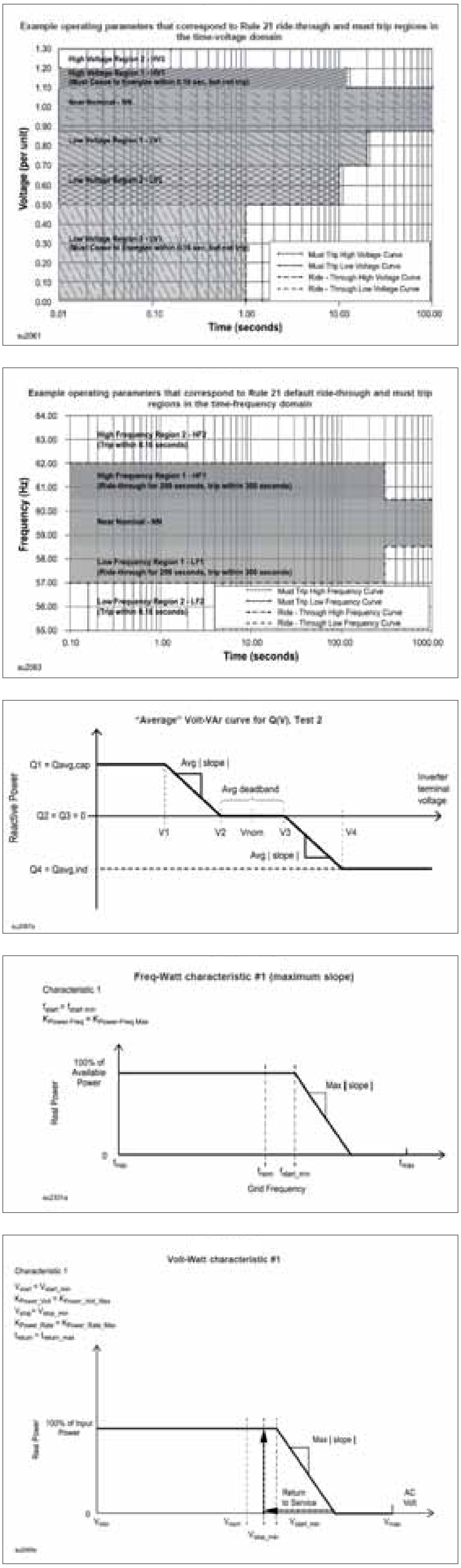
At the advent of PV generation, when the percentage of energy generated via PV was still quite low, the grid interconnection requirements were based on a "get out of the way" approach, meaning the PV inverters and other distributed generation equipment would go offline if the grid voltage or frequency transitioned outside the ranges of normal operation. However, as the grid faces ever increasing penetration of PV generation, that approach is reaching the limits of its usefulness.

The original utility interconnection requirements of IEEE 1547 Edition 1 state that DG devices must cease output current if grid instability conditions occur; however, utilities with high percentages of distributed generation are moving to new enhanced functionality to reinforce grid stability and the new technology required to accommodate this change must be able to operate safely in this new environment. A new methodology, designed to support the unique attributes of a grid that includes PV and works to minimise fluctuations to enhance grid stability was required.

Updating UL 1741 for an international audience

In 2014, an updated UL Standard, UL 62109, represented a significant step forward in harmonising PV power conversion equipment safety requirements with an international perspective. As a result, this standard is now the US harmonised version of the international PV power conversion standard IEC 62109, which was originally based on UL 1741. Utilities and authorities having jurisdiction (AHJs) require distributed generation that is reliable, safe, compatible with the requirements of the National Electrical Code (NEC) and has been tested and constructed to withstand the rigours of daily, full power operation under harsh electrical and environmental conditions.

While the UL 1741 and UL 62109 standards address many similar concerns, there are also key differences. UL 1741 was written to cover all forms of distributed energy (DE)/distributed generation (DG) source types, whereas UL 62109 was written specifically for PV applications (including specific requirements for battery-based energy storage) while also anticipating and addressing the connection of other (non-PV) energy sources. Unlike UL1741, IEC 62109-2 addresses the specific requirements for PV inverters but specifically excludes grid interconnection requirements. The UL 62109-2 draft standard being developed will reference UL 1741 for grid interconnection requirements as many US electric utility commissions require a UL 1741 certifi-



Credit UL

Figure 1. Some of the standard test protocols specified in UL 1741 SA. From top: voltage ride through; frequency ride through; volt/Var; frequency watt; volt watt

cation for grid interactive PV inverters. National differences in the US/UL versions of IEC 62109 allow products to be brought into the U.S. market with little redesign and retesting required, while still allowing compliance with U.S. NFPA 70 National Electric Code (NEC) requirements. Many of the challenges of increased growth in PV generation have been addressed by the development, expansion and use of the UL 1741 and UL 62109 standards.

Necessary updates to UL 1741

'Grid support interactive' inverters, often referred to as 'advanced' or 'smart' inverters, are the future of smart grids and improved energy distribution, and the advanced inverter movement is now in full force. Worldwide solar power rose by a staggering 76GW in 2016, with the US and China leading the charge by almost doubling the solar added in 2015 [2]. In recognition of this growth and the growing need to address the changing landscape in the US market, UL published its long anticipated update to UL 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources,* in the autumn of 2016. Supplement SA for grid support utility interactive inverters and converters was published as a 60-page addition to the UL 1741 2nd Edition base standard to address safety concerns and performance needs of inverters that perform critical stabilising functions during abnormal grid events in lieu of tripping off line to get out of the way. To help strengthen smart grids and support their broader use, the UL 1741 Supplement SA specifies test methods that evaluate an inverter's ability to take action in accordance with specific utility defined performance criteria to help the utility grid stay within normal operating conditions, (hence the term "smart").

The intended next stage for grid support/advanced inverter functionality will allow electric utilities to intelligently control DG equipment to maximise grid reliability and flexibility. This feature is the foundation of the smart grid and the future of energy distribution with increasing amounts of DG. Both California and Hawaii (which runs on its own independent grid run by Hawaiian Electric Company, HECO) mandated advanced inverter functionality and the need to comply with these new requirements, raising the bar for grid interconnection in the US by establishing the need for new grid support inverter testing and certification requirements.

The new UL 1741 Supplement SA addresses this need and is the result of 19 months of work from a diverse panel with representatives from the inverter industry; electric utilities in California, Hawaii and Arizona; Sandia National Laboratories; National Renewable Energy Laboratory (NREL); Electrical Power Research Institute (EPRI); and other labs. Supplement SA is built on UL 1741 and specifies the test methods required to evaluate compliance with an electric utility 'source requirement document' (SRD) for limits and parameter settings.

Due to the high amount of PV and wind generation installed in California and Hawaii, these states first took action and expanded their grid interconnection requirements to improve power generation, efficiency and environmental impact. California's Electric Tariff Rule 21 (Rule 21) and Hawaiian Electric HECO 14H are SRDs that were written to define the specific grid interconnection requirements for these utilities and both can be evaluated using the requirements and tests in the UL 1741 Supplement SA even though it was not written exclusively for either market. For example, Arizona and other markets in the United States are making progress with green energy and grid modernisation and, as progress continues, further SRDs may be added. In addition to the technical requirement changes in California Rule 21 and Hawaiian Electric 14H, both also include a deadline for all inverters to be certified "listed" as a UL 1741 Supplement SA "Grid Support Interactive Inverter" for all new installations as of 7 September 2017.

Currently, UL 1741 SA contains both required and optional tests. Required tests are listed and described below, using the language from the standard:

- **Low/High Voltage Ride Through.** Testing determines how the inverter responds to low and high grid voltage excursions that are deemed abnormal. Ride through response behaviours include Momentary Cessation, Permissive Operation, or Mandatory Operation.
- **Low/High Frequency Ride Through.** Testing determines how the inverter responds to low and high frequency grid excursions that are deemed abnormal. Ride through response behaviours include Momentary Cessation, Permissive Operation, or Mandatory Operation and Trip.
- **Ramp Rate (Normal & Soft-Start).** Testing confirms the inverter's ability to ramp smoothly from one power level to

another over time, in accordance with specified characteristics.

- **Specified Power Factor.** This test verifies an inverter's ability to provide reactive power to the grid by operating at a specified non-unity power factor which is used to assist in maintaining stable grid voltage.
- **Volt/VAr Mode.** Testing verifies an inverter's ability to absorb or supply reactive power in response to fluctuations in grid voltage within the specified parameters for the test.
- **Anti-Islanding.** This test verifies an inverter's ability to trip off-line within two seconds of an unintentional islanded condition. This test is run with the inverter's worst case combination of grid support functions and settings.

There are also two optional tests included in the UL 1741 Supplement SA that may be required by some SRDs:

- **Frequency Watt.** This test verifies an active power response to a change in grid frequency. As grid frequency increases, the desired response of the inverter is to decrease active power output. Likewise, as frequency decreases it is desired for the inverter to increase active power output.
- **Volt Watt.** This test verifies an active power response to a change in grid voltage As grid voltage increases the desired response of a grid support inverter is to reduce its power output so as to not contribute to further increase in the grid voltage. Likewise, as voltage decreases it is desired for the inverter to increase power output.

When combined with one or more SRD, UL 1741 Supplement SA becomes an evaluation and certification programme that is capable of meeting the needs of various electric utilities. Essentially, the UL1741 Supplement SA becomes a multi-purpose tool into which a utility's SRD is inserted, and that combination is used to validate if an inverter meets that utility's specific performance criteria. This structure means it may be possible to reduce test time by combining the criteria of multiple SRDs into one test sequence. However, there will be a large volume of test data even if only one SRD is used and, after testing, the data must be carefully reviewed and mined for specific results before being further calculated to validate compliance with various manufacturer ratings and declarations.

It is important to note that, while UL 1741 Supplement SA marks a significant update within the industry, the standard does not serve as a blanket for utility interconnected products. Three key standards (detailed below), including the original UL 1741, are merged to evaluate a utility interconnected product with grid support functionality.

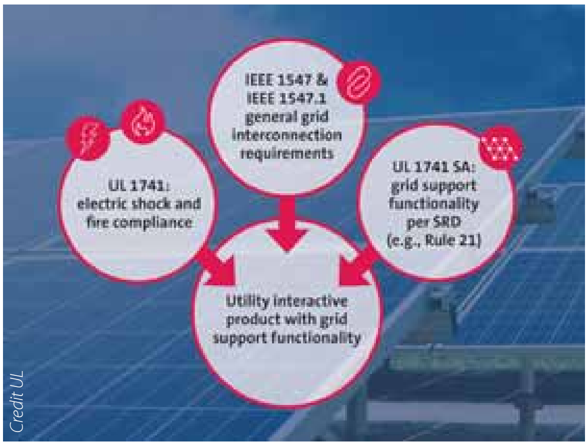


Figure 2. The standards used to evaluate a utility-interconnected product with grid support capabilities

Moving forward

While considerable effort has been made to address changes in the industry, additional work is in process to help further this cause. Presently, UL 1741 Supplement SA covers all certification needs for grid support interactive inverters of early adopters such as California Rule 21 and Hawaii 14H, but changes are already planned in response to upcoming industry updates. First, IEEE 1547 2nd Edition is expected to be published sometime in early 2018. Then, in mid to late 2019, IEEE 1547.1 2nd Edition should be published, as well. At that time, another revision is planned for UL 1741 to replace the UL 1741 Supplement SA requirements with references to the newly revised 2nd editions of IEEE 1547 and IEEE 1547.1. However, this also leaves a gap of approximately 15-18 months between the anticipated publication dates of the new IEEE 1547 and IEEE 1547.1 standards.

Currently, there is interest from utilities to use the IEEE 1547 2nd Edition as soon as possible. To help fill the gap, work has begun to develop an SRD based on the parameters in the soon-to-be published IEEE 1547. This will allow for the use of the existing UL 1741 Supplement SA standard and test protocols to provide a certification that addresses a majority of the IEEE 1547 2nd Edition requirements.

Just as standards and testing requirements are changing in response to new technologies for the smart grids of tomorrow, new technologies continue to evolve to address the growing demands for green energy and safer solutions. This means that many exciting, innovative products will be working their way through product development and into the market. However, these products will be required to meet safety and in some cases performance requirements before being accepted in most major global markets, including the US and Canada. With this area still experiencing intense growth, it is likely that some of these new products will not fit neatly into existing codes, standards, and certifications, but UL can work with manufacturers and the larger PV industry to understand changing needs and develop an evaluation programme that works for all parties involved.

With every major industry change comes the need for evaluation of the current safety standards and, if necessary, updates to these standards to accommodate the changes. This process will always be continuous and evolving and UL will continue to work with the industry and interested stakeholders to help ensure that all aspects of safety and performance are being considered in tandem with innovation. Though it remains impossible to know for sure where the global PV industry will go from here and which regions will continue to push global growth, it is fair to say that PV technology has proven to be a viable green energy solution with potential to integrate into smart grids as long as advanced smart-inverter technology performs, is safe, available and ready to meet the needs of tomorrow. ■

Author

Tim Zgonena has worked for UL since 1990 as principal engineer for distributed energy resources equipment and systems. His responsibilities include the development, maintenance and application of UL's certification requirements and delivery of UL conformity assessment services for utility grid interconnection systems equipment, inverters and converters, PV BOS equipment, engine generators, wind turbines and wind turbine system components. He serves on several distributed generation IEEE, IEC and AWEA technical committees and is a member of NFPA 70, NEC Code Making Panel 4.

References

[1] https://energy.gov/articles/top-9-things-you-didnt-know-about-americas-power-grid
[2] https://www.theguardian.com/environment/2017/mar/07/solar-power-growth-worldwide-us-china-uk-europe

India's 'head in the sand' over solar grid integration challenges

Grid | Curtailment of PV generation is an increasingly common phenomenon in India as the country's solar capacity expansion outstrips the grid's ability to accommodate it. Tom Kenning reports on efforts being made to address the problem and the role storage could play in providing a solution

Despite the 'must-run' status of renewable energy generation in India, now enshrined in national electrical grid codes, curtailment has still hit several states and many wonder whether enough is being done to accommodate the huge projected additions of solar and wind capacity in the coming two years. At a roundtable of more than 30 CEOs at the recent REI Expo in Delhi, it was noted that India is in a massive excess power supply situation, albeit temporary, and that the distribution companies (discoms) are unclear whether they still need to procure renewable energy generation. Many have tipped energy storage to come to the rescue for any grid integration troubles, but there's still no policy on storage. While the issues are clearly well known to the government, it can appear at times that both the government and the various solar developers are ploughing on with new capacity, without enough tangible action on these transmission constraints.

To give an indication of just how important the issue is for the solar sector and the central government's goals, Dr. Rahul Walawalkar, executive director of the India Energy Storage Alliance (IESA), says: "Based on our interactions with the concerned authorities it is clear that grid constraint is the most important challenge that could prevent India from meeting the 100GW by 2022 target."

Credit Tom Kenning

Government awareness

At an early stage, the government started working on 'green energy corridors' to transmit solar from renewable energy-rich states to areas of high power demand such as the big cities. It also freed up energy trading by waiving inter-state transmission charges. There are two phases of these green energy corridors, says Pankaj Batra, who oversees planning around integration of renewables into the grid at the Central Electricity Authority (CEA). One is complete to a large extent, while the second one is being implemented.

However, this infrastructure does not benefit every solar PV project. Ministry of New and Renewable Energy (MNRE) secretary Anand Kumar has stated publicly that India is well aware of the challenge of intermittent power in the renewables sector and thus the government is now also looking to focus on hybrid systems and improving forecasting and scheduling rules, but perhaps most tellingly, Kumar called out for international partners to come in and show India the way on grid management.

There is clearly, therefore, admission of the issue at a government level, also signified by the fact it has already conducted a number of studies, including one in partnership with the US-based National Renewable Energy Laboratory (NREL)

India's grid is struggling under the weight of new capacity additions from solar and wind

a few months ago, says Vinay Rustagi, managing director, Bridge to India. There have also been talks about the Ministry of Power developing a 15-point agenda plan to deal with transmission and distribution issues etc.

"So all that is very positive," adds Rustagi. "But I think the tsunami is going to reach us before most of these things become operational and effective."

Discom tactics

Discoms and the transmission companies do have many reasons to hide behind if they cannot absorb this new renewable energy generation.

"In the past in India, the way the grid has been balanced has been either by way of by load shedding – if demand is too high, you cut down the customers – or if the generation is too high, you cut down the suppliers without compensating. That has been the historical practice and I

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Black silicon cell
Nano texture method leads to higher cell efficiency
Uniformity in the cell's overall appearance

5BB cell
Lower series resistance
Higher module efficiency

Microcrack protected /PID protected
Triple EL tested for high quality control
Applied anti-PID cell and high reliability encapsulation material

280W
Output power can reach 280W and above for 60-cell module

20%
cell efficiency level for mass production up to 20% and above

9.6%
Power output increase of 9.6% per unit area (compared with 260W)

4.8%
A 6% BOS costs reduction per Watt (compared with 260W)

*48pcs,60pcs,72pcs modules and other options available

Shanghai Aerospace Automobile Electromechanical Co., Ltd.
Web：www.ht-saae.com
E-mail：pvmarketing@ht-saae.com

FORTUNE 世界 500	Bloomberg TIER 1	60YS	10 million+	1.8 billion+	100+	600+
		Based on nearly 60 years experience in solar technology R&D by CASC	10 million+ USD R&D investment per year	Corporate 's total assets is over 1.8 billion US dollars	Over 100 independent intellectual property rights for cell & module	Established over 600 PV power plants in China and overseas

* All above information on technical parameters is for reference only. HT-SAAE reserves the right to modify.

Credit MNRE

Green energy corridors have been devised to ease pressure on the grid from renewables capacity additions

think not enough attention is being paid even today in anticipation of the actual capacities that are coming up and how those issues are going to be resolved," adds Rustagi.

"It's head in the sand right now," adds Kuljit Singh, partner, transaction advisory services at consultancy EY. However, Singh also says there have been changes in the competitive bidding guidelines, which provide that if a solar developer is confronted with grid issues, it can receive a form of deemed generation benefit, so power purchase agreements (PPAs) become more like take-or-pay PPAs. However, Singh notes that this still exposes some of the earlier projects to the problem.

For example, Indian conglomerate Adani went public on an early project, by submitting a petition to the regulator in the state of Tamil Nadu claiming that power produced from its 648MW Kamuthi solar project was being curtailed. In this case, the discom was likely to have been put off by the high tariff of around 7 rupees per unit (US$0.107), and solar's must-run status was clearly flouted.

Referring to the general lack of urgency on grid issues, Rustagi says: "This is unfortunately a classic Indian way of operating both for the public and the private sector. Everybody is focused on the here and now because there are always enough challenges and frustrations and enough problems to deal with, and there are very few people actually thinking about how this is going to play out."

For Rustagi, it was clearly visible when multiple solar tenders were coming out in 2014 and 2015 that India could not actually sustain such a large amount of capacity and this has been partly the reason for the current and ongoing hiatus in solar tender issuance in India, while some old tenders have even been cancelled.

"It is a typical Indian syndrome that people are focusing on auctions, execution and financing, because curtailment is not a problem here and now, but we see that as a major issue that is going to come up in the next two to three years."

Southern states

The crunch point will be most felt in southern India, whose states have the highest penetration of renewable energy, but the lowest power demand.

"Historically the southern grid in India has been isolated from the rest of the Indian grid and it was very congested, so in that last two years curtailment for the wind sector in Tamil Nadu was as high as 30%," says Rustagi. "Now that situation improved last year and it may improve even more, because a lot of investment has gone into the southern grid, but I think it is inevitable that as renewable capacity rises, more and more curtailment risk will continue to occur."

Other affected states include Rajasthan in the north west and Madhya Pradesh in central India. Together with the south, these states could soon have around 30-40% of their total power demand coming from renewables, which is a huge percentage coming from intermittent and unpredictable sources, says Rustagi. This makes the issue far more complex than simply adding green corridor and transmission capacity. The key is being able to absorb that power and it will need a lot of policy-level reform, particularly in making the power demand itself more resilient and flexible.

"It means a lot of ancillary market reforms in terms of making coal and gas more flexible. Progress on all those fronts, including on the storage front, is actually much slower than we would have expected it to be given how fast the renewables sector is growing," adds Rustagi.

What can developers do?

To prevent or alleviate these grid troubles, developers can be selective in their project locations. They need to examine how the project is connected to the grid, whether it is a state grid or a national grid and at what voltage level, and whether it is a high- or low-tension grid. Rustagi says all these can have a huge impact on the risk of curtailment.

"Some developers are already quite smart on these things," adds Rustagi. "So you will find developers who are selling power only to NTPC of SECI [state-owned off-takers], they are connecting only to the national grid. If you are in a solar park connecting right at the power grid substation at, let's say' 765kV etc. then your risk of curtailment is almost minimal barring some technical defaults. So there are ways in which the developers can manage, mitigate and minimise that risk."

Unfortunately, not every developer is as savvy; there a dozen large developers who know the market well, but there are "literally hundreds of developers of all sizes across India", says Rustagi. Multiple firms are building 1-10MW projects and many do not have the capability to mange this grid integration risk.

Must-run

Curtailment is a cause of major apprehension for any solar developer, but the new bidding guidelines, mentioned earlier, have offered some hope in that respect

Pankaj Batra of the CEA says that the financial implications of purchasing solar and wind are working in their favour as it now makes economic sense for discoms to purchase this renewable energy, since the prices have come down so low in comparison to thermal power.

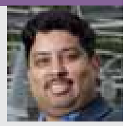
The 'must-run' concept remains largely on paper, but is not enforced. Madhya Pradesh has already announced intentions to remove the must-run status and it remains unclear just how much protection developers have from discoms flouting the rules.

"It does look likely that more and more states will over a period of time say that must-run status is not practically or technically feasible and we have to schedule all this power and it has to go through some kind of common grid dispatch norms," adds Rustagi.

At a recent IESA meeting in Delhi, the CEA also discussed the potential for bringing the leeway for forecasting inaccuracy down from 15% to 5%. This is just an idea at the moment, but while it presents a challenge to solar plant operators, it would also help the cause of the discoms in balancing the grid. Moreover, it would also pave the way for energy storage providers to integrate their systems with solar plants to help ease sudden power fluctuations and improve forecasting abilities (see box). However, such a policy will ultimately need the backing of the Central Electricity Regulatory Commission (CERC). It is CERC that lays down the guidelines to be adopted by states, but states also have the freedom to accept or reject CERC guidelines.

If grid constraints do really start to impact the sector, the resolve prime minister Narendra Modi has for progressing solar is so huge – for him it is a pet project – that one can imagine drastic action will be taken. It's still not clear just how much disruption the industry will face in the meantime, but India has the advantage of being able to learn from the mistakes of mature solar markets, such as Germany. And if anyone heeds the calls from MNRE secretary Kumar, India may well get a much needed boost of expertise from foreign grid management experts to get to grips with what is clearly an increasingly pressing issue.

Storage to the rescue



Dr. Rahul Walawalkar, executive director of the India Energy Storage Alliance (pictured), discusses the on-going debate about mandating storage with large-scale solar projects and the current status of storage in India

"The Central Electricity Authority (CEA) committee formulating these regulations believes mandating storage with solar/wind is an option for the long run. In addition, ancillary services market regulations are expected to be formalised in due course and energy storage assets can play a crucial role in the space. The Central Electricity Regulatory Commission (CERC) has released a staff paper on energy storage-related regulatory changes, and is expected to release the final approach paper before end of the year.

"The Solar Energy Corporation of India (SECI) last year even released a request for proposals for six projects for solar plus 10% storage to demonstrate the advantages of hybrid projects. The Indian renewable energy industry has also realised this and is exploring hybrid solutions with energy storage that can offer more sustainable and scalable solutions in India.

"Unfortunately current regulatory mechanisms and the focus on lowest cost reverse bid-based auctions have created a challenge in implementing this. Under current regulations, solar power projects are deemed must-run plants and hence they can't be backed down by the utilities for any reason including grid constraints. Although backing down of generation is clearly visible in some parts in recent times the developers are banking on the regulations to bail them out. Also there is too much focus on just building additional transmission capacity, and not sufficient effort is provided on improving flexibility of the system and improving utilisation of the T&D infrastructure.

"Nearly 50MWh of energy storage projects are under auction in India. A few developers did evaluate the feasibility of setting up battery pack assembly to cater to this market. The solar industry is playing a wait and watch game to decide on back-end assembly/manufacturing or partnering with international suppliers to cater to this demand.

"The global energy storage industry is actively looking at the Indian market and has already deployed over 1GWh of li-ion based solutions in India in the past two years for the telecom tower market. This year, various Indian manufactures such as Acme, Delta and Exicom have set up >1GWh annual assembling capability for manufacturing li-ion packs. Also the anticipated electric vehicle market has resulted in multiple global players considering li-ion cell manufacturing in India as well. Suzuki has announced the first gigawatt-scale cell manufacturing plant to be built in Gujarat and we anticipate that with the right policy support at least two such manufacturing plants will be announced in next six months.

"We anticipate that India could get at least 3-5GWh annual cell manufacturing capacity by 2020. In the meantime, India will continue to be a large importer for advanced energy storage solutions.

"The recent solar power project tenders have created a strong interest among solar developers towards energy storage. The interest is likely to sustain in the near future. IESA has witnessed very strong interest from solar developers, and over 20 such companies including Sterling & Wilson, Hero Future Energies, Vikram Solar are part of IESA and are actively developing capabilities in this area."

Delivering on record low PPAs

Project delivery | Abu Dhabi's giant 1.2GW Sweihan PV plant made headlines last year for achieving a record low bid price. With construction well underway, Tom Kenning and John Parnell look at how the project is being executed

Credit Sterling & Wilson

Construction of Sweihan is due for completion in 2019

Many emerging solar markets of the past two years have been characterised by headline-grabbing bids that trigger very different responses.

The mainstream liberal press uniformly herald that solar has beaten coal on price. Optimists within the solar industry herald another milestone in its development. Sceptics, or realists, depending on your own viewpoint, will question how the project will be delivered at that cost without any direct subsidy.

One project that followed this trajectory was the 1.2GW Sweihan plant in Abu Dhabi. Bids for the project, submitted in September 2016, were all under US$0.037/kWh with a consortium of Jinko Solar and Japanese conglomerate Marubeni winning out with a bid of US$0.0242/kWh.

The facility is being delivered for the emirate's utility, the Abu Dhabi Water and Electricity Authority (ADWEA).

To answer the question of how such a project can be delivered, we spoke to Keith Symmers, project director at Sterling & Wilson, the engineering, procurement and construction (EPC) firm charged with the task of delivering one of the world's largest single-site solar farms at a hugely competitive rate.

"Local attitudes for the project are very supportive," he says. "Land grants and project sponsorship by ADWEA helps to put an official stamp on the project. That said, the local municipality (Al Ain, Abu Dhabi, UAE) is the agency with jurisdiction on all permitting, with no shortcuts given. Once design is complete, permitting steps take four to eight weeks."

The project is considered part of the UAE's wider economic objectives to free up oil for export, create local jobs and decarbonise its electricity generation while meeting soaring demand. But anyone looking in from the outside should be mindful of Symmers' appraisal, "no shortcuts".

This is where external perspectives on project development in emerging solar markets can diverge from reality. There is nothing new about state-owned utilities freeing up land for infrastructure, particularly in countries where land is readily available. It makes perfect sense to trade that land for a lower PPA. Many European governments will be envious of the opportunity to trade land for low PPA prices rather than the administrative and financial burden of legacy feed-in tariffs and clean energy certificate schemes. The US, under the previous administration, also sought to open up government-owned land for solar development.

Together ADWEA, Jinko Solar and Marubeni have formed a project company to act as an independent power provider (IPP) and deliver on the PPA contract.

System design

With a targeted completion date in 2019, S&W has the unique problem of delivering on a project so large that the technical landscape for solar projects will have had time to move on considerably from when it was appointed in June 2017 to the final commissioning date.

From grading the site to component selection, S&W is faced with the challenge of maximising output with proven technologies while mitigating for the environment the project will operate in.

"The land is greenfield desert in Abu Dhabi. It is characterised as medium density sand mixed with gatch, a clay-rich sand, but some areas are hardened sandstone. Sand dunes, around 8m high, needed to be graded, with sand used as a fill mixture in low areas as well as to backfill buried cable trenches," says Symmers.

Possibly with scale in mind, 1,500V(DC) architecture was rejected with the wide availability of 1,000V components winning out.

"Structural design responsibility lies with S&W. Design aspects are supported by Krinner ground screws and a superstructure from Greencells. More than 300km of cable is to be installed. Four separate cable manufacturers are being used based on adherence to standards, pre-approvals by the utility, cost, manufacturing capacity, transportation time, and adherence to our delivery schedule."

Symmers explains that the project has been split into five portions, with each of those divided down into blocks.

"Four Ingeteam Sun 1165TL PowerMax

B420 inverters are used in each block," he says. "Selection was based on suitability to meet the functional specifications of the project, company reputation, manufacturing capacity, warranty terms, service level agreement, and delivery schedule."

According to Ingeteam's own specifications, the B420 inverter has a recommended array power of 1,178-1,513.2kWp, meaning each block is somewhere between 4.8 and 6MW.

The emphasis put on delivery schedules goes some way to further explain the choice of 1,000V architecture for a project of the sort of scale that some may have thought was a solid choice for 1,500V.

East-west

There are more surprises still when we look at the site layout.

"We're not using a tracker. Instead, an east-west design, with half the panels facing east at a five-degree tilt and half facing west at the same tilt," Symmers says.

It's worth remembering how dramatically air-conditioning impacts on the demand profile in the region compared to say, parts of California, where the peak smoothing of a single-axis tracker has become near ubiquitous. The east-west option over trackers could be partly to do with the scale of this 1.2GW project. Even market leader NEXTracker has installed 10GW in its entire history and at the time of writing stated that the largest single install was "over 300MW".

The density of the site is also interesting. The project is one of abundance but it is also one of economy.

"Aside from interior roads, there is no gap on site larger than 1m. This design maximises the energy density at this latitude and region of the world," says Symmers.

This compact design is in part enabled by the proposed robotic cleaning process. This removes the need for wide channels between the banks of arrays to accommodate vehicle-based cleaning. A waterless system will be used for this. S&W has the O&M contract for the first two years of operation.

Less surprising is the use of modules from consortium partner Jinko Solar. As a partner, it is highly unlikely that Jinko's margin on the panels matches what a third-party sale would generate, offering yet more efficiencies. The selection of high-power modules again highlights the issue of energy density that seems to define S&W's approach.

"We are using Jinko Solar's Eagle PERC 72 355-370W modules, approximately 3.3 million of them in total. They have high reliability, bankability, manufacturing capacity and high efficiency for the constraints to maximise power given a set project boundary," explains Symmers.

The great unknowns

There are of course other factors that contribute to the PPA price outwith the system itself.

It is understood that a 1.6 multiplier will be in place during the summer months lifting the average annual PPA price to something closer to US$0.29kWh over the course of the year.

Financing details for the project are relatively sparse, with a "syndicate of local and international" banks involved. The state utility will be considered a reliable off-taker.

It is a safe assumption that ADWEA, as a project partner, would also have drawn highly favourable financing conditions, from banks local and otherwise. Marubeni, an US$11 billion company in its own right, is also going to be able to attract beneficial interest rates. Grid connection charges for the plant, some 120km from Abu Dhabi, are also likely to have been in some way absorbed by the state.

Lows

Clearly not all low tariffs are created equal. Be they in Mexico, India, Saudi Arabia or the UAE, there is always more to the story than the headline figures themselves. But the support afforded to these projects, be it subsidised grid connection or free land, is a more solid foundation for a low PPA than, for example, a strike price. These bids, which either top up the rate to match market prices or see the provider reimburse the guarantor if market prices move above the "strike price", create variable outlay, or income for the governments involved. The pitfalls of feed-in tariffs have featured plenty on the pages of this journal.

The land on which Sweihan is being built is predominantly clayey sand and stone

Credit Sterling & Wilson

Critics point to the provision of land and cheap finance as explanations of why these prices are not market driven. Governments and regulators are defining partners in energy markets, however. That's unlikely to change while energy continues to be of such huge strategic importance.

Complaining about these conditions, or comparing the prices across borders, where conditions vary greatly, is neither productive nor warranted. Solar power is of sufficient importance in a number of emerging economies that governments are offering the same sort of assistance that as long been used to seed road building or deep water ports or coal-fired generation.

The Sweihan project may not demonstrate a route to US$0.272/kWh solar in Germany, but with a focus on energy density and tight control on logistics, you can understand how the price can be made to work under these conditions.

Understanding any eye-wateringly low PV tariff requires a pragmatic consideration of the project's full context. Comparing tariffs across borders is fruitless. Equally, so is complaining about an energy investment receiving assistance from a host government.

Over the border in neighbouring emirate Dubai, its own state utility is building a "clean coal" plant at what is expected to be a global low for power generation anywhere in the world. You can be sure that concessions made to that project, which again is a strategic choice to diversify the fuel mix, are similar to those Sweihan will receive.

In short, behind the tariffs, are the details. Perceived cash-rich Gulf states are not throwing good money after bad and they are not treating solar as a low carbon loss-leader. Speaking about Saudi Arabia's own record low tariffs (US$0.017/kWh), the Saudi solar trade body said that "they do not reflect private sector economic reality". With the energy industry so entrenched in public sector policy, that might not be a fair reality within which to judge solar's lows. ■

Land, bankability and regulation - Southeast Asia's solar snags

Region update | Southeast Asia's PV markets are entering a post-subsidy phase, creating numerous policy and regulatory challenges for developers. But, as Tom Kenning heard at November's Solar and Off-Grid Renewable Southeast Asia event in Bangkok, there are still plenty of opportunities

Credit Kanadaurlauber/Wikimedia Commons

The 'SaCaSol' PV power plant in the Philippines. Southeast Asia's solar markets face numerous regulatory barriers

Once seen as a region guaranteed to deliver higher solar project returns than most other parts of the globe, Southeast Asia's margins are beginning to feel the squeeze with greater competition and the steady adoption of auctions over subsidy support. As the more mature market begins to grapple with the post-subsidy era, this article looks at the region's competitive tendering activity and where large-scale solar opportunities can found amidst an apparent lull.

The case for solar remains strong in Southeast Asia since power demand is still growing rapidly in many of its markets, but traversing the unique regulations and policies of each country and knowing which PV segment is most suitable remain challenging.

In some countries, regulatory barriers on the utility-scale side are pushing the short-term opportunities into commercial and industrial (C&I) rooftop solar, but there are hopes for Malaysia where the market is maturing with its Large-Scale Solar (LSS) auction programme, and Vietnam with its new feed-in tariff (FiT) for solar and wind.

Land remains a major issue, with one analyst at the Solar and Off-Grid Renewables Southeast Asia (SORSEA) 2017 conference in Bangkok, Thailand, in November noting that getting 500-plus hectares of contiguous plots of land is nigh on impossible in the ASEAN region. As a result, the corporate PPA market, mostly in rooftop solar, which is not constrained by land, looks set to fly, again excepting some regulatory challenges. Meanwhile, floating solar is the word on everyone's lips, with its much-hyped ability to bypass the land constraint issue. The region is of course, awash with bodies of water, from hydro dams and thermal power ponds to man-made reservoirs.

Ultimately, large-scale PV progress is still limited and the industry will be hoping for an uptick in activity over the next 12 months, particularly as the capacities tendered so far have been tiny in comparison to the size and population of the countries involved. Indeed, Abhishek Rohatg, a Bloomberg New Energy Finance (BNEF) analyst notes that Southeast Asia is "far behind" other regions in auctioned capacity, while also having "comparatively higher" risks.

Many criticisms of utilities being reluctant to open up to renewables have been aired, although some including Meralco of the Philippines and TNB of Malaysia are pursuing renewables projects, which is seen as positive sign. Others such as PLN of Indonesia, are seen as "not having any money", which is a major drawback for budding solar developers.

Thailand's latest cooperative utility-scale programme is winding down and the Philippines has PPAs of all forms stuck at the regulator's office. But perhaps Malaysia will push on with a third round of its LSS auctions and the big question marks around the highly promising Vietnamese market could start to get answered; if Vietnam's much touted multi-gigawatt pipeline – one government official recently put the figure at 17GW – actually goes from development into construction, then the industry might start to change its attitude towards the solar PPA, whose parameters have taken a battering in the media due to its infamous off-taker and curtailment risks. This would make Vietnam a bastion of strong project returns in the region due to the attractive subsidy, which is set to continue up until 2019, while most other markets have culled their FiT programmes.

Thailand

With its large-scale solar ambitions constricted to a complex co-operative scheme, the other major hope for developers in Thailand is the country's recently announced hybrid 'firm' PPA scheme, which seeks to encourage energy storage being coupled with large-scale renewable energy projects to generate a fixed output from each system.

This tender had been four to five times oversubscribed, says Dave Edmonds, vice president, business, IMI Group, which demonstrates a high level of interest, but it's not clear yet whether these projects will be able to offer notable returns to investors.

Meanwhile, Franck Constant, founder and CEO of Constant Energy, says that corporate PPAs, particularly in solar rooftops, are set to boom over the next three to five years in Thailand, as well as much of the rest of the region. Despite current rules preventing such solar systems from feeding power back into the grid, significant power savings can already be offered to large corporates, without even the benefit of net metering regulations.

Philippines

The Philippines has gone from a FiT at US$0.17/kWh in early 2016 to a Competitive Selection Process (CSP) resulting in US$0.058/kWh as the lowest price this year. It is one of the first countries in the region to grapple with the post-subsidy era.

Leandro Leviste, CEO of developer Solar Philippines, says the CSP wining price undermined claims of developers that regulation and policy support were needed to grow the PV industry, but not all developers can take this merchant risk and Leviste admits that many developers have either stopped or left the Philippines due to regulatory barriers, such as the backlog of permit approvals at the Energy Regulatory Commission (ERC).

However, he also says: "This price should set a benchmark for the region, where high land costs, moderate irradiance and relatively high interest rates had previously led others to believe that Southeast Asia prices would remain higher than other regions."

Carlos Gatmaitan, chairman of MRC Allied, points out that the Wholesale Electricity Spot Market (WESM) is a welcome backup option to the regulated market for PV generators, and he notes that the demand for electricity per capita in the Philippines is rising at around 7% each year, which means solar should have a role to play to fill the gap between supply and demand.

Referring to the restriction of 40% foreign ownership on Filipino projects, Allard Nooy, CEO of Singapore-based InfraCo Asia Development, says that the Philippines has a number of credible partners available to alleviate the issue – adding: "The liquidity in the market is very high. It's got a pretty deep debt market at the moment, therefore usually international financing is not required, which helps, but in terms of being restricted to 40% you are able to get around that on a number of different arrangements."

Malaysia

Malaysia's second round LSS auction results are due to be released soon, and they are widely expected to hit new lows for the country, having been heavily oversubscribed.

The auctions are due to procure up to 250MW each year to reach 1GW by 2020, says Dr Azhar Abd Rahman, project director of the renewables division at major utility TNB. This makes it one of the only ASEAN markets with active large-scale tendering activity at present. Rahman says securing a partnership is a difficult task and it is important to build up a presence in the market to succeed. He also hints that prices are continuing to go down.

However, Akmal Samah, COO of Malaysia'a Sustainable Energy Development Authority (SEDA), the body which conducts the auctions, says that many of the incumbent energy firms and utilities have been reluctant to accept renewable energy. There have been no serious technical issues so far, but he warns that as capacity closes in on 1GW that could create "some resistance" from the utilities.

The nation will also be hoping that the second auction does not see a repeat of the first, in which several projects have not gone ahead. The most high profile of these was a 50MW(AC) project by Malakoff, whose approval was withdrawn after a change in location.

The SEDA representative admits that the authority could have tightened its selection process in the early stages of its original FiT programme as well. Just 520MW of renewable energy capacity has been built so far out of 1.4GW that had been approved. SEDA has in fact been under pressure to cancel some of these approvals for delayed projects and to give the quota to other developers who are more ready and experienced to conduct these projects.

Vietnam

Vietnam is now set to offer some of the best returns in the region, with the introduction of a generous US$0.0935/kWh FiT for projects completed by June 2019 drawing many developers to the market.

The government is also considering auctions beginning in 2020, once the FiT comes to an end, says Dr Tuan Nguyen Anh, Renewable Energy Centre, Institute of Energy, at the Ministry of Industry and Trade (MOIT).

Nguyen gives the usual Vietnamese government line by announcing bombastic pipeline figures and claiming "huge" levels of interest from international developers, despite negligible reported action on the ground.

He says MOIT will also have completed a solar PV assessment study by January 2018. Land is already seen as a major constriction for solar in Vietnam, with conflicts looming in the agricultural and forestry sectors. PPA parameters are still a major concern, although Nguyen says that a kind of 'take-or-pay' PPA is being discussed, which could comfort some developers.

Dispute resolution and curtailments are inadequately addressed in the PPA, says Allard Nooy, however, in terms of the off-taker risk with the monopoly utility, EVN, he offers a refreshing alternative to the huge negativity around the issue to date, using his previous experience with EVN on other power projects.

"EVN is not a very creditworthy organisation – that's absolutely true," he says. "But the fact of the matter is that on foreign invested IPPs they have never ever

Hopes are high that floating solar plants will overcome Southeast Asia's land constraints

defaulted on a PPA. And given our most recent experience with a hydro project, they have paid us in the last 18 months every month on the dot. So our experience has been actually quite good for EVN."

Indonesia

Indonesia targets 5GW of solar by 2020 in its National Development Plan, but the utility PLN has come up with a 10-year plan, which more or less disregards solar. However, it does have an ongoing tender out, with a ceiling price of US$0.07/kWh. This has been criticised for being unreasonably low by some developers, says Leandro Leviste, but despite this, at least 120 developers still applied to the tender.

Stefan Robertsson, senior advisor at economic consultancy the Lantau Group, says that there is "no doubt" the country will have plenty of solar deployment in the long term, but in the short term it is easy to be "cautiously pessimistic". The financial difficulties of PLN remain the key barrier, and the current minister appears very focused on keeping costs down for PLN, rather than raising electricity prices and making solar more viable.

"You have basically very poor regulation that goes back to the tariff setting in Indonesia," Robertsson adds.

He says the upcoming bid for 160MW in Sumatra could add some momentum, but this will depend on what tariffs come out of it and whether the awards get dragged out over a period of time. There are plans for a second tender for around 80MW in Kalimantan, but Robertsson says these capacities are very small in comparison to the size of Indonesia.

"For the next one to three years there will be progress, but it will be limited progress," he adds. "In the end it's very much tied to the economics. There's very little financial support or financial incentives above tax credits from the government."

Andre Susanto of Bluejay Energy offers a similar perspective: "The biggest issue is PLN doesn't have any money. They only have two income streams which is revenue from households and C&I clients and government subsidy, which is given directly to PLN."

Unless the consumer tariff is raised to provide PLN with more money, he says, then the larger-scale PV progress will remain stuck, but he did praise the country's progress in micro-grid deployment over the last 12 months.

Emerging markets

Cambodia, Laos and Myanmar have tended to trudge behind other ASEAN markets in solar progress. But there are signs of progress with major utility-scale solar park plans for Cambodia in partnership with the Asian Development Bank (ADB) starting to take shape and a tender earmarked for June 2018, work beginning on a 220MW solar plant in Myanmar and talk of huge floating solar potential in Laos.

Cambodia was praised for its openness to foreign investment, but is still seen as risky. Kenneth Stevens, managing director of Leopard Capital, says: "A country like Cambodia, which is still a cowboy kind of place – Wild West – is open to foreigners coming in and open to foreigners doing it, sometimes too much. They expect the ADBs to pay for the roads, to pay for the power, the IFCs [International Finance Corporation] to come in and do their thing..."

Nevertheless, as a AAA-rated body, ADB has the power to capitalise on first-of-kind projects across the region, such as the 10MW PV plant with Sunseap in Cambodia. The bank has also worked on rooftop investments in Thailand, is pursuing large-scale projects in Myanmar and is in discussions over floating solar in Laos, says Pradeep Tharakan, senior energy specialist, ADB.

Rooftop solar in Cambodia is currently under threat, however, as a draft regulation has been issued that has brought uncertainty over the legality of both completed and new PV projects, without a newly introduced permit.

Floating PV

Floating solar is making its mark across the globe and Southeast Asia looks set to become a major market, after pioneer firm Ciel & Terre announced manufacturing plans in Thailand and Vietnam as well as more progress in Malaysia.

ADB's Tharakan says: "There's always a downside that comes along with [new power sources] and in solar it is land. Arable land is in short supply in Southeast Asia and so it's going to be hard to find hundreds and hundreds of acres each time to build these plants."

Due to these constraints, floating PV opportunities were cited for almost every Southeast Asian market during the SORSEA conference, particularly on hydro dams.

The Solar Energy Research Institute of Singapore (SERIS) is also pioneering with the world's largest test centre for floating solar. As it happens, Singapore continues to have a burgeoning rooftop solar industry, but as a market remains restricted by land.

In the long term, Southeast Asia still shines as a major opportunity for solar PV and in the meantime, the off-grid sector can capitalise on the huge number of islands and un-electrified populations, where major grids make less sense. Overall progress in the next 12 months could largely come down to regulators. Perhaps a good summary of the current predicament of the industry came from one delegate at SORSEA, discussing the Philippines, who said: "The GDP is growing and power demand is growing, which is perfect for solar, but there's nothing we can do about the regulations." ■

EGing PV: China's billion dollar solar secret

When PV Tech visited EGing PV in early November, the company was in the midst of its busiest period of installing and commissioning new equipment for its various factories. EGing claimed that the upgrade to full capacity on its high efficiency PERC cell lines was almost complete, with the expectation that it would reach 2GW of PERC module capacity in Q1 2018.

Compared to other public listed companies, EGing PV, with its equity value of RMB6.6 billion (US$1 billion), is known within the industry for its low profile, despite the company's involvement in many different areas of the PV industry, such as ingot pulling, wafer cutting and the manufacture of cells and modules. EGing's additional presence in the PV plant sector makes it in effect very much a fully vertically integrated company.

"In the past years, despite the fluctuation of the macro economy and market situation, EGing PV has been focusing on every step in the value chain, maintaining high levels of investment in R&D, and continuously improving on its industrial technologies and scope of technical innovations. By doing all this, EGing has accumulated a series of well-developed advanced technologies," says Yao Weizhong, deputy general manager of EGing PV.

Taking ingot pulling as an example, EGing possesses the technologies for p- and n-type mono ingot pulling and multi-feed for mono manufacturing, together with low power thermal field technology, and has finished upgrades on crystal rod single-wire cutting equipment, expanding this from 8.5 inches to 9 inches for the mono ingot pulling process. At the same time, EGing has also initiated the development of multi-feed technologies in the mono production process (see figure 2).

In terms of wafer cutting, EGing already has a well-developed diamond wire-cutting ability for mono wafers and is finalising upgrades of its diamond wire cutting machines and mortar online recycling systems. It is expected that the upgrade of the polysilicon cutting machines will be completed before the end of 2017, in order to maintain the current cost advantages.

Although involved in many disciplines on the manufacturing side, EGing's most competitive areas are still its solar module and its PV plant business. EGing's upstream business mainly serves its own in-house module manufacturing requirements, meaning that cell manufacturing has become an important development.

Figure 1. ingot pulling technologies utilised by EGing

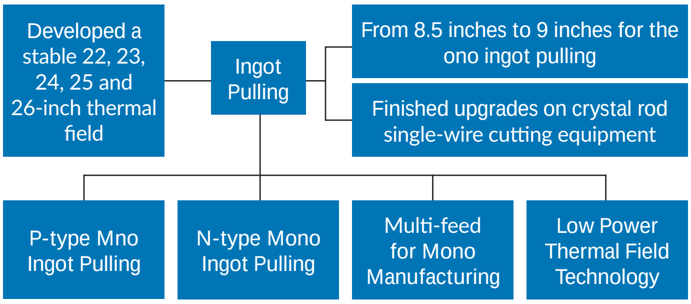


Figure 2. EGing capabilities in ingot pulling

One of the first mass-production manufacturers of PERC cells

Currently, PERC represents the highest efficiency technology for the PV industry's mass production of cells and modules. Compared to conventional alternatives, the high efficiency PERC process has added in three extra steps: back side passivation, back side coating and laser processing. In this way, the conversion efficiency rate has been increased by 1.2% and 0.8%+ for mono and poly products respectively. These substantial improvements on efficiencies are the main reason behind its popularity.

Hanwha Q CELLS recently announced its intention to adopt PERC technology for the China market, but with the upgrade of its own PERC lines nearing completion, EGing feels confident that it remains some way ahead.

Few companies paid attention to PERC technology back in 2012, let alone focused on its development. After making the decision on the technology route, EGing PV gradually set up its R&D team and co-founded a joint R&D centre and an industrial and academic research base with Shanghai Jiao Tong University and Soochow University.

By the end of 2015, EGing PV had successfully completed trial mass production of PERC cells, and then began the transformation and upgrade of its conventional production lines to PERC.

"Up to now, our PERC cell production capacity has accounted for more than 60% of the overall cell capacity, and we expect to complete the upgrade of the remaining lines in Q1 2018, making EGing PV one of the first mass producers of PERC cells," Yao notes.

EGing has currently achieved 21.4-21.8% efficiency for mono PERC products in mass production, and 19.7-20.3% for mass produced poly PERC products.

Zhang Kaisheng, EGing's deputy technical director, says: "Through auto-upgrading, we have effectively solved the EL problems caused by equipment and human operators during mass production. EGing's Rainbow series PERC high efficiency mono and poly module (60 cells) could achieve 295-310W and 275-290W power output respectively. It has been confirmed that, under the same outdoor testing environment conditions, PERC modules have a 3-5% output power gain when compared with conventional modules."

Besides PERC technology related developments, EGing PV simultaneously began research into and investment on the following process study areas: n-type mono cells, p-type double sided cells, multi-busbar cells, developments on black silicon cells, diamond-wire poly cells, diffusion process of high sheet resistance and metallisation of ultra-fine lines and the B/P selective emitter process.

Multi technologies with deployments, early entry to era 4.0

EGing PV's module products have benefited from the company's approach to research in the cell area, and EGing has made significant progress. In recent years, EGing has successfully achieved mass production, making full use of its technical advancements in the areas of tape frame importing, half-cut, multi-busbar modules, p-type modules with double sided cells, double-glass module frame tape, reduced thickness double-glass modules and hotspot free modules. All these technologies substantially reduce the damage rate during production, installation and transportation of modules, and effectively increase their power output and reliability. By lowering module costs, the dual goal of cost reduction and increased efficiency has been achieved.

Yao continues: "Currently, EGing has successfully carried out mass production of 60-cell mono high efficiency standard modules (the Rainbow series), with power output of over 300W. Peak power reached 310W at the research stage, and output of the single side module (60 cell) peaked at 320W when combined with new technologies."

In the area of bifacial/glass-glass modules, EGing has completed upgrades and improvements in its p-type PERC cell and module processes. After one year's R&D, and combining PERC and double sided technologies, EGing's p-type PERC bifacial/glass-glass module products (Janus II) have passed all tests and been certified by VDE. The Janus II range is expected to be available from January 2018.

"The Janus II 60-cell module is capable of achieving an overall power output of 330W and above, and the 72-cell configuration 400W and above, making EGing an early entrant into the PV 4.0 era. EGing PV holds two patented inventions and six utility model patents on double glass modules, with an additional two patents on bifacial cells pending approval," Zhang continued.

Zhang goes on to point out that Janus II technologies enhance system output by raising the utilisation rate of the reflected lights on the back side; the gain in output could be 10-30%, further lowering unit costs and increasing the overall rate of return. The products have a broad deployment future in areas such as distributed systems, water surface applications, highway noise walls, parking sheds and plants in areas prone to heavy snow.

"In addition, due to recent advances in the diamond-wire cutting process on poly products and the dramatic reduction in costs, EGing PV has carried out upgrades to its diamond-wire cutting equipment and introduced relevant cell processes. EGing has achieved significant results - pairing with PERC technologies, we could provide 60pcs high-efficiency modules with power output of 275-290W, meeting customer requirements for high-efficiency poly modules. The products, combined with PERC processes, are expected to reach full production capacity at the end of 2017," Yao adds.

EGing's module testing laboratory is a key part of the company's advanced R&D. According to An Quanzhang, in charge of the laboratory, EGing's lab has been approved by testing organisation VDE's TDAP

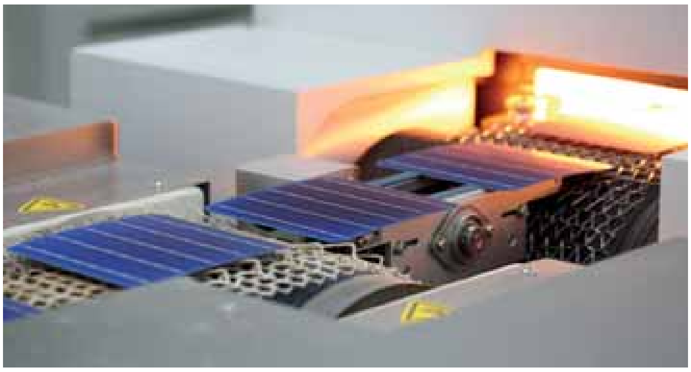


Figure 3. High-efficiency cell production line

Figure 4. Janus II modules

programme, and has in fact entered into a mutual certification relationship with VDE, one of the most influential international module testing entities.

The laboratory is mainly responsible for R&D and testing of new PV materials, processes and products, processing hundreds of pieces of equipment of different sizes.

Smart manufacturing helps reduce costs and improve efficiency

In 2010, EGing PV introduced a module production line with the world's highest automation level, with a nameplate of 500MW. It was installed and commissioned in the first half of 2011, setting what was then the world record for the highest automation level and capacity of a module production line, leading the company, well ahead of the rest of the industry, into the PV 4.0 era.

Thanks to its advanced levels of automated manufacturing, EGing PV continues to improve its overall performance in this area, with the main focus always being on automation levels and production efficiency. EGing embraces the changes made possible by automated production, developing new manufacturing processes and enhancing supply chain efficiencies from different disciplines, in order to achieve real cost reduction and increased efficiency for the ongoing smart manufacturing of PV products.

EGing PV has been classified in the top category as a 'Jiangsu Smart Manufacturing Demonstrative Factory', and likewise in the listing for 'Green Manufacturing System Demonstrative Enterprises' by the Chinese Ministry of Industry.

"Moving forward into the future, EGing will continue to invest in smart manufacturing. As labour costs increase, we will invest more in unmanned factories," says Yao.

Towards standardisation in PV plant reporting

Technical due diligence | PV plant data reported to stakeholders has hitherto lacked consistency. Christos Monokroussos, Matthias Heinze, K. Dixon Wright and Mark Skidmore report on efforts by the IECRE to harmonise the information being reported to investors, regulators and others over a project's life cycle

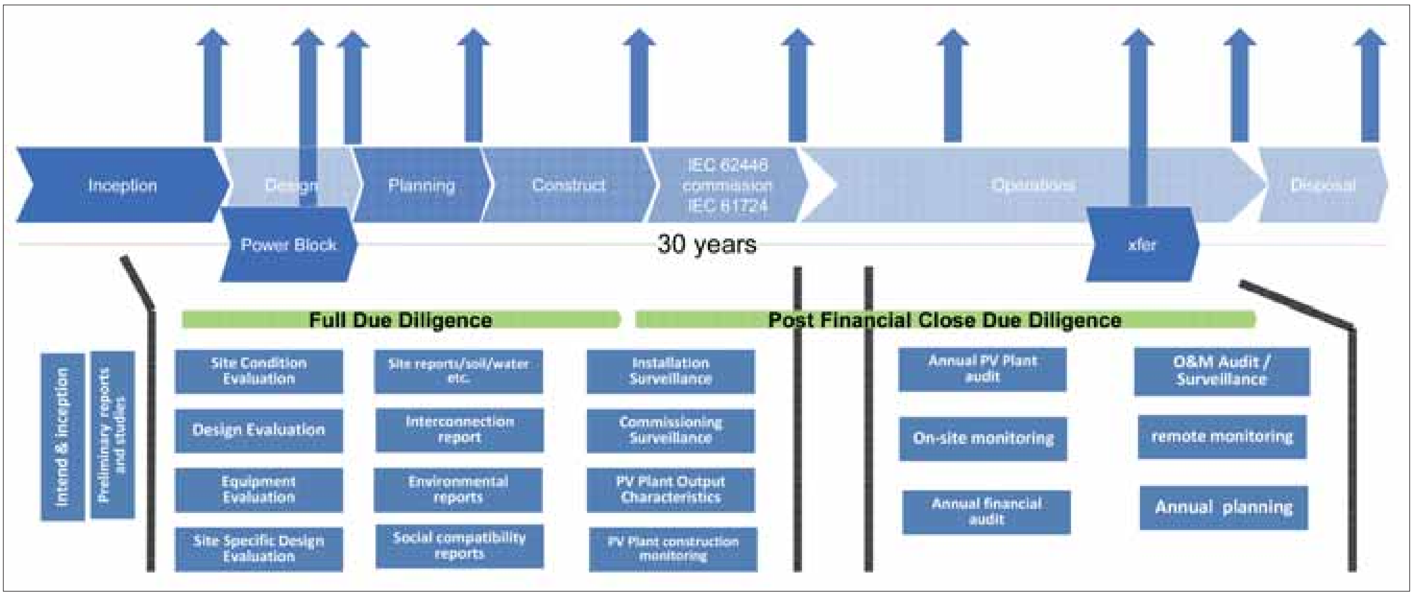


Figure 1. Plant life cycle and due diligence

PV power plants have high initial costs that can be a barrier to development. New PV power plant procurement worldwide increasingly relies on a tender process involving reverse auctions for purchase power agreements (PPA) contracts. The resulting low price should place high importance on oversight due diligence to minimise risks to financial stakeholders.

Whereas this is often scrupulously observed for administrative and legal issues, the technical component of this oversight is often less developed. It may also be noted that tenders have little if any commonalities and, most disconcerting, currently technical due diligence is neither standardised nor based on standard definitions within the industry.

We present two new avenues: 1) presenting project risk transparency to financial markets for competitive pricing on financing, financial guarantees, insurance and surety for improved bankability; and, 2) corresponding strengthening of technical due diligence for new projects to be built and to facilitate existing projects with change of ownership and re-financing.

Status quo of PV system expenses from financial markets

The lender and financial markets currently underwrite projects by coordinating the various information and analytical assessments from multiple stakeholders in the given project. The coordination requires aggregating data from different sources, each with their own nuanced treatment of data that requires manual interpretation, manual processing and data entry into systems. Each of the components from the financial markets that impact the financial cost of project development likewise aggregate data from different sources; again each of these has its own particular nuances as regards interpretation and entry into industry-specific systems to generate premiums, fees and interest charges.

Figure 1 depicts a highly simplified view of a project lifecycle, showing a typical US project flow and tranche assignments. All 'up' arrows represent minor (small arrows) and major (large arrows) transfers of funds, a "tranche". The list of reports and documents may be neither necessary nor complete for each milestone.

The role of independent engineering reports

Independent engineers (IE) provide unbiased and impartial evaluations, reviews and assessments as part of the due diligence process during various phases of the PV plant life cycle. IEs use a combination of technical, financial and other necessary information and

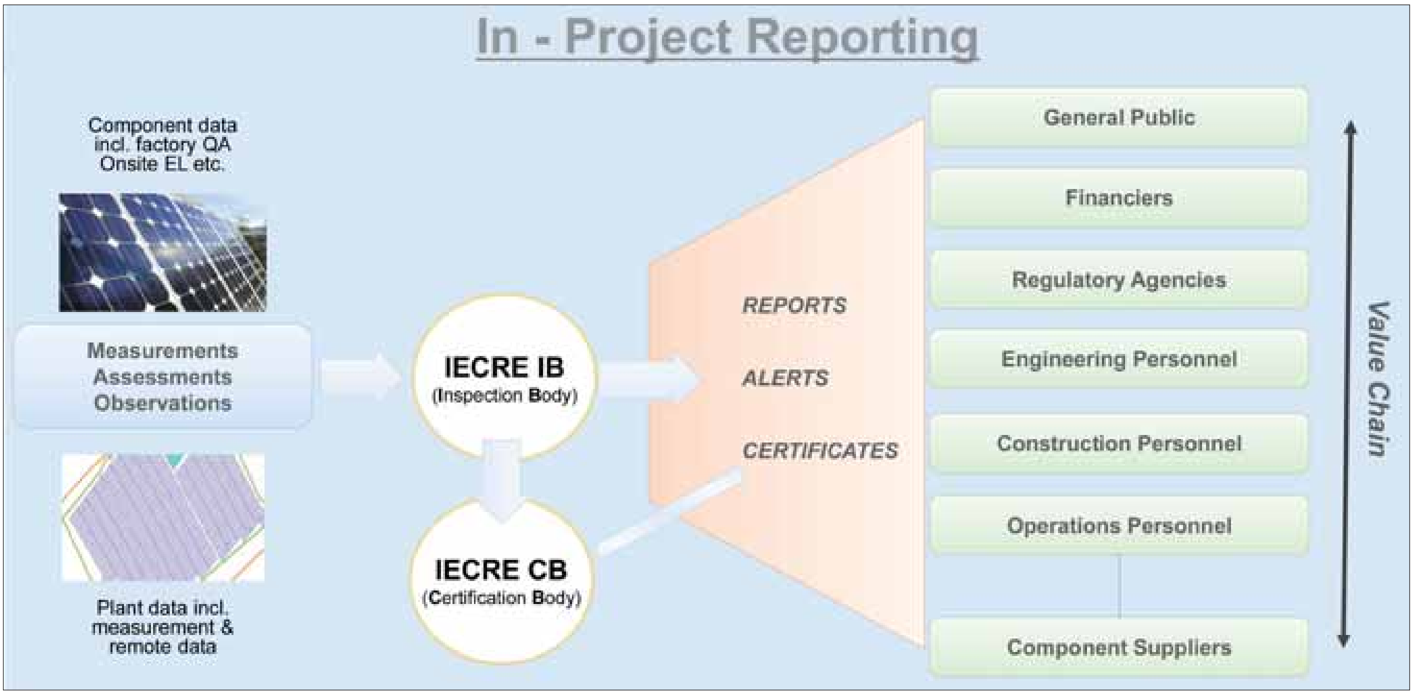


Figure 2. In-process IECRE reporting

data to assess the performance metrics that help stakeholders gain confidence and may be required as part of their fiduciary responsibilities. IE activities may be required at each life cycle milestone. IE involvement may be continuous at intervals or at specific instances (e.g. continuous monitoring, warranty reviews, yearly performance audits, damage assessments). Independent engineering's principal object is the PV plant, but all components are potentially a target of IE scrutiny. IEs may exercise oversight in all phases of plant life cycle as required by stakeholders. Figure 2 shows how IECRE due diligence in-process reporting would be structured from a value-chain perspective.

Of special concern is that PV plants rely on mass production of components, making production, process and supply chain-related quality assurance (QA) services necessary as part of the due diligence process prior to commissioning. In this context, it is important to note that the standard IEC 62941 for PV module production QA has recently been released by the IECRE (IEC Renewable Energy).

The IECRE role and fundamental principles

The IECRE is setting out to bring a modicum of standardisation to the process of due diligence assessments in PV power plants (known as the IE process). The status quo hitherto was that those conducting IE work were doing so at their own discretion. Not only was nobody checking the checkers but the process, the output, information and data could be entirely undefined and the resulting data could not be interoperable – one measurement may or may not compare to another.

As an example, buyers of stocks or bonds would be oblivious that the "capacity" of a PV power plant in megawatts could mean a variety of things; "capacity" in one statement could mean something else in another.

The IECRE is ensuring that all inspection and certification bodies are subject to a strict peer review process that verifies impartiality, competence, accountability and transparency of the data.

Figure 3 identifies stakeholders that the IECRE is serving and the informa-

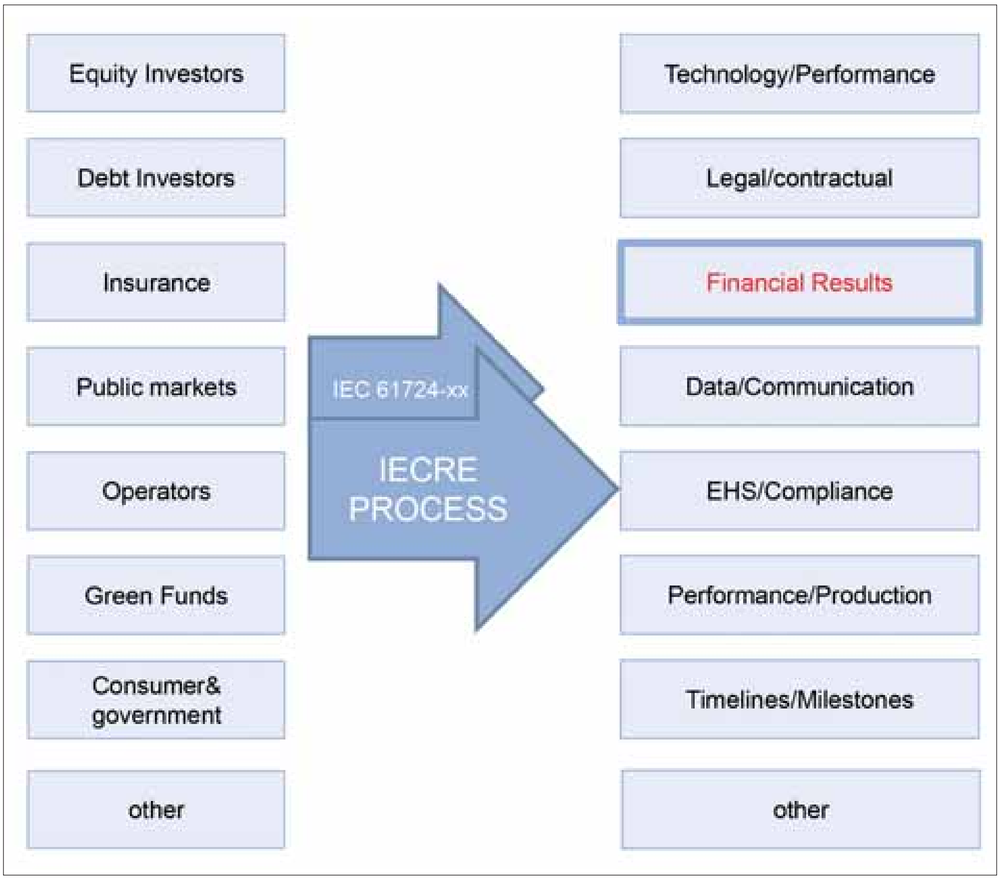


Figure 3. Stakeholders and data needs

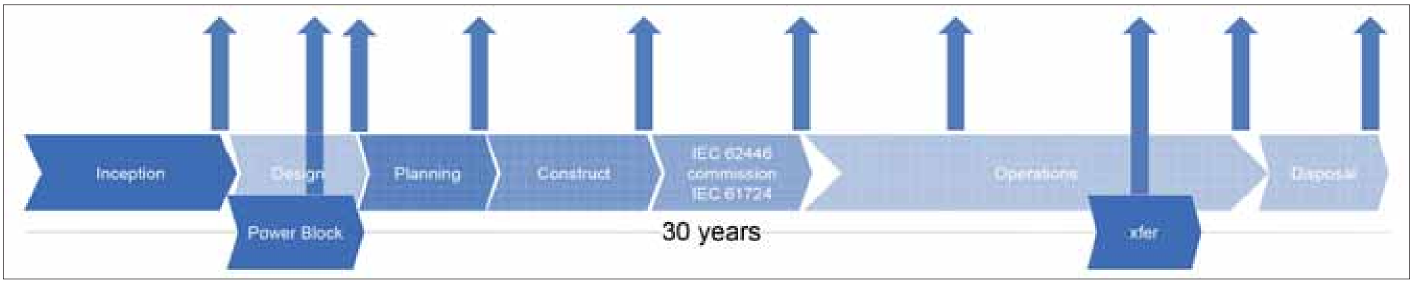


Figure 4. PV plant IECRE milestones

tion provided to them within the IECRE process. IEC 61724-xx (i.e. various parts of this standard) is one of many standards that the system draws on to achieve standardised data. In PV systems financial, legal, contractual and technical data are interconnected; they must all be included in the taxonomy. The IECRE is providing the strict naming and identification to transport such data. A large number of critical data elements of interest to stakeholders are identified and precisely defined in IEC standards. Some data elements have no underlying specific IEC standards currently in existence and for some there may never be IEC standards.

Yet the mere fact that a unique identifier can be used, an overarching process is provided and the parties conducting due diligence are subject to a peer review process, improves on the status quo.

Figure 4 illustrates how data is collected in reports and then collated. The results of these reports are formal "certificates" that contain a predetermined set of data fields. They are issued by qualified independent engineers at the major milestones. Milestones may also entail transfer of funds and require the associated reporting by independent parties (e.g. annual reports). In case of the ICERE process this data is obtained by the IECRE inspection bodies and verified (certified) by the IECRE certification bodies. Data is submitted to the IECRE and selected data – certificates – made available at the IECRE for the public to view. Other IECRE data, such as detailed technical data and related financial figures, is communicated at these milestones to the stakeholders in accordance with contractual obligations and authorisations between the stakeholders and the IECRE inspection body.

Informal internal reports utilising the ICERE standards can serve as low-cost interim reporting to stakeholders in between formal milestones (i.e. certificates) set according to stakeholders' needs and contractual obligations.

These internal B2B reports are helpful, and follow the traditional practice of internal balance sheet and profit and loss reporting in between CPA financial statements for company financial performance. Just as the third-party annual CPA statement is a routine practice, reporting the annual IEC certification from an independent qualified third party is a critical component.

Being able to track internal reporting against the IEC certificate for system reporting will be just as important as tracking the company financial reporting against the CPA statements. The regular providing of performance data, companywide or system specific, provides financial markets with information that can support better terms and conditions, and the CPA and ICE formal reports provides confidence.

Data elements are uniquely named, identified and characterised where possible (where IECRE standards exist). Critically, references to supporting international standards (IECRE/IEC) are made in the Rules of Procedure in the normative and informative annex of the document. The process of obtaining data, determining tolerances, QA issues, definitions etc., is contained in international standards such as the IEC 61724 – x series; data thus obtained is unambiguous – for example capacity is defined in the IEC standards along with the measurement technique.

Individual data element reporting occurs along this timeline for every milestone. Where data elements repeat they will be reported using the same identifier and definition, for data elements with underlying IEC standards, using the same (e.g. measurement) technique.

If requested, the client also receives comprehensive "reports" at each milestone.

Data elements are provided as "IECRE certificates". This data can be divided into three groups (see Figure 5). Data from preceding milestones is of relevance at later milestones. However, this only yields useable information if the data is uniquely identified and the information is standardised. As an example, a uniquely named data "availability_1" must be precisely defined (in case an IEC standard is being prepared) in order to be meaningful compared between year two and three in the plant's life. An example for fixed data is a plant identifier (a unique name for the plant) and location (latitude/longitude).

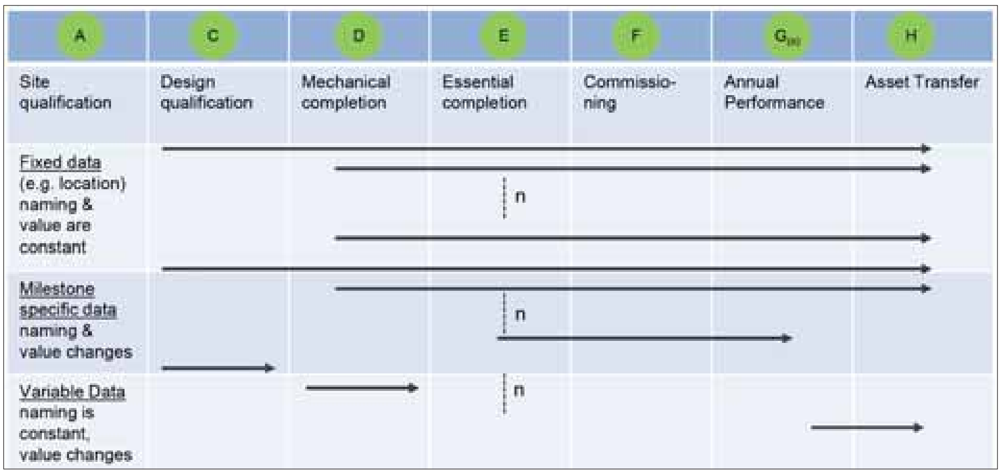


Figure 5. Sample data flow over time

IECRE and XBRL

XBRL is a structured data format for data reporting between financial institutions, regulators, financial

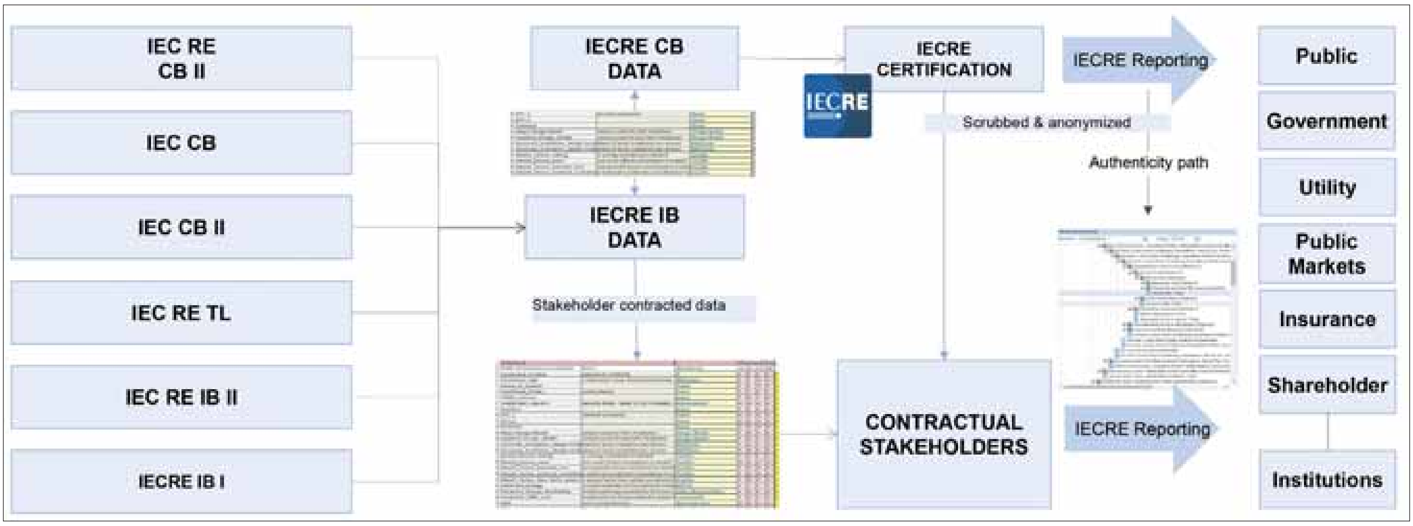


Figure 6. IEC data to XBRL reporting

markets, investors and other parties that demand data consistency and interoperability. Many public markets require reporting in XBRL. IECRE data identifiers and definitions have been incorporated into the XBRL taxonomy (see Figure 6) as part of the USA Department of Energy-funded Orange Button programme. All data generated in the IECRE scheme can be presented in XBRL format. The individual fields in Figure 6 maybe not be visible but the functioning of the IECRE system should be visible (for further information see www.xbrl.org). Note that the IECRE releases only the smaller set of certificate data to the public whereas other data may be made available by stakeholders in PV projects.

Surety as a risk management tool in PV project financing

Surety bonds are financial products similar to letters of credit except they can respond to a default by providing a cure. A letter of credit is often cash collateralised due to its "on demand" liquidity, leaving the beneficiary with the responsibly for managing the default and accountable for the use of the funds drawn. The surety, on the other hand, responds to a default by working to cure the default, in collaboration with the beneficiary, and relieves the beneficiary from having to manage the external aspects of the default by tendering the problem to the surety.

By employing Surety Based Risk Management, PV project owners seeking financing can demonstrate mitigated risk from contractor default during construction, which can help secure competitive pricing. Project owners can also use surety bonds where financial guarantees are required to lessen the need for additional lender financing through letters of credit. Reduced credit requirements can make it easier for lenders to provide the capacity required for funding the project.

The surety industry is active with XBRL US and has been expanding the XBRL taxonomy to incorporate surety terms and definitions. XBRL US is likewise active with the Orange Button to expand the XBRL taxonomy to incorporate IECRE 61724 data terms and definitions.

With the surety industry, as with other financial markets, able to leverage the XBRL taxonomy for high data quality and reliable data exchange for processing and administration of surety risks, they will be able to streamline and implement data analytics for underwriting, predictive analytics for risk mitigation and quantified, mutually accepted data benchmarks for predicable claims response.

Conclusion

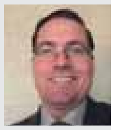
The IECRE is providing a new standardised process to address the issue of widely diverging tenders, RFQs and, consequently, due diligence reports. The IECRE provides process standardisation, a peer review process for the IECRE inspection and certification bodies, standardised data naming and definition for data along the entire PV plant life cycle. Not only does this provide for greater performance transparency, it is critical to the transactable energy network of the future that, for example, would employ blockchain technology. Sophisticated financing demands sophisticated, digital, timely, well-defined and reliable data to meet due diligence needs. Bank financing combined with Surety Based Risk Management, with both leveraging common IECRE data, enables improved risk management, and reduced risk will support more competitive terms and conditions for PV asset financing. ■

Authors

Christos Monokroussos has 10 years of experience in the field of PV research. His activities centre on characterisation of solar cells, PV modules, PV measurement systems and PV module reliability. He is an active member in the IECRE. Christos earned his doctorate degree in photovoltaics at Loughborough University, UK. He is the director R&D in the TÜV Rheinland Group solar and fuel cells business field.

Matthias Heinze has several decades of experience in the field of PV plant qualification and monitoring, laboratory module and component testing, performance measurement and failure analysis. He is an active member of the IECRE. Holder of a university degree in engineering, Mr. Heinze serves as director business development of TÜV Rheinland Group.

K. Dixon Wright is senior vice president at Wells Fargo Insurance Services and leads the SGIP PAP25 for Harmonising Financial Data and the XBRL-CET (Construction Energy Transportation) working group to promote the use of data standards in the solar, construction and surety industries.



Mark Skidmore has over 14 years' experience in the solar industry, and over 18 years' experience in the construction contracting industry. As a registered professional electrical engineer, certified energy manager, and NABCEP solar professional, Mr. Skidmore also holds a university degree in mechanical engineering and serves as solar plant services manager at TÜV Rheinland Group in Tempe (USA).

Life cycle management and recycling of PV systems

Recycling | The end-of-life handling of PV equipment is becoming an important element in the total life cycle costs of PV generation assets. Parikhit Sinha, Sukhwant Raju, Karen Drozdiak and Andreas Wade of First Solar look at the growing importance of PV recycling

In 2015, estimated annual global volumes of electronic waste (e-waste) reached a record 43.8 million metric tons and global e-waste generation is expected to increase up to 50 million metric tons by 2018 [1]. Even though solar PV panels significantly differ from typical consumer electronic products, global regulators view PV panels increasingly in the context of e-waste regulations. Solar PV currently accounts for less than 1% of total annual e-waste volumes. However, as PV deployment continues to grow exponentially, cumulative PV waste is expected to amount to 1.7 million-8 million metric tons by 2030, equivalent to 3-16% of total e-waste produced annually today [2]. As global PV demand increases and more modules and systems reach the end of their useful life over the next 10-15 years, recycling will become increasingly important for all PV technologies to ensure that clean energy solutions do not pose a waste burden.

In addition to ensuring compliance with evolving regulatory waste management requirements, PV recycling offers an opportunity to influence project economics in an increasingly commoditised market. As component prices continue to drop, the financial provisions related to decommissioning, collection and recycling become more relevant to the levelised cost of electricity (LCOE) for PV generation assets. These provisions have to be taken into consideration during PV project development, site permitting and when putting PV system components on the market (i.e. PV modules, inverters, other electrical and electronic products).

Voluntary and regulatory approaches to end-of-life management in leading markets

In most countries, PV panels are classified as general or industrial waste and managed in accordance with general waste treatment and disposal requirements [2]. Beyond general waste regulation, voluntary and regulatory approaches have been specifically developed for managing end-of-life PV waste.

The European Union (EU) was the first to adopt PV-specific waste regulations by mandating the recycling of all solar panels under the Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU). Since 2012, the provisions of the WEEE Directive have been transposed into national law by the EU member states, creating the first mandatory market for PV module recycling. In the United States, PV panel disposal is covered under the Resource Conservation and Recovery Act, which is the legal framework for managing hazardous and non-hazardous waste. In 2016, the US Solar Energy Industries Association (SEIA) partnered with PV manufacturers and installer-developers to voluntarily launch a national PV recycling programme, which aims to make affordable PV recycling solutions more accessible to consumers [3].

In Japan, end-of-life PV panels are covered under the general regulatory framework for waste management (the Waste Management and Public Cleansing Act), which defines industrial waste generator and handler responsibilities and waste management requirements including landfill disposal. In 2015, a roadmap for promoting a scheme for collection, recycling and proper treatment of end-of-life renewable energy equipment was developed, followed in 2016 by a guideline promoting proper end-of-life treatment of PV modules including recycling [2].

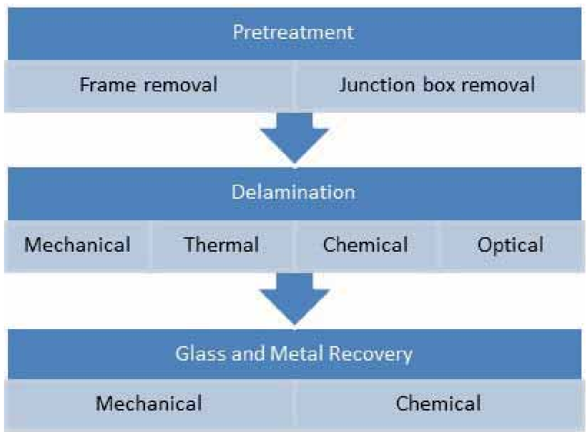
China has no PV-specific waste regulations but has sponsored R&D on PV recycling technologies through the National High-tech R&D Programme for PV Recycling and Safety Disposal Research under the 12th five-year plan. Directives for accelerating the end-of-life management of waste PV modules are also expected in the 13th five-year plan. In India, PV waste is managed by the Ministry of Environment, Forest and Climate Change under the 2016 Solid Waste Management Rules and the Hazardous and Other Wastes (Management and Trans-boundary Movement) Rules [2].

Internationally, a new sustainability leadership standard for PV modules (NSF 457) includes product end-of-life management criteria covering take-back and recycling.

PV recycling technology

In recent years, R&D projects on PV recycling technology have been sponsored in Europe, China, Japan and Korea, and there has been significant patent activity for both crystalline silicon (c-Si) and thin-film PV module recycling technology in the same regions as well as in the United States [4]. Recycling technology can be categorised as either bulk recycling (recovery of high-mass fraction materials such as glass, aluminum and copper) or high-value recycling (recovery of both bulk materials and semiconductor and trace metals). Bulk recycling is similar to existing laminated glass recycling technology in other industries, and may not recover environmentally sensitive (e.g., Pb, Cd, Se) or valuable (e.g., Ag, In, Te, solar-grade Si) materials in PV modules. High-value PV recycling consists of three main steps: pretreatment to remove the metal frame and junction box, delamination

Figure 1. High value PV recycling process steps



to remove the module encapsulant and recovery to extract glass and metals from the module (Figure 1).

Some common goals in PV recycling technology are to maximise recovery yields, minimise impurities in the products of recycling and minimise capital and operating costs to be competitive with other disposal options. Ensuring worker safety and environmental protection are additional priorities that are implemented through management systems such as OHSAS 18001 and ISO 14001, and air emissions controls and wastewater treatment technology.

In addition to technology, other related considerations that affect the viability of PV recycling are effective collection schemes, predictable waste volumes, customers for the products of recycling and regulations on the handling and transport of waste. These factors can affect commercial decisions on when and where to site PV recycling facilities and whether to operate them in a centralised or decentralised (mobile) manner [5].

The recovery value of a PV module

PV panels typically consist of glass, aluminum, copper and semiconductor materials that can be successfully recovered and reused at the end of their useful life (Figure 2). By mass, today's typical crystalline silicon PV panels consist of approximately 76% glass, 10% polymer (encapsulant and backsheet foil), 8% aluminium, 5% silicon semiconductor, 1% copper (interconnectors) and less than 0.1% silver (contact lines) and other metals including tin and lead. Thin-film CIGS and CdTe PV panels consist of higher proportions of glass: 89% and 97%, respectively [2].

Current PV waste volumes remain low as modules have a lifetime of 25 years or more. However, as global PV deployment continues to grow and more modules reach the end of their useful life over the next 10-20 years, PV waste is set to increase nearly 40-fold by 2030 under a normal loss scenario, which assumes a 30-year module lifetime. Leading solar markets including China, the US, Germany, Japan and India (Figure 3) are expected to represent the majority of these projected PV waste streams [2].

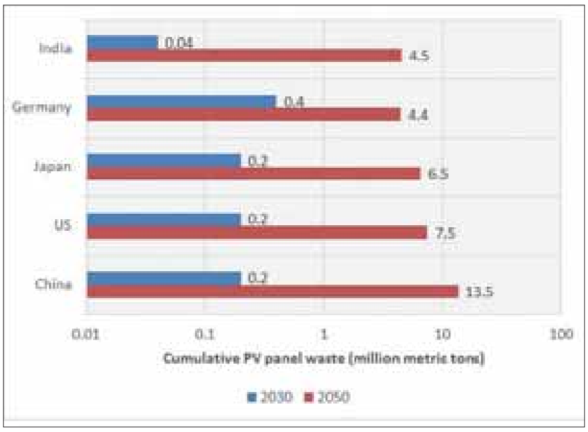


Figure 3. Estimated cumulative PV waste volumes in leading solar markets by 2030 and 2050 (regular loss scenario) [2]

By 2030, the recoverable value from recycling end-of-life PV modules is estimated to amount to US$450 million. The recovery value of glass alone has the potential to exceed US$28 million, assuming an average secondary material market price of US$30-50/mt depending on recovery quality of the glass [6].

In Europe, the current raw material recovery rate for recycling PV modules is 65-70% by mass and is in line with the EU WEEE Directive. CENELEC, the European Committee for Electrotechnical Standardisation, has developed a supplementary standard specific to PV panel collection and treatment (EN50625-2-4 & TS50625-3-5) to assist treatment operators. The standard specifies various administrative, organisational and technical requirements aimed at preventing pollution and improper disposal, minimising emissions, promoting increased material recycling and high-value recovery operations, and impeding PV waste shipments to facilities that fail to comply with standard environmental and health and safety requirements. The standard includes specific depollution requirements whereby the content of hazardous substances in output glass fractions shall not exceed the following defined limit values:

- 1 mg/kg (dry matter) cadmium (Si-based PV); 10 mg/kg (dry matter) cadmium (non-Si-based PV)
- 1 mg/kg (dry matter) selenium (Si-based PV); 10 mg/kg (dry matter) selenium (non-Si-based PV)
- 100 mg/kg (dry matter) lead

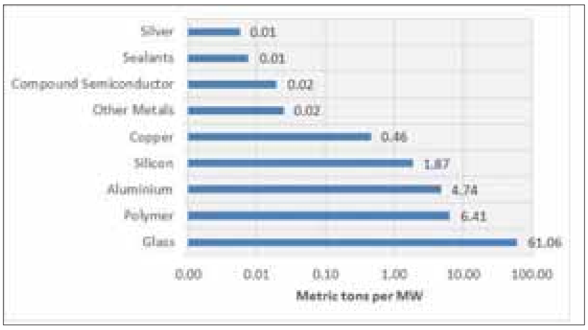


Figure 2. Average recoverable material fractions of PV Panels in 2030 based on [2]

The residual value of a PV system at end-of-life

Decommissioning cost modelling

Decommissioning a PV system at end-of-life involves dismantling and disposing of the system. For utility-scale PV projects, local permitting requirements often include stringent decommissioning and land remediation measures [7] [8]. These specify disconnecting the project from the grid, removing the installed features (modules, trackers, electrical wire, inverters, transformers, fencing, O&M building, etc.), and recontouring and revegetating the land to its preconstruction condition. For example, the following utility-scale PV projects in the US and Germany have decommissioning plans containing detailed cost estimates for dismantling, disposal and site restoration.

- Desert Stateline Solar Farm Project (300 MW_{AC} PV project in California) [7];
- Helmeringen I Solar Park (10 MW_{AC} PV project in Germany) [8];
- Silver State South Solar Project (250 MW_{AC} PV project in Nevada) [9].

Costs from these and other representative projects can be aggregated and used to model the present value of the net cost to decommission a PV power plant (NDCPV):

$$NDC_{PV} = \frac{[(DC_T + IC_T + MR_T + LF_T) - SV_T - LV_T]}{(1+r)^T}$$

where,

$DC_T + IC_T$ = Direct cost (labour, equipment) and indirect cost of PV plant de-installation, demolition, recovery, and land reclamation in year T.

MR_T = PV module recycling cost in year T.

LF_T = Landfill disposal cost in year T, including landfill tipping fees and hauling, of non-salvageable material.

SV_T = Scrap value of steel, copper and aluminum recovered during PV solar field and power equipment removal and sold to recyclers at prices prevailing in year T.

LV_T = Value of reclaimed land in year T.

r = Rate of annual discount applied to costs and revenues realised in year T.

In order for net costs to be negative (profitable), the scrap metal value and/or land value must exceed the decommissioning costs. In particular, there are large quantities of steel, copper and aluminum in PV power plants (Figure 4) associated with mounting structures and electrical cables.

Recent economic analysis indicates that the commercial scrap value of PV power plant decommissioning (mainly associ-

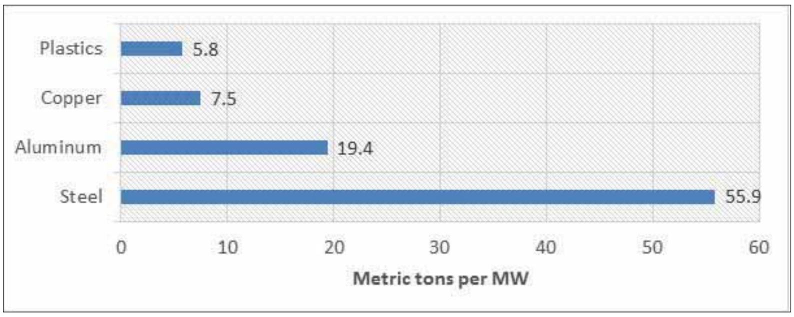


Figure 4. Material fractions of PV power plants [10]

ated with scrap steel and copper) exceeds decommissioning costs, incentivising recycling over disposal. Decommissioning cost optimisation modelling by Fthenakis et al. [11] estimated a net profit of up to US$1.58 per module area. Monte Carlo analysis by ERM [12] indicated 100% confidence in a net profit from PV plant decommissioning when land value was included and up to 95% confidence in a net profit when land value was excluded, depending on plant design scenarios such as above-ground versus below-ground cabling. High-value recycling scenarios in both studies indicate opportunities to positively influence project economics and the LCOE of a given PV project, with net revenues of up to US$0.01-0.02/W from project decommissioning (excluding land value).

State-of-the-art: the First Solar recycling process

In 2005, First Solar established the industry's first voluntary global module recycling programme and has been proactively investing in recycling technology improvements and driving down recycling costs ever since (figures 5-7). In contrast to mechanical recycling processes which focus on recovering major components such as glass, copper and aluminum, First Solar's high-value recycling process is able to recapture more materials while retaining their maximum value so they can be reused in new First Solar modules and new glass or rubber products. First Solar's state-of-the-art PV recycling process recovers more than 90% of the semiconductor material and approximately 90% of glass.

First Solar's first-generation recycling technology was based on the mining industry and involved moving glass and liquid from process to process with a modest 10 metric tons per day capacity. In 2011, First Solar developed its second-generation recycling technology, which was based on the chemical industry batch process of circulating liquids within scalable reactor columns (30 metric tons per day capacity).

In 2015, First Solar developed its third-generation recycling technology which achieves superior glass and semiconductor purity with reduced capital and operating (chemicals, waste and labour) costs. The continuous-flow process improves the recycling efficiency and throughput, increasing the plant's daily recycling capacity from 30 metric tons to 150 metric tons.

First Solar is proactively investing in recycling technology improvements to drive down overall PV waste collection and recycling costs. By 2018, First Solar recycling plants will have zero liquid waste discharge and will convert most of the incoming PV waste streams into valuable raw materials for other industries.

Figure 5. First Solar's first-generation recycling technology based on the mining industry's batch process

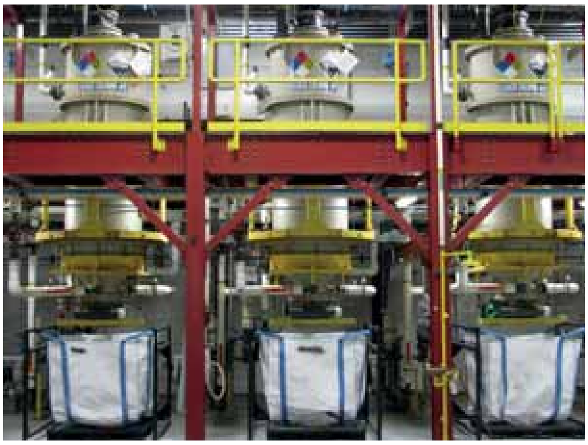


Figure 6. First Solar's second-generation recycling technology based on the chemical industry's batch process

Figure 7. First Solar's third-generation PV recycling technology based on a continuous-flow process

Conclusions

The responsible life cycle management of PV systems is not only becoming a compliance requirement, e.g. in the European Union where PV module recycling is already mandated by the EU WEEE directive, but also offers opportunities to positively influence project economics and the LCOE of a given PV project by leveraging cost-effective, high-value recycling technologies. In addition to creating value from secondary resources, PV recycling services help de-risk the decommissioning and end-of-life phase for PV asset owners. ■

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References

[1] C. P. Baldé, F. Wang, R. Kuehr and J. Huisman, "The Global E-Waste Monitor", United Nations University, IAS-SCYCLE, Bonn, Germany, 2014.

[2] S. Weckend, A. Wade, G. Heath and K. Wambach, "End-of-Life Management: Photovoltaic Panels", International Renewable Energy Agency (IRENA), International Energy Agency Photovoltaic Power Systems Program Task 12 (IEA PVPS Task 12), Abu Dhabi, Amsterdam, 2016.

[3] E. Butler, "SEIA National PV Recycling Program", in *Solar Power International*, Las Vegas, 2016.

[4] K. Komoto and J. Lee, "End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies", IEA-PVPS T12-10:2017, 2017.

[5] D. Ravikumar, P. Sinha, T. Seager and M. Fraser, "An anticipatory approach to quantify energetics of recycling CdTe photovoltaic systems", *Prog. Photovolt: Res. Appl.*, vol. 24, pp. 735-746, 2015.

[6] Eurostat, "Recycling – Secondary Material Price Indicator", 2014. [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/Recycling_%E2%80%93_secondary_material_price_indicator#Glass.

[7] Desert Stateline, LLC; LSA Associates, Inc., "Closure, Decomissioning, And Reclamation Plan - Stateline Solar Farm Project San Bernadino County, California", U.S. Bureau of Land Managment, Needles, San Bernadino County, California, USA, 2014.

[8] Schimpf, G. et.al.; Gehrlicher Solar AG, "Untersuchungen zum Recycling einer konkreten PV Anlage", Forum Solarpraxis, Berlin, Germany, 2011.

[9] Silver State Solar Power South, LLC; CH2MHill, "Facility Decommissioning Plan Silver State Solar South Project", Bureau of Land Management, Las Vegas, NV, USA, 2014.

[10] J. E. Mason, V. M. Fthenakis, T. Hansen and H. C. Kim, "Energy Payback and Life-cycle CO2 Emissions of the BOS in an Optimised 3.5MW PV Installation", *Prog. Photovolt: Res. Appl.*, vol. 14, no. 2, pp. 179-190, 2006.

[11] V. Fthenakis, Z. Zhang and J. Choi, "Cost Optimisation of Decommissioning and Recycling CdTe PV Power Plants", in Proc. *IEEE PVSC*, Washington D.C., 2017.

[12] A. Cates and R. Stifter, "PV Power Plant Net Decommissioning Cost Model Technical Report", Environmental Resources Management (ERM), San Francisco, CA., 2017.

The legal pitfalls of PV acquisitions

Secondary market | Many mature solar markets are seeing strong investor interest in acquiring operating solar assets. But as the lessons from Italy show, transactions in the secondary PV market come with numerous legal risks attached, necessitating thorough due diligence, write Arturo Sferruzza and Ginevra Biadico of Norton Rose Fulbright

Credit Enel Green Power

Even after the retrospective cut in renewable energy incentives in Italy, the acquisition of operating solar photovoltaic (PV) plants in Italy under the right conditions may still provide strong financial returns to investors.

Nevertheless, irrespective of the financing structure or size of the project, there are risks associated with such transactions that a buyer will need to get comfortable with during the due diligence process.

A thorough legal due diligence exercise should cover a wide range of issues, including land rights, permits and environmental aspects, grid-connection rights, corporate aspects, any construction aspects that may be still relevant, O&M, as well as the existing financing agreements in place.

Property

Property due diligence would be initially required to establish whether the development of the PV plant on the site was allowed from a development planning perspective. If it emerges that, at the time of the construction works, the site had a "cadastral" classification that was in principle not suitable for the installation of the PV plant, or if the site fell within an area of special environmental value (like a special preservation zone or a site of European significance), then it is necessary to establish if the local authority amended the cadastral classification of the land or if specific environmental proceedings were carried out to evaluate the potential impact of the project on the environment.

To ensure that the permits were legitimately issued and the incentives are lawfully paid, it is necessary to investigate if the developer had in place at the start of the authorisation procedure the requisite land rights in respect of the site where the PV plant has been built, and if it has continued to hold such rights during the incentive period. The nature of the land rights (proprietary right versus land lease) giving the project developer use of the site may impact on the bankability of the project, as banks usually require security over the land itself.

Experiences from Italy's thriving secondary solar market underline the need for thorough legal due diligence on acquisitions

It is standard for a 20-25 year surface right to be granted, often with an option to renew for a further period of time if the project remains operational. A buyer should make sure that the duration of the land right is aligned with the duration of the incentive period, at no extra cost. In the case of rooftop PV installations, the owner of the building is required to grant the project special purpose vehicle (SPV) full access to the roof in accordance with health and safety regulations, and responsibility for maintenance works on the building, the roof and the PV plant needs to be adequately allocated.

In the context of property due diligence, both legal and technical advisors should review searches at the land registry to ensure that the site is not affected by prejudicial encumbrances or third party rights (such as pledges, civic uses, or pre-emption rights) and that all titles affecting the site are reported on. However, excerpts from the land registry have limited legal value and the assurances that the SPV has acquired the land rights from the full owner of the land and that no prejudicial encumbrances affect the site may only be obtained through a 20-year notarial report *(relazione notarile ventennale)* prepared by a public notary. A 20-year notarial report may be a useful instrument to understand if the root of title over the land is good or not, allowing a purchaser to take adequate remedies in the sale and purchase agreement (SPA) in connection with the findings of the notary search.

If the 20-year notarial report shows that titles to the site have been transferred through donation or under wills, then there is a risk that legitimate heirs *(eredi legittimari)* may be entitled to start a legal claim, claiming that the donations made by the deceased or the provisions of the will have prejudiced the mandatory quota of the estate reserved to them at law and, therefore, asking for the restitution of the site or the payment of the value of the site. The buyer will expect a full indemnity against any losses or expenses arising from any claims that may be brought by any legitimate heirs, so as to pay them and avoid the restitution of the site.

It is advisable that the buyer's advisors review the findings of the 20-year notarial report well in advance of the signing date, in order to make sure that potential encumbrances (e.g. foreclosures, mortgages, etc.) or other issues (e.g. unregistered property rights, existence of donations or wills, etc.) are known in advance and that adequate protections are contemplated in the SPA.

A key part of the property due diligence is to check that the SPV has the rights to lay a cable to the point of connection to the grid. If the grid connection works have not been carried out by the grid operator, then full due diligence would be required, with the same level of detail as previously carried out for the project site itself. It is also crucial to identify where the electrical cables cross roads or other infrastructure (such as gas or water pipelines), so that it can be established whether the necessary consents were been obtained from the competent authority. Concessions for the use of public land may often trigger annual fees and taxes to be paid to local authorities.

Buyers will seek to confirm that all permits are valid and effective, that there is no risk of judicial review, that no additional permit is necessary and that the conditions set out in such permits (e.g. in terms of distances from buffer zones, and environmental mitigation measures) have been complied with.

"A thorough legal due diligence exercise should cover a wide range of issues, including land rights, permits and environmental aspects, grid-connection rights, corporate aspects, any construction aspects that may be still relevant, O&M, as well as the existing financing agreements in place"

Avoiding challenges

In the secondary market, the risk that third parties may challenge the authorisations is quite remote due to the expiry of the statutory appeal periods. Notwithstanding this, an assessment of this risk may still be necessary in the event that new post-completion authorisations are granted to implement changes to the original authorised project or to rectify discrepancies between the as-built and the authorised project design. In this respect, it is crucial to understand if any changes are material. If they are material the authorisation procedure would be much more complicated and the entitlement to the incentives may be at risk.

Furthermore, any public authority is entitled to act in "self-defence" and annul an administrative act formerly approved when it becomes apparent that the relevant administrative act had been issued in breach of any provision of law and an actual and current public interest exists to support annulment of the act. According to recent changes in law, the power to annul in self-defence may be lawfully exercised only within 18 months, but this time limit is subject to some exceptions. A potential buyer would be interested in confirming that no circumstances exist that may lead the public authorities to start an action in self-defence.

The risk of third-party challenges and public authority actions in self-defence against the authorisations reduces with the lapse of time since commissioning of the PV plant. However, there is still a residual risk of forfeiture or revocation of incentives due to facts or circumstances existing prior to the award of the incentive. From a legal perspective, this risk assessment is the most important exercise to be carried out. The *Gestore dei Servizi Energetici* (GSE), Italy's state energy management agency, has a general power of inspection on PV plants. Depending on the seriousness of the violation, the GSE may order the suspension or the revocation of the incentives and seek to recover all of sums already paid.

When it comes to the granting of permits and administrative matters, the key issues known in the market that may adversely impact the incentives are generally related to the legality and completeness of the authorisation relating to the type of plant, its size, location and the date of title release. This is due to the fact that Italian legislation, over the years, has proven to be complex and inconsistent. Because responsibility for energy matters has been vested, since the 2001 constitutional reform, both in the state and in the regions, the regulatory framework relating to the permits necessary to construct a PV plant is different in every region. This situation has ultimately resulted in a series of regulatory mismatches rendering the applicable authorisation procedure uncertain, due to the cumbersome nature of the multilevel regulatory system, the tangle of administrative competences and the increase of the litigation between state and regions.

Major issues for market relate to PV plants authorised by means of a simplified deemed-consent procedure *(dichiarazione di inizio attività)* and which have been built on adjoining plots of land. Since 2008 some regions have introduced guidelines to detect instances where applicants were seeking separate authorisations for ajoining projects to ultimately build larger PV plants that should have been authorised through more complex procedures. The regulation relating to the subsidy for solar PV generation has been amended since 2011 to take account of these issues. The so-called "Fourth Conto Energia" introduced certain criteria which must be applied when calculating the capacity of PV plants for the purpose of determining the applicable level of incentive. This is to prevent operators from splitting a single PV plant into multiple sites to benefit from an incentive that is higher than that applicable to the plant considered as a whole. Finally, pursuant to Ministerial Decree dated 23 June 2016, the GSE can consider many items as an indicator of "malicious fractioning", including the fact that plants share the same grid connection infrastructure or the same electrical line.

Portfolios comprising PV plants subsidised according to the Second Conto Energia that have applied for the benefits under the Salva Alcoa Law have to be analysed with particular attention. Some of the most serious issues generally relate to problems in the drafting of the certificate of completion of the works, the absence of any notice of completion submitted to the grid operator and the authority, or the lack of documentation demonstrating the actual completion of the plant by 31 December 2010 (e.g. pictures showing the installation of modules, inverters and transformers, parts labelling and shipping documents).

The legal and technical due diligence exercise will also investigate whether a grid connection agreement is in place between the SPV and the competent grid operator, whether the export/import capacity is sufficient for the project's planned generation output, whether all the connection costs have been paid, the grid connection works have been completed with no outstanding liabilities, that the grid connection granted by the grid operator is not limited in time and that the date of entry into operation of the plant is compatible with the project's accreditation under the incentive regime granted by the GSE.

Environmental risk

There may also be environmental risks. Various laws may require a current or previous owner, occupier or operator of property to investigate and/or clean-up hazardous or toxic substances or releases at or from a property. These owners, occupiers or operators may also be obliged to pay for property damage and for investigation and clean-up costs incurred by others in connection with any such substances.

The standard set of representations and warranties to be given by the seller in an SPA is expected to cover most of the above issues. Generally, there will be no liability on the seller's side if the relevant issue has been "fairly" disclosed. On the other hand, if the seller has not been able to provide access to a comprehensive suite of documentation, then from the buyer's perspective it would be prudent for the due diligence exercise not to limit the representations and warranties of the seller in the SPA and for the buyer to negotiate appropriate pro-sandbagging language in the SPA.

Depending on the findings of the due diligence, buyers may also seek a purchase price reduction or special indemnity protections in the SPA alongside representations and warranties. In general, it is important to make sure that monetary caps on the seller's liabilities allow sufficient compensation and that any time limit on the buyer's ability to claim under the indemnities allows sufficient time for completion of surveys plus a few additional months to prepare the claim.

In this context, there is a trend towards requiring warranty and indemnity (W&I) insurance, providing cover for breaches of warranties, covenants and indemnities given by the seller under an SPA. This insurance product seeks to bridge the gap between the buyer's wish for deal protection and the seller's desire for a clean exit. Advantages for buyers may include the duration of the coverage, and the reduction of the risks of an insolvent seller. W&I insurance is designed to cover unexpected issues that arise after a deal has completed; however, this assumes that the buyer has performed thorough due diligence on the target rather than relying on the policy (and that the seller has carried out a thorough disclosure exercise). Insurers will expect a balanced negotiated SPA and that the due diligence exercise has been robust and complete. Indications that the due diligence process has been skipped or rushed could lead to a high premium, lowering the scope of the coverage or denial of a policy entirely. Environmental issues, defects in the construction works, bribery and corruption are generally excluded from the scope of W&I coverage.

Finally, it is not uncommon for sellers to seek earn-out provisions, for instance, in the event that, after the closing date, the competent authorities approve a repowering or grant a special subsidy in addition to the Conto Energia incentives (such as the Tremonti Ambientale). While the approval of a repowering may be a win-win situation for both the seller and the buyer, the feasibility and the conditions for the simultaneous application of Conto Energia incentives and other types of public subsidies should be prudently verified depending on the applicable Conto Energia.

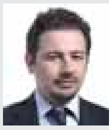
Notwithstanding these issues identified, there is a strong secondary market for Italian PV projects which demonstrates that risks are manageable provided that buyers undertake the appropriate level of due diligence and achieve adequate mitigation measures within the SPA. ■

PV market consolidation

As subsidies for PV dwindle in many of the European solar markets that initially thrived on mechanisms such as feed-in tariffs, the importance of the secondary market is coming to the fore.

Italy has seen significant activity in this space, earning it the unofficial badge of Europe's leading secondary solar market. The UK, meanwhile, has also emerged as a leading secondary market player, as the initial investors in PV projects sell up to secondary investors looking to amass large portfolios of operating assets. Some analysts have predicted UK solar to have the most concentrated ownership among mature market by the end of 2017.

Authors



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Analysing BIPV affordability

BIPV | One argument frequently used against building-integrated PV is its high cost relative to normal building materials. But as Laura Maturi and Jennifer Adami argue, evidence gathered from real-life BIPV projects suggests otherwise

Several recent international surveys [1] [2] carried out among BIPV stakeholders reveal that one of the main obstacles for the widespread deployment of building-integrated PV (BIPV) systems is the high cost. The economic issue is still perceived as a barrier by architects and contractors, who are the main BIPV stakeholders.

On the other hand, the drastic cost breakdown of PV in recent years has enormously decreased BIPV prices leading to cost competitiveness with standard building materials.

It is thus essential to increase the trust of architects, investors and financial stakeholders, by showing business cases and real stories. Architects' perceptions are highly influenced by tangible examples and real experiences – more than by theoretical calculations.

We have analysed 16 realised BIPV projects as business case studies, providing information on their final user costs. The case studies were selected from among more than 40 examples collected in a local "call for case studies. Our investigation field is not focused on "extraordinary, 'archistar'-designed" BIPV projects, but on "ordinary BIPV high quality", meaning BIPV examples of a high quality, but which have high replication potential in Europe. The sample group includes several kinds of integration typologies from both private and public sector applications.

The case studies analysed by EURAC challenge the cost argument often made against BIPV

Case studies

In order to collect the most representative case studies for our investigation (i.e. ordinary BIPV high quality examples), a local call for case studies was launched by contacting most of the engineers, architects and professionals of the Trentino-Alto Adige region of northern Italy. This region has been very active in recent years in the BIPV field by boosting PV use and building energy efficiency through several measures: incentive schemes, dedicated policies, awareness raising, guidelines development and public engagement in the use of PV in public buildings. Out of more than 40 collected cases, the best ones were selected through an internal workshop.

The meaning of the acronym BIPV in this case-study analysis is intended to convey a broader meaning compared to the EN 50583-1:2016 "Photovoltaics in buildings" standard definition and in particular refers to a triple concept of integration: technology, aesthetic and energy integration. Technology integration is meant as the capability of the PV system to be "multifunctional" (as intended in the EN Standard) and aesthetic refers to the architectural appeal. "Energy integration" refers to the capability of a PV system to interact

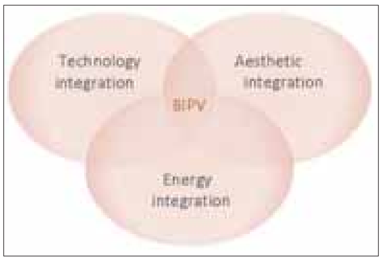


Figure 1. BIPV integration concept

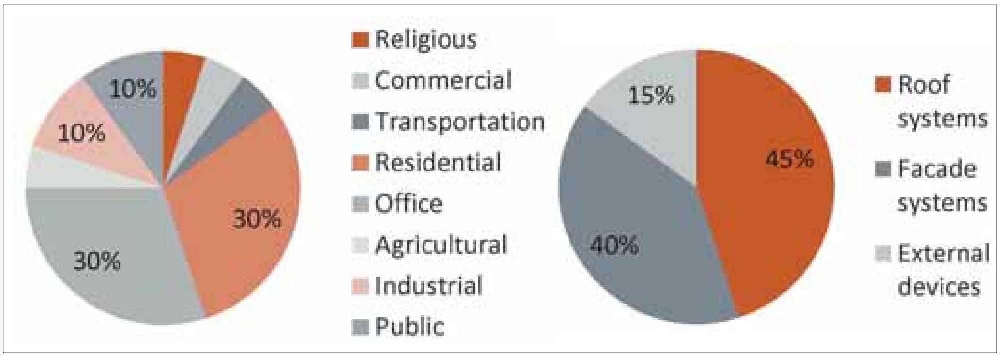


Figure 2. Building typologies (left) and architectural integration types (right) presented in the case studies

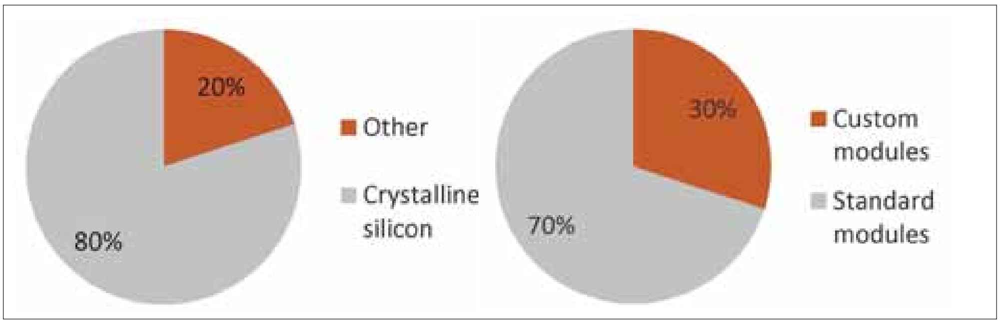


Figure 3. PV technologies (left) and module types (right) presented in the case studies

with the building and district energy system in order to maximise the local use of the produced electricity.

This is in our view a quite important aspect, which is often not considered in the traditional BIPV definitions. In fact, despite the existing "BIPV" definitions, we believe that in order for BIPV system design to be successful, all three aspects must be considered. The selected BIPV case studies are considered respondent to this triple concept (see Figure 1, previous page).

The selected BIPV systems have been installed in a variety of building typologies. They include office, residential, agricultural, industrial, community, religious, commercial and transportation buildings. Most of them have been integrated during the building construction (around 60%), the other ones represent retrofit intervention.

Several architectural integration types are shown, including opaque and semi-transparent roof, warm, cold and double-skin façades as well as external devices such as parapets and solar shading elements. The most predominant are façade and roof systems.

The different building typologies represent both private and public ownerships, giving an overview of the different approaches to the BIPV matter, especially regarding the decision-making related to economic issues (see Figure 2).

In terms of PV module materials, crystalline silicon technology is the most widely exploited, being used in around 80% of the analysed case studies. Most of the modules are standard products (only 30% are custom-made modules). It shows that in many cases appealing BIPV systems can be realised without needing customisation (Figure 3). A more detailed case studies description is found in [3].

BIPV final user cost

The economic matter is tackled from two different perspectives: the "PV" perspective – normalising the cost to kWp, and the "building" perspective – normalising the cost to m^2.

Looking at the PV perspective, results show that the cost of the analysed BIPV systems, whose construction years lie between 2004 and 2015, ranges from €2,500/kWp to €8,300/kWp, with an average of around €5,500/kWp.

> "BIPV system capital cost lies in an acceptable range and is in fact even cheaper than some standard passive building materials"

This variation can be ascribed to several factors, such as the type of technological integration, type of components and, most important, the construction year, since the cost of PV has seen an impressive decrease in the last few years.

In particular, looking at the technological integration types, the following average values are found:

- Opaque cold façade: ~€7,900/kWp
- Semi-transparent roof-façade: ~€5,100/kWp
- External device: ~€4,900/kWp
- Opaque tilted roof: ~€4,400 /kWp

In order to look at the economic matter from a different perspective, the cost has been normalised to the envelope covered surface (€/m^2), thus using an indicator which is normally used in the building sector. The cost of the analysed BIPV systems ranges from €300/m^2 to €1,300/m^2, with an average of around €600/m^2.

In particular, looking at the technological integration types, the following average values are found:

- Opaque tilted roof: ~€600/m^2
- Opaque cold façade: ~€850/m^2
- Semi-transparent roof-façade: ~€500/m^2
- External device: ~€500/m^2

As the €/kWp index, the cost variation can be ascribed to several factors. In particular, this time a crucial role is played by the PV module efficiency. For this reason, looking at this indicator might be misleading but it is very useful to compare the BIPV system cost with standard building materials. It demonstrates that in fact, the BIPV system capital cost lies in an acceptable range and is in fact even cheaper than some standard passive building materials (e.g. glazed curtain walls, stone and others) [4]. This, without even considering the payback time period, which ranges from four to 11 years for the presented case studies (this information was not available for all cases) and which is "infinite" for standard passive solutions (without taking into consideration energy savings).

As mentioned above, the cost variation of BIPV is widely influenced by the construction year, due to the falling costs of PV recent years. Figures 4 and 5 show the trend over the years of the final user BIPV systems cost, considering the "PV" and "building" perspective.

A clear decreasing trend is shown for the last decade (from 2004 to 2015) with values of ~€8,000/kWp and ~€950/m^2 in

CONCEPT OF THE S'TILE MODULE TECHNOLOGY

The innovative character of the S'Tile Modules is based on the manufacture of the i-Cell (integrated cell), i.e. a cell bearing on the same silicon wafer several cells smaller than standard cells, and on Pad-to-Pad connection technology. The i-Cells then are laser-cut in 4 or 5 equal pieces, and through S'Tile's patented Pad-to-Pad connection technology these pieces are soldered into strings. The rest of the process flow is more or less equal to standard module which makes it very attractive for upgrading of existing facilities (capital reuse) for the production of 60- or 72-cell equivalent modules.

Moreover, custom sizes and shapes (round, square, hexagonal, triangular, a.o.) can be manufactured that, thanks to the smaller cell-sizes, offer excellent fill-factor and hence excellent power density.
In order to automate the Pad-to-Pad connection technique, S'Tile engineers developed the soldering process with a supplier of commercial stringers into a cost-effective and mechanically robust solution. The company also offers advisory services in order to upgrade

The differentiating approach of S'Tile is a technology to increase the peak power delivered by the modules by reducing the energy dissipated by Joule effect within the module, and the losses created by shadowing from copper tapes. This approach also leads to a reduction in the consumption of interconnection materials between cells, such as silver, copper and tin, which makes S'Tile technology one of the most efficient in terms of the costs of consumed materials in relation to power delivered and carbon footprint (in kg CO2 emitted per kW produced).

The advantages of this module technology are manifold:

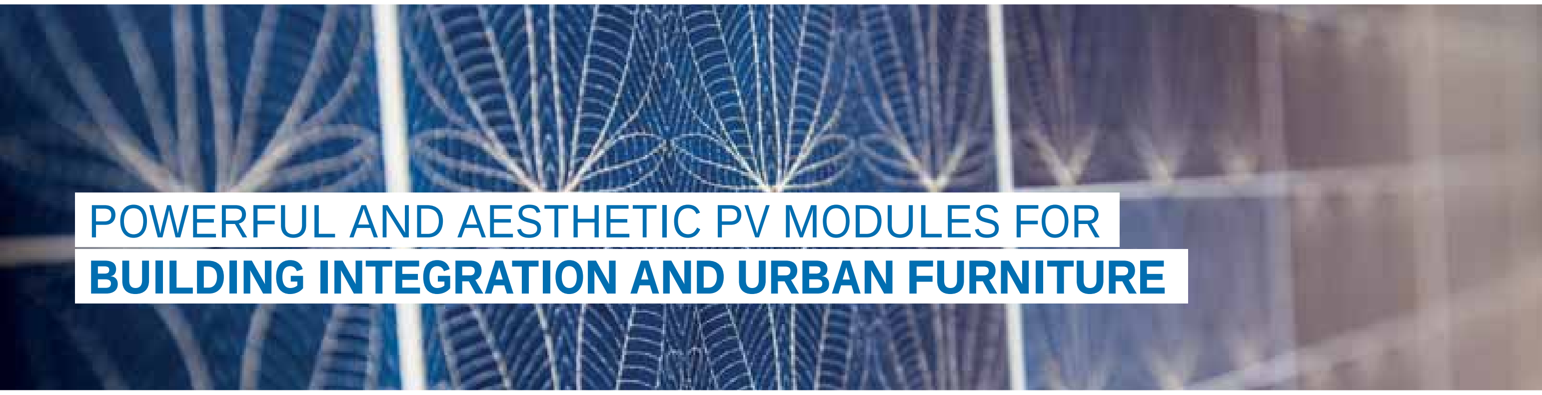
- Reduces resistive losses by over 16 times thereby increasing module efficiency.
- No need for bus bars on the cell resulting in a 50% reduction of shading losses and silver usage.
- The innovative Pad-to-Pad cell interconnection process reduces copper ribbon consumption by 75%.
- Power output ~10% higher compared to equivalent conventional modules.
- This all results in significant materials cost savings at higher module power.
- Module can be "All-Black" with minimal space losses between the cells. Very attractive for the eye.

Unique opportunities available to clients and industrial partners

- Flexible production of standard and customized modules in the Poitiers-1 line, up to 15 MW/year.
- Subcontracted manufacturing for the S'Tile branded modules.
- Licensing of the module technology.
- Co-investment in future capacity expansions.
- Distribution partnership.

S'TiLE

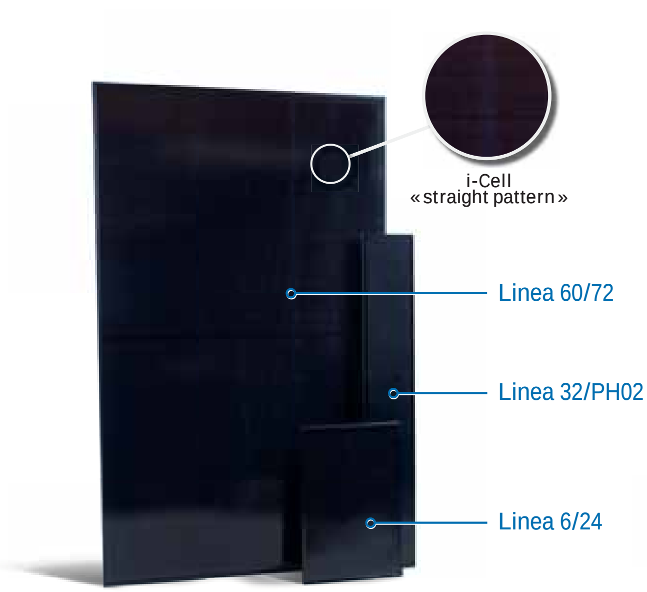
A NEW CONCEPT OF PHOTOVOLTAIC SOLAR MODULES



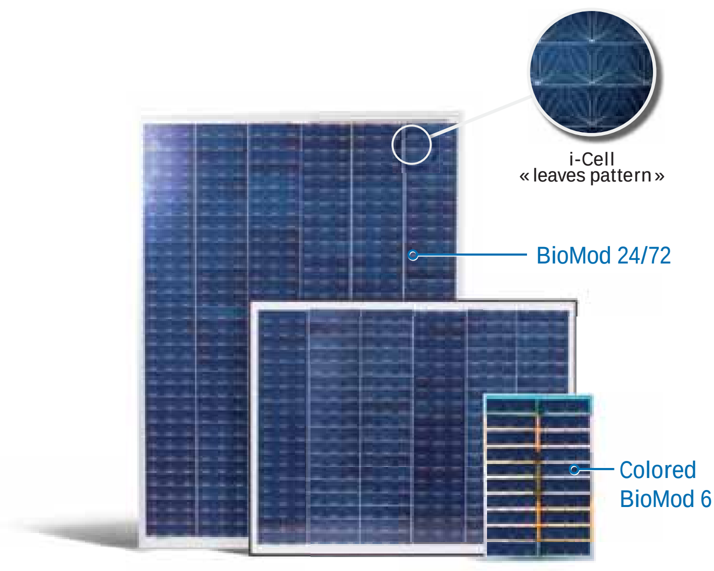
POWERFUL AND AESTHETIC PV MODULES FOR **BUILDING INTEGRATION AND URBAN FURNITURE**

CUSTOMIZED MODULES

MODULES LINEA «FULL BLACK»



BIOMIMETIC MODULES



POWERFUL

AESTHETIC

SUSTAINABLE

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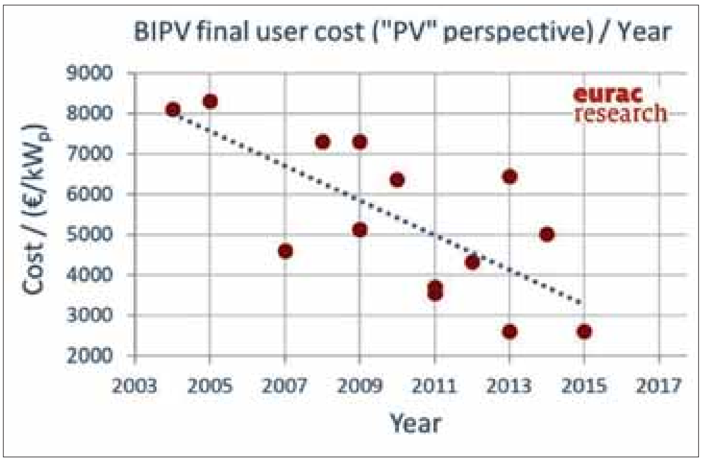

Figure 4. Final user costs of the analysed BIPV systems per construction year, normalised to the system nominal power

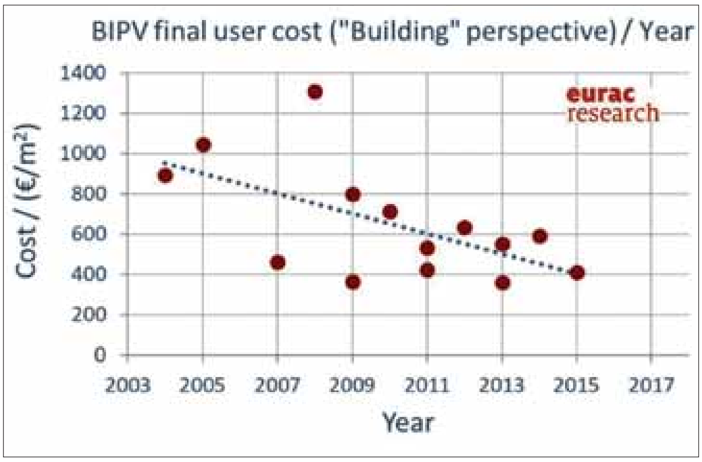

Figure 5. Final user costs of the analysed BIPV systems per construction year, normalised to the envelope covered surface

2004 and of ~€3,300/kWp and ~€400/ m^2 in 2015.

By comparing this data with standard, non-integrated PV systems, we might conclude that the BIPV trend cost in 2015, corresponding to €3,300, is not too far from a ground-PV solution (considering a baseline cost of around €2,500/kWp, typical of small plants in the last few years).

Conclusions

These tangible examples demonstrate that, despite the fact that the economic issue is still perceived as a barrier against the widespread deployment of BIPV systems [1], [2] the use of PV in architecture is in fact viable for many cases. A clear decreasing trend over the years during the last decade is shown (see Figure 4 and Figure 5). Even if some incentive schemes are over in Europe (e.g. the "Conto Energia" for Italy, which lasted from 2005 until 2013), they have paved the way to an irreversible process that cannot now be stopped.

In Italy, the current support schemes rely mainly on two measures: a tax credit, which allows to recoup 50% of the capital cost in 10 years, and the "net billing scheme" managed by agency GSE, which valorises from an economic point of view the energy delivered to the grid. The economic viability of BIPV systems is thus preserved, even if we can somehow read a conceptual shift in the way to reward it: the "Conto Energia" boosted the formal and technological integration (through a higher contribution foreseen for "innovative BIPV"), while the current schemes pursue energy integration, in order to maximise the energy match between the produced and consumed energy.

The energy integration concept is becoming more and more important to meet the new building concept and its energy provision. In fact, also thanks to EU policies such as the NZEB (Nearly Zero Energy Buildings) concept and renewable energy goals [5], [6], buildings are becoming more than just stand-alone units using energy from the grid. They are becoming micro energy hubs consuming, producing, storing and supplying energy, thus transforming the EU energy market from a centralised, fossil fuel-based, national system towards a decentralised, renewable, interconnected and variable system.

> "Despite the fact that the economic issue is still perceived as a barrier against the widespread deployment of BIPV systems, the use of PV in architecture is in fact viable for many cases"

Eurac Research is currently coordinating a European research project named EnergyMatching [7] to address these issues related to BIPV energy integration developing new concepts and technologies in this direction. In this context, PV integration is irrevocably destined to play an essential role in the years to come and, learning from the experience gathered in realised projects, BIPV systems have certainly the opportunity to improve in all the three aspects of technology, aesthetic and energy integration. ■

References

[1] PVSITES H2020 project. 2012. "BIPV market and stakeholder survey: summary of results."
[2] International Energy Agency, "Task 41 - Building Integration of Solar Thermal and Photovoltaics – Barriers, Needs and Strategies."
[3] L. Maturi, J. Adami, F. Tilli, "BIPV in Trentino Alto Adige - The beauty of power generation." In press.
[4] G. Verberne et al. 2014. "BIPV Products for Façades and Roofs: a Market Analysis."
[5] European Commission. 2010 "Directive 2010/31/EU of the European Parliament and the Council on the energy performance of buildings (EPBD)."
[6] European Parliament and European Council. 2009. "Directive 2009/28/CE on renewable energy sources (RES)."
[7] Energy Matching H2020 project, www.energymatching.eu

Authors


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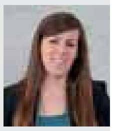

Jennifer Adami is a junior researcher at the Institute for Renewable Energy of Eurac Research. She approached the green buildings field taking a LEED training course. After graduating from Venice University with a degree in architecture and innovation she majored in the BIPV field, working on related design issues and realised case studies.

PV bypass diode faults: current testing and scope for future test development

Module degradation | A working group of the international PV Quality Assurance Task Force has been undertaking research and testing initiatives aimed at improving the design and long-term reliability of module junction boxes and bypass diodes. Vivek Gade and Narendra Shiradkar, who are active leaders of this work, report on efforts to shine a light on a hitherto poorly understood aspect of module reliability

The PV industry has been through significant price reductions in the recent years. The competition to provide the best at the least cost can lead to compromises in design for long-term reliability and quality. The industry needs to keep growing while reducing risks for investors, reducing cost of capital and avoiding a black eye in the event shortcuts are taken in the highly competitive PV landscape. Component design and evaluation become very critical under such circumstances. A reductionist approach is very important to improve product quality through use of robust components.

PVQAT was formed after the Ministry of Economy, Trade, and Industry (METI) in Japan approached the US Department of Energy (DOE) in late 2010 with a vision to initiate an international effort on PV reliability. In July 2011 an International PV module quality forum was held in San Francisco. This forum helped form an international PV module quality assurance/reliability task force.

Task force group #4 was formed to focus on junction and diode reliability with an aim to propose test protocols and standards that would eventually lead to robust designs and ultimately lower the levelised cost of energy (LCOE) from solar. Several industry experts joined the team, drawn from the US National Renewable Energy Laboratory, solar panel manufacturers, junction box manufacturers and diode manufacturers. Apart from the group in USA, significant contributions have come from teams working in other geographic locations namely Japan, China and Europe.

High diode temperatures in forward bias observed inside a junction box

The group investigated several different aspects of junction box and diode reliability, starting with the accuracy of technical datasheets and exploring and performing new qualification tests. Some of the unique work performed involved collecting information of real failures in the field, with an effort to recreate these failures through controlled chamber testing, and failure analysis of field failures using analytical tools to understand the root cause and failure mechanism.

Bypass diode failures

Bypass diode failures can be encountered in two modes: short circuit and open circuit failures.

Short circuit failure

When a bypass diode fails in short circuit, it shorts the sub-string of 20 or 24 cells within a 60- or 72-cell module respectively. Typically, commercial modules have one diode per sub-string and there are three such sub-strings within a module. Therefore, short circuit failure of one diode results in a one-third power loss for the module. This would immediately put the module out of assured performance warranty. In this case, either the diode or usually the whole junction box needs to be replaced to bring the module power back to normal values. In the worst case, where the junction box cannot be replaced in the field, the entire module needs to be replaced.

Open circuit failure

Bypass diodes are used in PV modules to prevent the application of high reverse voltage across cells under the event of shading. When a bypass diode across a sub-string of cells fails in open circuit, this condition is similar to not having the diode across that sub-string. This type of failure does not affect the module performance under normal (unshaded) conditions. However, in case a cell in the same sub-string experiences shading, there is nothing that can prevent the application of voltage generated by all other cells in the module across the shaded cell in reverse bias. This leads to failure of the shaded cell due to excessive power dissipation. In a worst-case scenario, the temperatures can reach very high values, posing a threat of fire hazard. Therefore, open circuit failures of bypass diodes are regarded as safety risks. In this case, either the diode or usually the whole junction box needs to be replaced to eliminate safety risk. In the worst case, where the junction box cannot be replaced in field, entire module needs to be replaced.

Field failures

The following discusses a junction box failure due to short circuit. The unit containing three ultra-low VF Schottky Barrier Rectifier diodes failed in the field. The part was electrically tested and found to be a total short circuit.

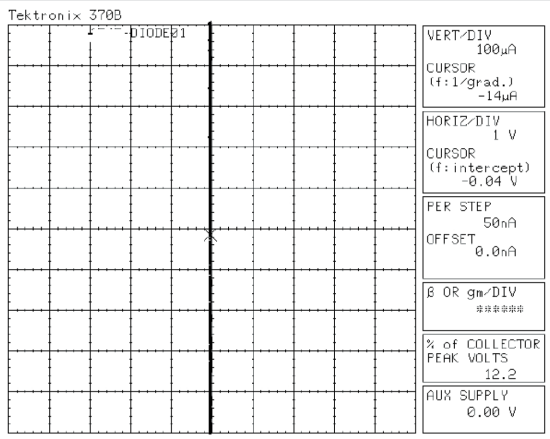


Figure 1. Testing showing total short. As resistance approaches 0, the slope approaches infinity, i.e., the I-V characteristic becomes vertical through the origin. This is an ideal short circuit; the voltage is zero for any current through

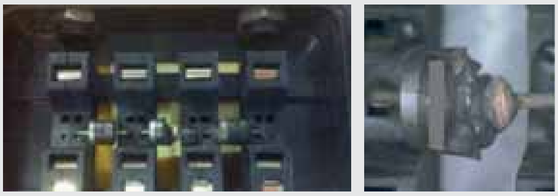


Figure 2. Diode failure involving cracked epoxy packaging potentially due to high temperatures caused by electrical over-stress

It is possible that the centre diode may have been severely damaged by the electrical overstress (EOS) event and diode on the right to a slightly lesser extent. Unfortunately, little could be learned from the failure analysis due to the extent of the damage to the diodes; resulting in the die fracturing in several places and the epoxy mold compound carbonising on the front face of the die, preventing it from being removed by standard chemical methods. It was clear from the damage to the die, packages, and the surrounding plastic unit that the over-stress event was very severe, generating significant temperatures. Significant melting of the surrounding plastic unit has also occurred. This diode has also been extensively damaged.

Failure detection and field failures

Short circuit failures are relatively easier to detect as compared to open circuit failures and can be detected using a variety of techniques. This is because diode failures in short circuit often result in a loss of one-third of the module's voltage in open circuit (Voc). Therefore, even with a simple multi-meter, it would be possible to detect such a significant drop in module Voc. In fact, it is also possible to identify a sub-string of cells with a short-failed bypass diode using infrared imaging. Of course, when a regular I-V trace is performed on the module, diode short circuit failures can be easily identified. In a laboratory, when electroluminescence imaging is performed on a module, the entire sub-string of cells with a short-failed diode appears dark.

On the other hand, open-failures of diodes are not easy to detect as they impact the module performance only under shading. Therefore, I-V tracing under partial shading or use of specialised equipment such as a diode checker is necessary in order to identify open failed diodes.

Failures may or may not have any visible signatures such as burn marks on the diodes or junction boxes. Difficulties in detecting diode failures may be the reason why only very few published studies are available that have reported diode failures in any significant quantity. The box, left, details one detected instance of a diode failure.

Failure mechanisms/stressors leading to diode failures

Temperature over-stress in forward bias

When a PV module is partially shaded, the bypass diode turns ON and its temperate begins to increase due to power dissipation in forward bias. If this condition persists for a long duration, the diode temperature eventually stabilises as the diode reaches a steady state. If the diode temperature exceeds the maximum rated temperature, the diode may undergo failure due to this single event of temperature over-stress. The bypass diode thermal test in IEC 61215 is introduced as a check to screen out designs of bypass diodes/junction boxes that are susceptible to failure under partial shading due to temperature over-stress. Junction box designs qualified under IEC 61215 have demonstrated reduced infant mortality from temperature over-stress events.

Gaps: The current bypass diode test is performed at 75°C ambient temperature and its first part involves passing current equal to short circuit current of the module through the diode for one hour and monitoring if the diode temperature exceeds maximum rated temperature. The maximum temperatures achieved under these test conditions are representative of rack-mounted modules in moderate climates. However, these days modules are increasingly being deployed in hot climates and also in roof mounted configurations, in which the test conditions experienced in field are much harsher. Therefore, it is necessary to revise the test conditions to reflect this reality and reduce the occurrence of false positives under the current test when the module is deployed in hot climates.

Long-term high-temperature operation in forward bias

If a partial shade scenario persists for long duration, and is a daily occurrence, diodes may end up spending significant amount of time at high temperature in forward bias. This may lead to diode failure due to continuous operation at a high temperature. This type of behaviour is not assessed by the bypass diode test in IEC 61215, which only tests a diode at an elevated temperature for a total of two hours.

Gaps: Currently there is no standard to test the susceptibility of junction boxes against failure due to long-term operation at high temperature in forward bias.

Thermal runaway in reverse bias/ forward to reverse transition

As explained above, a diode operates at a high temperature if the partial shading is held on the module for significant amount of time. If the shading is suddenly removed, the diode immediately turns to reverse bias. If the power dissipation in reverse bias is more than the power taken out by the junction box cooling system, the temperature of the diode begins to increase further. Since reverse current (and power dissipation) exponentially increases with temperature, this leads to a further rise in temperature until this cyclic process results in diode failure.

Gaps: Until recently, there was no standard available that would test the junction boxes for susceptibility against failure by thermal runaway. Initiatives from the PVQAT diode group members have led to the development of IEC 62979 (drafted by Uchida-san, Japan) to assess the susceptibility of junction boxes towards thermal runaway. However, qualification under this standard is not yet mandatory.

Long-term high-temperature operation in reverse bias

When the module is not subjected to partial shading, the diodes are reverse-biased. This is the normal mode of operation for bypass diodes and they spend significant duration of their service life in this state. When the modules are deployed in moderate climates and/or in rack-mounted configuration, the temperature of bypass diodes in reverse bias is not considerably high. However, for the case of modules deployed in hot climates and/or roof-mounted configurations, the diodes may operate at elevated temperatures (but at a temperature less than necessary to cause thermal runaway) for a long duration and may undergo failure due to increased junction leakage because of the release of impurities on the silicon die surface. Prolonged temperature exposure may lead to degradation of material properties and eventually inferior electrical performance. More testing and research is needed in this area to establish the exact mechanisms.

Gaps: Currently there is no standard to test the susceptibility of junction boxes against failure due to long-term operation at high temperature in reverse bias.

Thermal cycling

PV modules are tested for their robustness for thermal cycling during the tests in IEC 61215. However, when the diodes are in forward biased due to recurrent partial shading, the ΔT (the difference between maximum and minimum temperature) experienced by the diodes is much higher than that experienced by the modules. In this case, the large temperature fluctuations may cause diode failure by solder bond failures at the die or in the worst case crack propagation in the die itself due to thermal cycling.

Gaps: Currently there is no standard to test the susceptibility of junction boxes against failure due to exposure to significant amount of cyclic thermal stresses.

Electrostatic discharge (ESD)

Until recently, ESD was a major cause for diode failures in a PV module manufacturing line. The diodes may fail during module assembly due to high voltage spikes generated through contact by humans/machines or equipment such as a flash tester.

Gaps: Initiatives from the PVQAT diode group members have led to the development of IEC TS 62916:2017, (drafted by Kent Whitfield) to assess the susceptibility of bypass diodes against failure by ESD. The test specification provides the opportunity to perform the tests and measure the efficacy of this test. This also helps address any need to make further changes and if no changes are needed based on the data collected this could be potentially be a test standard in the future and potentially be made a mandatory standard test.

PVQAT diode group initiatives to address the gaps

As discussed, the only mandatory qualification test for bypass diodes/junction boxes is the bypass diode test in IEC 61215-1 and a functionality test at the end of IEC 61730-2, which addresses the issue of temperature over-stress in moderate climates. It was realised that bypass diodes in the field experience several different stressors and may fail by various failure mechanisms. The diode group of PVQAT is focused on developing methodologies and accelerated tests to address diode failures by the different failure mechanisms discussed above. The goal is to make available methodologies to screen for reliable bypass diode/junction box designs that would provide longer service life in field against different failure mechanisms. The work on ESD and thermal runaway has led to development of IEC TS 62916:2017 and IEC 62979:2017 respectively.

For the other failure mechanisms, efforts are focused on understanding the underlying physics and developing models that can explain failure data due to respective stressors such as high-temperature forward bias operation, thermal cycling etc. Once these models are identified, it would be possible to determine the field equivalents of various accelerated tests and develop tests that would simulate 25 years in the field (for a given end use environment and failure mechanism). When new diode/junction box samples are used in such accelerated tests, it would become possible to predict the service life of diodes under various end use environments.

Research efforts are now focused on developing a bypass diode test for hot climates. IEC TS 63126 Guidelines for qualifying PV modules, components, and materials for operation at higher temperatures.

The intent would be to develop a test to simulate service life under mechanisms such as high-temperature forward bias operation (currently assuming the Arrhenius model), and thermal cycling (currently assuming a modified Coffin-Manson model). Moreover, in order to address the issue of failures by thermal cycling, the group has recommended passing current through the diode for at least 50 cycles during the normal thermal cycling test on PV modules followed by a diode functionality test.

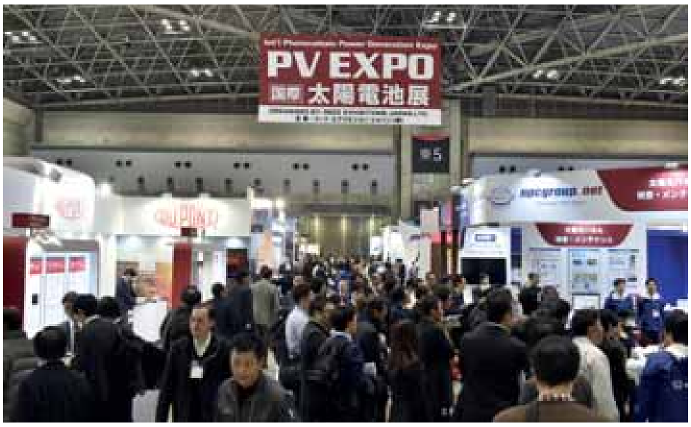
Efforts are also underway to develop a framework to establish direct predictive relationships between the failure mode parameters (activation energies for high-temperature forward bias and thermal cycling, thermal runaway crossover temperature) of diodes, the field stressors determined by the thermal resistance, module current, climate of deployment and mounting configuration, and the diode lifetime in the field for the several different deployment scenarios. Even though diode failures have been reported by different entities for several systems, both ground-mounted and rooftop, actual field failures are very hard to come by for investigation in detail. ■

Authors

Vivek Gade has worked in the PV industry for over 13 years, focusing on reliability and manufacturing. He has been managing the Jabil Solar and Environmental Test Center (JSEC) in St Petersburg, Florida, supporting several gigawatts of manufacturing, quality and reliability, for over seven years. JSEC provides services such as PV component evaluation, module design, prototyping, testing, field evaluation and failure analysis to a wide range of customers. Jabil is primarily into creating unique, automated processes for its customers through several cutting-edge manufacturing service offerings including solar panel manufacturing. He has been a US ANSI TAG 82 and WG2 group member since 2010 and the USA leader of the PVQAT Task Group 4 on diodes and shading since 2011.

Dr. Narendra Shiradkar is a co-leader of the PVQAT Task Group 4 on diodes and shading. He is currently assistant professor at the department of electrical engineering, IIT Bombay and leads the module reliability initiative of the India's National Center for Photovoltaic Research and Education (NCPRE). Before that, he worked as Photovoltaic Research Engineer at Jabil Circuit Inc. He has a PhD with specialisation in module reliability from Florida Solar Energy Center, University of Central Florida.

Enter the Japanese market with high tech products at PV EXPO and PV SYSTEM EXPO 2018



Japan's largest PV industry shows, PV EXPO 2018-11th Int'l Photovoltaic Power Generation Expo and PV SYSTEM EXPO 2018-9th Int'l Photovoltaic Power Generation System Expo, will be held from Feb. 28 – Mar. 2 in Tokyo next year. Organised by Reed Exhibitions Japan, the events will take place at Tokyo Big Sight, covering both upstream and downstream business alongside technical conferences. Including concurrent shows, PV EXPO and PV SYSTEM EXPO are expected to attract 430 exhibitors from 18 countries and 70,000 trade visitors from 71 countries to source the latest PV technologies and products.

Photovoltaic (PV) power generation has become the top priority in Japan since the Fukushima Daiichi nuclear disaster in 2011. Since then, Japan's PV power generation capacity was calculated to be 94GW in 2015 and according to *Nikkei BP CleanTech Institute*, it is expected to increase to 129GW by 2040. This is much higher than the Japanese government's expectation. 65GW of the capacity is predicted to be distributed power generation and 29GW to be generated by mega solar. The distributed power will have particular advantages in cost comparison with utilities, as it could result in a more fixed, stable market.

The cost of solar panels has been decreasing over the years and compared to 6 years ago, the installation cost has halved. Even with improved solar panel performance, the installation payout period remains the same. As a result, more Japanese companies have started to invest in PV. Additionally from this year, the maintenance and management of PV power plants have become mandatory so the demand for new O&M technologies and services are on the rise. Places like Hokkaido, Aomori, Akita, Iwate, and other Tohoku areas still do not have many power plants, so more are expected to come.

Companies who are already planning to visit PV EXPO and PV SYSTEM EXPO have great interest in investing in solar panel cleaners, panel coating agents, anti-weed sheets, fences, grass cutters, etc. And many are willing to spend an estimate of 25 million to 5 billion JPY on management maintenance-related products within half a year to 2 years. (Based on Visitor Registration)

Major Japanese PV module manufacturers including Sharp, Kyocera, Solar Frontier and Panasonic have already been confirmed to exhibit again this year, alongside top ten global solar cell manufacturers such as Trina Solar, Yingli Green Energy, Canadian Solar, Hanwha Q CELLS, Jinko Solar and JA Solar.

With the further expansion of PV power generation in Japan, PV EXPO and PV SYSTEM EXPO are the best gateways to enter the Japanese PV market, as well as source the latest leading-edge technologies & products from across the globe for your business expansion.

Project briefing

STORAGE THE GAME-CHANGER IN UK'S FIRST SUBSIDY-FREE UTILITY-SCALE SOLAR PLANT

Project name: Clay Hill Solar Farm
Location: Flitwick, Bedfordshire, England
Project capacity: 10MW
Storage capacity: 6MW/6MWh

"This is where the market will go, and we need to build the first one," Steve Shine, chairman at UK renewables developer Anesco says, recanting a conversation he shared with the rest of his board. That direction was co-located solar and storage, designed to lighten the load renewables have had on the UK's grid; that first one was Clay Hill Solar Farm, the UK's first solar farm built entirely free of government support, which Anesco connected in the summer of 2017.

Anesco first conceptualised the site around 18 months previously, having planned a separate solar farm on land adjacent to the site which would come to be known as Clay Hill. Land owned by the same farmer – literally across a small access road – hosts a 5MW solar farm connected to the grid some months prior. That solar farm, the Hermitage Solar Farm, was completed under the Renewables Obligation (RO) scheme, the now-defunct UK support mechanism for ground-mount utility-scale solar farms. Hermitage was one of the last to be completed and receives just 1.2 RO certificates for each unit of electricity it produces, but that was enough to finance its development.

Clay Hill is not fortunate enough to receive such support, but does directly benefit from Hermitage being built. Clay Hill doesn't share a grid connection – it has its own – but it has been connected to the same part of the grid as Hermitage, allowing it to share some of the associated works. This shaved a little off the cost of the overall development, only helping its cause.

Construction was relatively swift. Development of the site started roughly two months after the RO window slammed shut on 31 March 2017 and the park was formally completed in August. It was then unveiled to the public the following month at an event which was also attended by UK climate change minister Claire Perry. Having joked about the site justifying its Clay Hill name – weather conditions in the UK had meant the ground more closely resembled a bog than a power station – Perry lauded Anesco's feat and described it as a momentous achievement for UK solar.

What she also mentioned was something Shine had been quick to stress to her and something he is only too quick to reiterate: that the farm could not have been developed without a considerable amount of collaboration with Anesco's supply-chain partners.

Supply-chain engineering

It was akin to locking Anesco's suppliers in a room and not letting them out until they could get it done, said one person who worked on the project.

Shine paints it in a slightly lighter manner, describing how Anesco held a serious of workshops with its suppliers as it looked to reduce the overall cost of the farm's development. "We completely re-engineered how we built [solar farms] in the past and rethought how it needs to be done," he says.

Anesco elected to source both the solar modules and accompanying batteries from Chinese manufacturer BYD and, in doing so, secured a better deal than most. In the end more than 30,000 315W BYD modules have been used, with five, 1.2MW batteries also included in the order.

It approached UK-based Hill & Smith Solar for the mounting frames and managed to remove several tonnes worth of steel from what was required for the project by electing for bespoke frames that took several millimetres off standard design sizes. This, too, contributed towards the overall savings achieved during the design and development stage.

Inverters were supplied by Huawei, which provided its brand new 1,500VDC string inverters for their first deployment in Europe. Shine admits that, at 10MW, there was the temptation to use a central inverter system at Clay Hill but the firm persevered with its belief that string inverters are too beneficial to overlook. Each of the Huawei inverters includes maximum power point trackers and 12 directly connected string inputs to improve flexibility in the PV

By Liam Stoker

strings, helping to maximise energy yield. The inverters are also expected to fail far less frequently – a problem which has reared its head for some of the UK's existing solar assets due to the country's surprisingly humid summers – and achieving savings in the long run.

Lord Browne of Madingley, chairman of Huawei UK, said the firm was proud to have a role to play in the site's development. "Significant technological advances, underpinned by industry collaboration have helped deliver the first subsidy-free solar farm in the UK and Huawei's smart PV solution has played a critical role in the successful delivery of this initiative… This project is evidence of how solar is not only one of the most competitive renewables, but is now able to compete with all forms of generation," he said.

In total, Shine says that Anesco managed to shave more than a third (35%) off the total development cost of the site just through the supply-chain engineering the company is quick to laud. It's these innovations that it holds up as examples that other developers could embrace to drive costs down further, although not every UK-based developer will have the leverage to lean on names like BYD as Anesco has done.

With the supply chain engineered and cost savings achieved, Clay Hill was ready to generate power. But it's not just power that solar projects have to produce, particularly if they're to be investable. It's the returns – especially so in subsidy-free environments – that will make or break a project.

The revenue stack

Such was the desire to see the project over the line that Anesco financed the site via its balance sheet. Anesco has historically sold the assets it has developed not long after their completion, but Shine says that this may change with Clay Hill. It could be sold in the coming years, but not before Anesco has used the site to demonstrate that its model works.

The panels are expected to generate more than 9,000MWh per year but, despite beneficial prices secured by Anesco's exhaustive supply-chain efforts, the export of power would not be enough to finance the site's development alone. It is for this reason that Clay Hill has been developed with 6MW of battery storage facilities on-site.

These batteries are pivotal to Clay Hill's economic viability. Not only can they be used to shift the sale of solar-generated power to peak times, achieving more lucrative prices on the UK spot market; they will also be utilised by Anesco to provide grid-balancing services to the UK's system operator National Grid.

The UK's transmission network is maintained at a frequency of 50Hz – the frequency at which power is transmitted most effectively – and kept to within 0.5Hz of it either side. National Grid has various tools at its disposal to keep it within those parameters and has been called upon to use these tools more frequently as greater levels of variable generation has come onto the grid. Battery storage has come to the fore as a pivotal technology in National Grid's suite of grid balancing tools.

In 2016 it handed out four-year support contracts to 200MW worth of batteries under its Enhanced Frequency Response (EFR) programme. Those batteries must respond within one second's notice should National Grid command them to and receive fees for both standing idle and being used in action.

While EFR has now closed to new applicants, battery storage plants can be supported through both the Fast Frequency Response (FFR) market – which acts in a similar fashion to EFR – and the Capacity Market mechanism, used by National Grid to procure reserve capacity at times in the winter months when the capacity margin is at its tightest.

Clay Hill's batteries will be eligible to

A brief history of UK solar subsidies

While some ground-mount solar farms in the UK, particularly those developed as part of community benefit schemes, have been developed using feed-in tariffs (and an even smaller number supported by the competitive auction process dubbed Contracts for Difference) the significant majority have been supported through the Renewables Obligation scheme. This was established by the UK government to incentivise the development of all forms of renewables generation and it lit a fire under the UK solar industry. The scheme rewarded developments with RO certificates for each unit of electricity generated that could be sold, providing a predictable revenue stream. Each year on 31 March the scheme degressed, awarding fewer and fewer certificates for completed projects. The ROC windows of 2015 and 2016 were particularly successful, bringing forward around 4GW of solar alone, which caused the government to close the scheme prematurely in 2017.

bid for any future frequency response markets and, crucially, have been entered into pre-qualification for the forthcoming Capacity Market mechanism. One of the criteria to bid for Capacity Market contracts is that generator stations are deemed to be newly built (to incentivise the development of new assets, rather than continue to support ageing, legacy infrastructure), and it is for this reason that while the solar farm connected and began generation in early September, the batteries were not switched on at the same time.

In that sense, Clay Hill has been built unlike any other solar farm operational in the UK today, although Anesco is also at the forefront of retrofitting existing, ROC-accredited solar farms with battery storage. It has done this at more than 10 sites in the UK to date following close work with the country's energy regulator Ofgem, done so to ensure that there is no chance of the site being subsidised twice; once for when the power is generated to the battery and another time for when it is dispatched from the battery.

Clay Hill has sought to set a standard that not just Anesco, but other solar farm developers in the UK and beyond, can replicate.

A replicable model

Anesco has another four solar farms just like Clay Hill that are shovel-ready. These will feature solar alongside batteries, in keeping with Shine's vision that renewable generators must do more to be accommodated into the future power system.

But the UK's Department for Business, Energy and Industrial Strategy, which is responsible for energy policy, has thrown something of a spanner in the works. The Capacity Market mechanism that could provide a highly bankable 15-year service contract looks like being tinkered to more

appropriately recognise the way in which different battery technologies work.

Given that the Capacity Market is designed to procure reserve capacity in the wake of a period of strain, National Grid expects them to deliver for a period of up to four hours. Lithium-ion batteries are unable to deliver their rated capacity for that period and, as a result, BEIS looks set to 'de-rate' them – allow them to enter the market at a set percentage of their overall capacity – from this or the next Capacity Market auction.

Shine acknowledges that some de-rating for batteries is inevitable, but says now is not the time. "It's a negative move at this particular time… it's not the revenue that investors want, it's the ability to raise debt and 15-year contracts that are vital," he says. Anesco is now investigating the potential for flow batteries to be installed rather than lithium-ion as a workaround, but given the comparative costs of the two technologies this looks more like being a longer-term play than anything else.

Anesco has replied to the government's consultation on the subject pitching a phased approach to de-rating. The full de-rating would be introduced in parts over three or four years in a similar fashion to how the RO subsidy scheme was phased out. This would, Shine insists, stave off investors' fears that the market could change overnight.

Even better still, Shine says, would be a set of tariffs that National Grid would pay projects like Clay Hill for the flexibility or reserve capacity services they could provide. Long-term contracts would provide investment certainty and there would be no subsidy involved, with renewables-plus-storage developments earning their crust.

It is perhaps a fanciful vision, but one that fits very much with the changing power landscape the UK is currently experiencing. Such a scheme would establish a place for solar in the UK power market, solve a critical requirement for the country's energy infrastructure and undoubtedly save millions in grid reinforcement works.

But until such a set of tariffs is introduced solar in the UK will have to find its own way. Clay Hill may have been the first subsidy-free project in the country but it will not be the last. PV Tech Power publisher Solar Media's in-house market research team is tracking a multi-gigawatt pipeline or projects that could be built as early as 2018, with international developers Hive Energy and Wirsol having unveiled plans for a 350MW project for the Kent coast in early November – by far the UK's largest solar project if realised.

Clay Hill will however be regarded as a landmark for UK solar, one realised through intensive supply-chain engineering and a flexible approach to its revenues. Shine says that despite operating sans subsidies, Clay Hill is poised to generate a better IRR than some ROC-accredited sites in the UK given what these are currently selling for on the secondary market. Anesco is keen to hold on to the sites for now but could look to sell in the long term. Investor appetite for sites like Clay Hill would be the surest sign yet that the UK solar market is back on track. ■

Solar O&M in the Middle East: technical challenges and solutions

Operations and maintenance | From sandstorms to extreme heat, solar installations in the Middle East face some unique operational and technical challenges. Experts from Jordan-based developer and O&M specialist MASE describe some of the innovative solutions emerging to keep plants running in the harshest conditions

The Middle East region has over the decade experienced an unprecedented growth in solar energy, with some countries targeting a triple-digit megawatt penetration of solar capacity. Developers, contractors, lenders and consultants now consider the Middle East region as one of the most promising solar energy markets. Pioneering countries such as Jordan, UAE and Morocco have already interconnected over 500MW of solar capacity onto their electricity grids.

However, whilst solar energy sees rapid penetration in the Middle East and more facilities interconnect to the region's grids, solar plant operators and asset management firms are facing unique technical and operational challenges not seen in other regions such as Europe and the United States where solar PV markets are generally more established. Local O&M firms such as MASE with acute knowledge of the operational particulars are pioneering solutions to overcome these challenges and are harvesting valid and reliable data in the process. This feedback is proving essential to stakeholders in the development of a bespoke technical blueprint to cater for the Middle East region's growing demand for solar energy.

Background

Over the past four years, Jordan has interconnected over 200MW of utility solar PV capacity, corresponding to approximately 5% of the country's total power generation. While traditionally Jordan has relied on 3.5GW of diesel- and gas-fired conventional power plants for energy generation, plans are underway to add a further 450MW of solar PV capacity over the next two years, boosting the total solar PV penetration in the overall mix to over 10%. The Jordanian grid is managed by the National Electricity Power Company (NEPCO) and is interconnected to neighbouring Egypt and Syria with plans to connect to Iraq and Saudi Arabia. This article contains data and analysis gathered by MASE, a regional operations and maintenance firm with over 80MW solar assets under care.

Extremely soiled PV panels in Jordan. Dust is one of the region's biggest challenges

As local and international solar O&M firms measure up to manage utility solar PV plants currently operational in Jordan and elsewhere in the Middle East region, they are having to deal with unique technical and operational challenges and innovate bespoke solutions to overcome them. Oftentimes, harsh weather conditions and unstable grid behaviour adversely impact the performance of solar PV plants by a daily factor of up to 40%. Also, soiling and high temperatures are proving to be more significant operational factors than originally anticipated.

The impact of soiling on plant generation

More than 80% of the Middle East region is desert and receives fewer than 25 centimetres of rainfall a year. This translates to a particular technical challenge for site operators who in many cases are expected to stand behind performance guarantees often benchmarked against less harsh foreign topographical conditions. Whilst soiling is a common concern for solar PV operators around the world, it poses a significant operational concern in the Middle East region, especially given that the majority of solar pants are constructed in remote desert locations, by virtue of the higher levels of irradiation in such locations.

In some extreme cases, soiling losses of up to 30% have been recorded when solar panels are left unwashed over relatively short periods of time (less than 60 consecutive days). The following data was collected from a solar plant located in Azraq, Jordan, a desert city to the north east of the country.

As Figure 1 demonstrates, the severe soiling recorded not only impacts the overall production curve, but also flattens the peak point during which the plant is expected to generate at its full capacity. In the case demonstrated in Figure 1, the plant was left unwashed for two consecutive months during the summer season (August and September) and was fully washed in October using water and specialised mechanical machinery.

Even though soiling can be managed by increasing the frequency at which solar panels are washed, site operators and plant owners must evaluate the economic cost benefit of each additional wash given the scarcity of suitable water sources in most countries in the region.

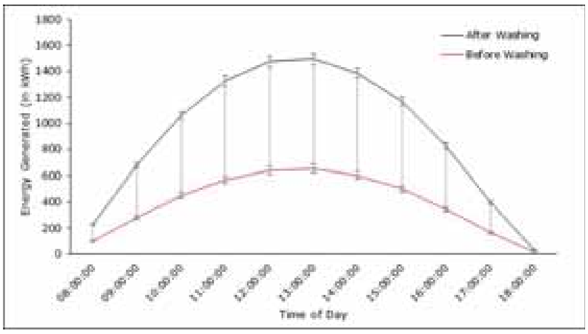


Figure 1. Impact of soiling on daily energy production

Figure 2. A solar PV plant in the midst of a severe sandstorm in Jordan

In the case above, the performance benefits are unmistakable and the plant is currently washed on average once a month during the summer season.

In addition to soiling, haphazard sandstorm behaviour is another significant weather anomaly common to the region and one that site operators must closely monitor. With its desert conditions, the Middle East region is prone to harsh sandstorms that often last for days and may reappear at random intervals. This poses a particular challenge to site operators, who will need to actively analyse area-specific weather forecasts and track sandstorm behaviour. This may be an alien task to operators in other parts of the world but is extremely relevant to site operators in the Middle East. To manage the impact of sandstorms on performance, local O&M operators use multiple site reference cell data gathered from the site coupled with weather forecasts to decide when it is best to clean. As sandstorms often appear haphazardly, site operators in Jordan refrain from washing solar panels in the days immediately following a sandstorm in order to avoid adverse further escalation of soiling.

As mentioned earlier, whilst soiling may not pose a significant operational challenge elsewhere, it is a main concern for local operators in the Middle East. MASE's experience is summarised as follows:

- On average, module washing in intervals not exceeding 30 days will maintain soiling losses to below 2%. Longer intervals may result in significant impacts on performance by up to 40%;
- Tracking sandstorm behaviour is essential and must be evaluated by site operators when scheduling washing sequences to avoid adverse impacts;
- Dry cleaning is not recommended, unless coupled with advanced cleaning robots, which are generally yet to prove their effectiveness in the Middle East.

Power limitation and equipment design

Whereas soiling is mostly an operator-managed concern, equipment manufacturers are responsible for thoroughly evaluating how their products perform when operating in harsh Middle Eastern weather conditions. The case for region-tailored equipment may require commercial evaluation, but PV module and inverter manufacturers need to consider that while their products may be suitable for one region they may not be for others.

Unsuitable inverter design and inadequate heat management have been flagged as two of the main issues curtailing the performance of solar plants in the Middle East. Inverter stations, which are typically designed to

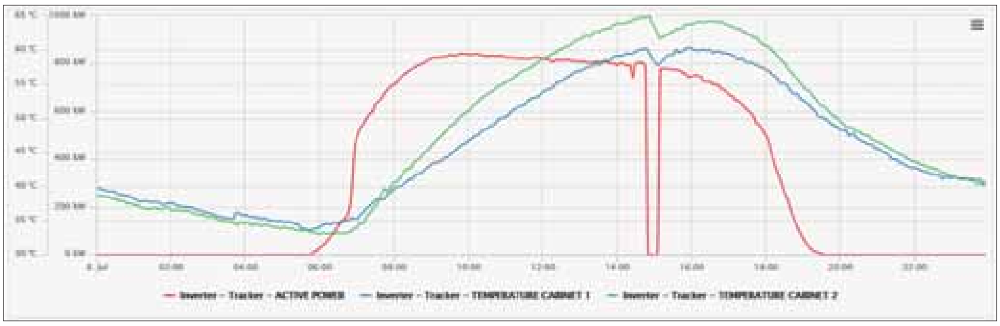


Figure 3. An event of Inverter shutdown due to high temperature

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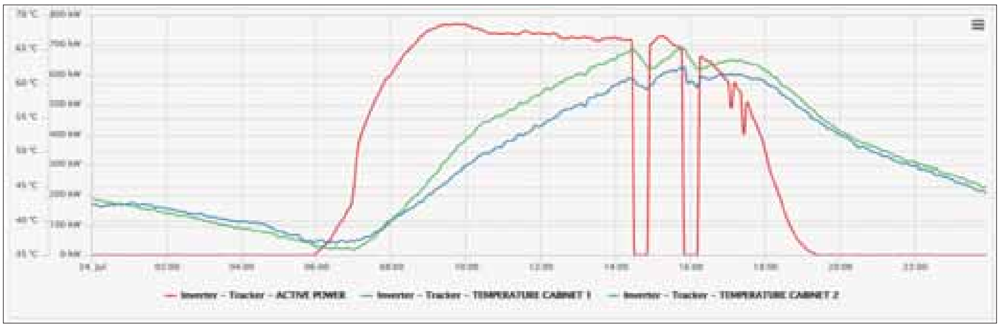
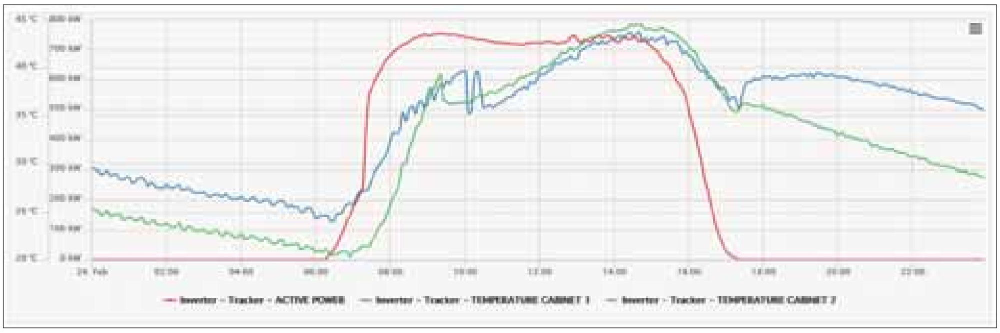


▲ **Figure 4. Two subsequent events of inverter shutdown due to high temperature**

Total Energy Lost per Day: 462.3 kWh			
Period 1		Period 2	
Time	Power (kW)	Time	Power (kW)
14:25	718.5	15:45	693.8
14:30	0	15:50	0
14:35	0	15:55	0
14:40	0	16:00	0
14:45	0	16:05	0
14:50	0	16:10	0
14:55	700.4	16:15	661.7
Total Downtime	20 minutes	Total Downtime	20 minutes
Energy Lost (kWh)	236.4	Energy Lost (kWh)	225.9

◀ **Figure 5. Inverter operation data and curtailment analysis**

▼ **Figure 6. Inverter operation when properly cooled and ventilated**



withstand predictable weather conditions of Europe, perform poorly in the Middle East. Consequentially, site operators have had to cope by implementing intuitive but temporary solutions to overcome cooling and ventilation complications.

Data has shown that inadequate internal cooling results in daily plant shutdowns of up to 15 minutes per day during the summer season. For developers and plant owners, this translates to a bearing on their revenue stream and may on occasion hamper their ability to meet financial and contractual obligations. For operators, inverter downtime will directly impact their performance indicators and decrease plant availability.

Inverter stations typically operate within a set range of internal temperature parameters and are also designed to tolerate temperature levels slightly beyond those limits. The power trend in Figure 3 corresponds to a standard inverter station with an internal temperature tolerance of 65 degrees Celsius, after which the inverter shuts down to protect itself and its ancillary equipment from overheating.

The inverter station to which the graph corresponds is of the enclosed type and utilises air flow cooling, which may be adequate in some regions but has proven to be impaired when faced with Jordan's hot summer climate. The graph demonstrates that once the internal cabin temperature reaches 65 degrees Celsius, the inverter shuts down for up to 15 minutes until its internal equipment cools down. On some occasions, the inverter stations shuts itself down more than once a day as demonstrated by the excerpt from the plant's SCADA shown in Figure 4.

For this particular plant, the recorded losses of power due to inadequate temperature tolerances add up to 460kWh per day or 2% of the plant's daily power, a significant concern when it is a daily occurrence.

To overcome this issue, MASE site operators installed separate air conditioning units which feed off the inverter's auxiliary power supply and are only triggered during times of peak heat as recorded by the plant's weather stations. While this solution has eliminated losses due to inverter downtime for the time being, it is understandably temporary and not ideal. A permanent solution requires proper inverter design that takes into account the Middle East's harsh conditions and excessive high temperatures during summer periods. Some inverter manufacturers have taken steps to that end and now offer inverter stations with more powerful cooling systems and also outdoor solutions that are meant to eliminate excessive heat resulting from the containerised enclosure. The benefits of these bespoke solutions include better performance, lower O&M costs and higher plant availability. When properly designed to withstand the region's specific weather conditions, the inverter would otherwise operate as demonstrated by the trend illustrated in Figure 6.

In addition to the inverter stations, ancillary equipment such as array boxes and string combiner boxes also suffer from excessive heat and dust build-up as a result of poor design. Typically, array boxes and ancillary containers ventilate through standard mesh filtration as shown in Figure 7 on the following page. This has been found to be ineffective in harsh desert conditions. Oftentimes, significant amounts of pulsed sands have been recorded, causing the following:

- Array box overheating, thus damaging string monitoring sensors and burning fuses;
- Dust accumulation, requiring more frequent cleaning;
- Degrading of IP protection features.

To solve this significant problem, MASE has worked with array box suppliers on a more potent filtration system that is aimed at avoiding the accumulation of pulsed sand in and around the array boxes. The solution, which is shown in

Figure 7. Standard versus enhanced array box filtration

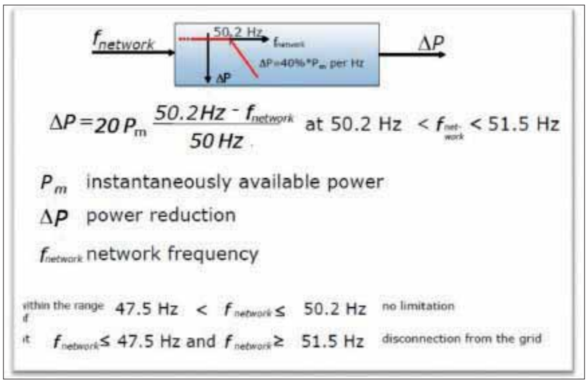


Figure 8. Active power control requirements – Jordanian Grid Code

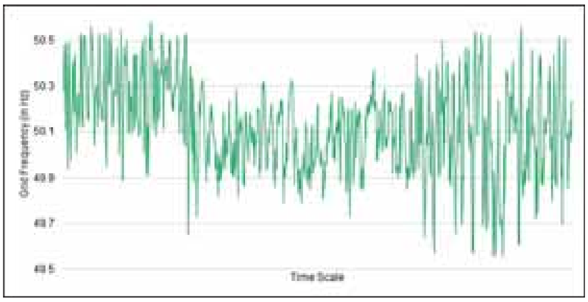


Figure 9. Recorded grid frequency

the images shown in Figure 7, is permanent and has proven to be effective in protecting the delicate contents of the array boxes.

In conclusion, the following recommendations form the outcome of these technical concerns:

- Inverter manufacturers and ancillary equipment suppliers must account for extreme weather conditions and topography of the Middle East when designing the equipment;
- Inverter and balance of system suppliers should work on enhancing filtration components to protect equipment from severe sandstorms and the accumulation of pulsed sand;
- Inverter behaviour must be improved to optimise performance and behaviour during periods of excessive heat.

Grid instability

Data recently analysed by MASE has shown that the Jordanian grid is considerably unstable, with frequency fluctuations recorded on a daily basis. This has been found to adversely impact the daily performance of solar PV plants as the Jordanian grid code currently applied to renewable energy generating units requires compliance with certain active power control covenants as shown in Figure 8.

As shown in this figure, renewable energy generating units (whether solar or wind) are required to gradually reduce their active power, while in operation, in cases of grid frequency exceeding 50.2Hz and disconnect from the grid in cases of grid frequency exceeding 51.5Hz.

Compliance with these grid requirements under Jordan's current grid conditions has resulted in power limitations of up to 15% on a daily basis, the reason being Jordan's unstable grid frequency as demonstrate by the trend in Figure 9. The grid frequency data shown in Figure 9 is recorded by a solar PV plant's SCADA over two days of normal operation.

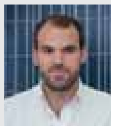
Site operators have little to no control over the grid frequency. On the other hand, grid management is the exclusive responsibility of the grid operator, the entity which also determines the grid code and operating requirements.

The recommendations arising out of the observations summarised in this section are:

- When assessing the technical feasibility of introducing renewable energy generating units into their network, grid operators need to understand the coherent operational characteristics of these generating units and their potential impact on the behaviour of the grid;
- Project developers and operators must actively evaluate the relevant grid codes and regulations as part of their overall technical due diligence and engage in a discussion with grid operators on the susceptibility of operational parameters and regulations;
- As part of their overarching approach towards renewable energy infiltration, regulators and grid owners must develop long-term plans to ensure the grid's technical sustainability by implementing supplementary projects such as energy storage aimed at stabilising and upgrading the grid. ■

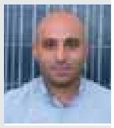
On p.72 Fraunhofer CSP researchers describe how to determine soiling losses on PV modules in desert regions

Authors

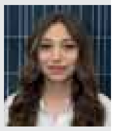


Tareq Khalifeh is director of operations at MASE, a utility-scale solar energy developer, operator and asset manager based in Jordan (www.mase-energy.com). He has over seven years' experience in originating, developing, operating and managing utility PV plants across the Middle East region. Tareq is an engineer, holds a master's degree in energy trade and finance and has a professional background in management consulting, utilities, project finance and solar asset management. In September 2016, the Middle East Solar Industries Association (MESIA) and Intersolar Middle East awarded Tareq the highest-category Solar Pioneer gold award in recognition of his achievements in advancing solar across the Middle East region.

Ady Almadanat has over three years' experience in the areas of solar plant operations, maintenance and management. He is currently responsible for operating solar PV assets of over 15MW in cumulative capacity and manages an array of tasks including preventive, corrective and conditional maintenance as well as analysis and reporting. Ady has a university degree in renewable energy engineering and is a principal member of MASE's O&M team.



Omar Baker is experienced in the design, engineering and construction of solar PV plants with a focus on distributed and utility solar. He operates and maintains a portfolio of over 400 distributed solar PV plants across Jordan and manages their periodical maintenance, troubleshooting, reporting and analysis tasks. Omar has a university degree in electrical engineering and is a principal member of MASE's O&M team.



Haya Shahatit is involved in the origination, implementation and operations of MASE's diverse portfolio of retail and utility solar PV plants under management. She holds a degree in electrical power and energy engineering and has extensive experience in project management, technical analysis and reporting. She is an active member of MASE's O&M team.

Determining soiling losses on PV modules in a desert climate

Soiling | Understanding the impact of soiling on PV modules and thus the most appropriate cleaning regime, is critical to preventing losses in module power and plant yield. David Daßler, Stephanie Malik and Akshayaa Pandiyan of Fraunhofer CSP describe a statistical method they have developed for accurately characterising the losses from soiling in desert conditions

Irradiation losses due to external causes, such as soiling or shading, remain the prominent source of a PV module's energy yield cutback. Consequently, effort and investment to mitigate them becomes essential, especially in cases of maintaining a large-scale PV plant. This can be simplified by identifying and analysing the key parameters related to external losses and developing a method to estimate them based on the former.

Dust, dirt, sea salt and pollen, originating from air pollution caused by mining activities, construction, agricultural activities and other natural phenomena, can lead to accumulation of particulate matter on the surface of solar panels. This is termed as *soiling*. Soiling leads to current reductions in the PV module which further affects the power and energy yield, especially in dry or arid areas. In general, these losses are referred to as *soiling losses*.

Existing soiling can only be removed by cleaning events, which can either occur naturally (heavy rainfall) or manually (maintenance cleaning). Previous studies on soiling have focused on desert or dry regions, which are susceptible to large aerosols in air, but also occur consistently with large solar resources. A recent study [1] by Mejia et al. reported an efficiency loss of 7.4% for a PV panel operated for an average of 145 days during a dry period in California; this is an order of magnitude higher than the losses due to cell degradation. Similar case studies have supported the significant impact of soiling losses on energy yield for different regions, but efficient methods of quantitative prediction of soiling is still a challenging task for researchers in PV modelling. The most important factor influencing the level of soiling losses are the dust properties (e.g. shape and size), moisture, humidity, frequency and intensity of precipitation, wind speed and the installation configuration of PV panels [2, 3]. A study by Haeberlin et al. [4], demonstrated the reversible effects of soiling losses before and after manual cleaning on a 60kW array. In addition, a recent work in Italy [5] reported a 6.9% reduction in performance for one site and 1.1% for another site not far from each other due to eight weeks of soiling. It can therefore be interpreted that large variability of soiling can occur even over short distances.

This article explains a method to determine soiling losses and to classify the soiling state of PV modules in desert climates, which can then be adapted for other climates based on PV plant system data.

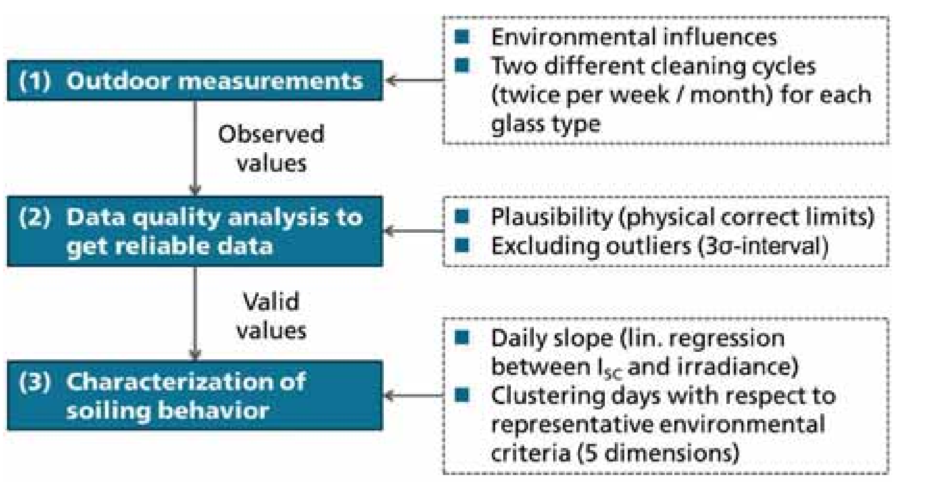


Figure 1. Flowchart of the investigations [8]

Methods

The impact of soiling on a running PV system depends on the local conditions, as described before. In order to determine the meaningful local soiling behaviour and to be able to make statements about the cleaning intensity, an understanding of the relationship between environmental factors and PV performance is necessary. The following approach extends from outdoor measurements (performance data) to extensive data analysis. Figure 1 structures the approach of this article.

In the first part, PV modules were characterized at standard test conditions (STC: 1000 W/m^2, 25°C, spectrum AM1.5) and tested under outdoor conditions with different cleaning cycles in a desert environment. This data contains detailed information about the state of natural soiling of the modules and relevant environmental influences over time.

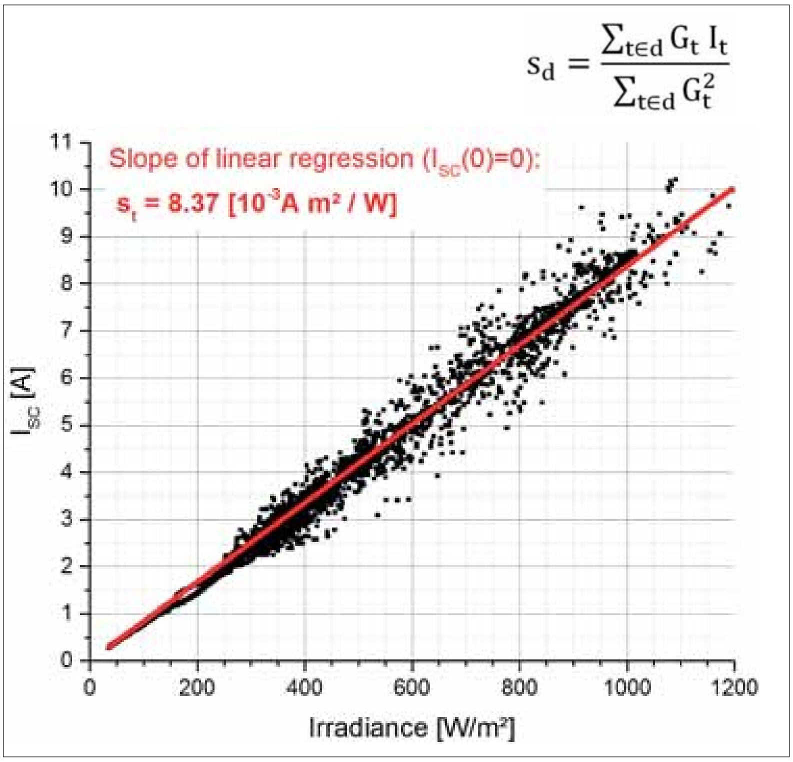
The collected data was then filtered in

the second step in order to achieve valid information for further data evaluation. Finally, the soiling losses were determined based on filtered data, taking into account the mean ratio between irradiance and module short circuit current. The current is only slightly dependent on the temperature and is directly influenced by transmission losses due to dust deposition on the module glass. In addition, the days were clustered due to different influencing environmental conditions such that the soiling losses can be characterised by cluster information. These steps are described in detail further in this article.

Outdoor measurements

Several months of outdoor data was measured (see Picture 1) to receive data about the module performance and environmental conditions. The measurements were made at the outdoor research platforms of photovoltaic modules at "Green Energy Park" (GEP) in Ben Guerir, Morocco (near Marrakech), implemented in a partnership with Fraunhofer CSP. GEP is a solar testing, research and training platform, in the green town of Ben Guerir,

Figure 2. Determination of daily mean ratio using slope of linear regression: E.g. relationship between I_{sc} and irradiance for one module on one day (09.06.2017) [8]



developed by IRESEN with the support of the Ministry of Energy, Mines, Water and Environment and the OCP Group [6] to develop and provide the access to research infrastructures and expertise at optimum costs. IRESEN (Research Institute for Solar Energy and New Energies) was established in 2011 in order to lead and promote

Picture 1. Outdoor measuring set-up and installed PV modules in Green Energy Park of IRESEN, Ben Guerir, Morocco [8]

R&D in Morocco in the field of renewable energy.

For this investigation, four PV modules were measured individually. The PV modules were built at Fraunhofer CSP Module Technology Centre, Germany. Apart from the front glass, the modules have the same layout and the same materials (solar cells, encapsulation, backsheet). Two different types of front glass (ARC and non-ARC) were used to study the soiling behaviour due to the glass type. The modules' performance at STC lies close to each other: ARC modules (Mod_1 and Mod_2) show 245Wp, 37V and 8.9A and non-ARC modules (Mod_3 and Mod_4) 244Wp, 37.1V and 8.8A.

The module measurements (IV-curves and module temperature) were measured synchronously in a time interval of 10 seconds and between the measurements, every module is operated at maximum power point (MPP). The weather data, however, was measured every 60 seconds and dust particle concentration were measured with an interval of 10 minutes. Different cleaning approaches were applied for each glass type: twice per week and twice per month. This results in a "clean" and a "soiled" group containing both glass types.

Data quality analysis

The measured module data was synchronised and filtered for further evaluation to avoid misinterpretations. The measured data have different intervals for various acquisition systems, therefore the weather data and the dust particle concentration were assumed as constant for the subsequent 60 s and 10 min interval, respectively. The data was processed for plausibility by imposing physical limits and statistical three-sigma limits [7]. This ensures that the quality of the analysing data used for characterising soiling losses is least affected by noise and outliers.

	Soiling rate [%/day]	
Module	Mean	Max (abs.)
Mod_1	-0.27	-0.57
Mod_2	-0.23	-0.36
Mod_3	-0.31	-1.16
Mod_4	-0.22	-0.34

Table 1. Maximum and average soiling rate [%/day] for each module.

Characterisation of soiling behaviour

Soiling losses

To determine module or system soiling losses, the linear relationship between short circuit current (I_{SC}) and irradiance (G) was used (see Figure 2).

After linear regression in a specific time period, a representative average relationship can be approximated. Due to the fact that the current is zero without any irradiation, it is assumed to use the linear regression model (I_{SC}) intercepting at the origin: $I_{SC} = s_d\ G$.

The resulting slope of the regression coefficient (s_d) characterises the quantitative conversion of irradiation energy into electrical current. In sense of this objective, the slope s_d determines the soiling state of the PV module.

The slope can be variably applied in terms of time period and PV module samples. In this case, the slope per day (sufficient data for a regression) and per module is determined to obtain a valid linear regression process. The slope s_d can be calculated as shown for any day (d):

Changes in the inclination of the regression slope from one day to another can be interpreted as changes in the soiling state

Parameter	Aggregation per day
Irradiance	Irradiance yield sum [kWh/m^2]
Dust particle (air)	PM total sum [10^3 µg/m^3]
Relative humidity	RH mean [%]
Ambient temperature	T_{amb} mean [°C]
Wind speed	WS mean [m/s]

Table 2. Characteristic parameters for clustering.

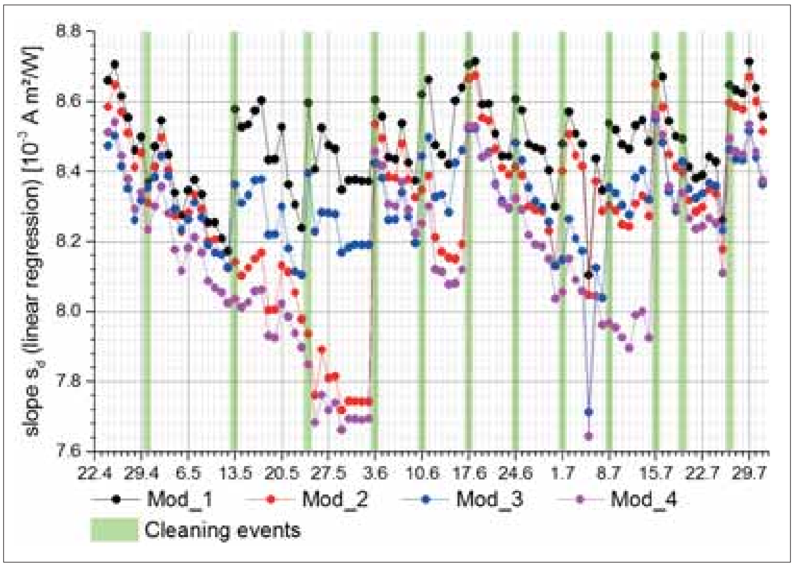
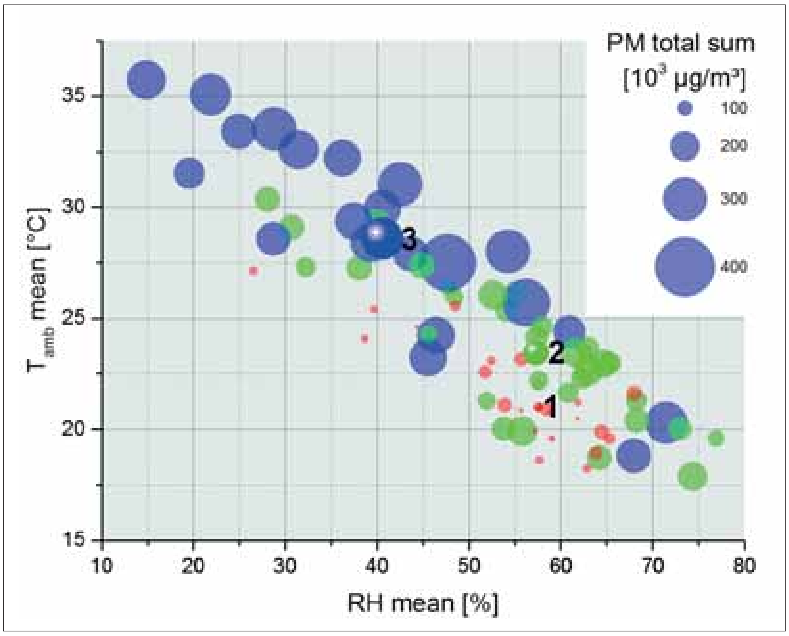
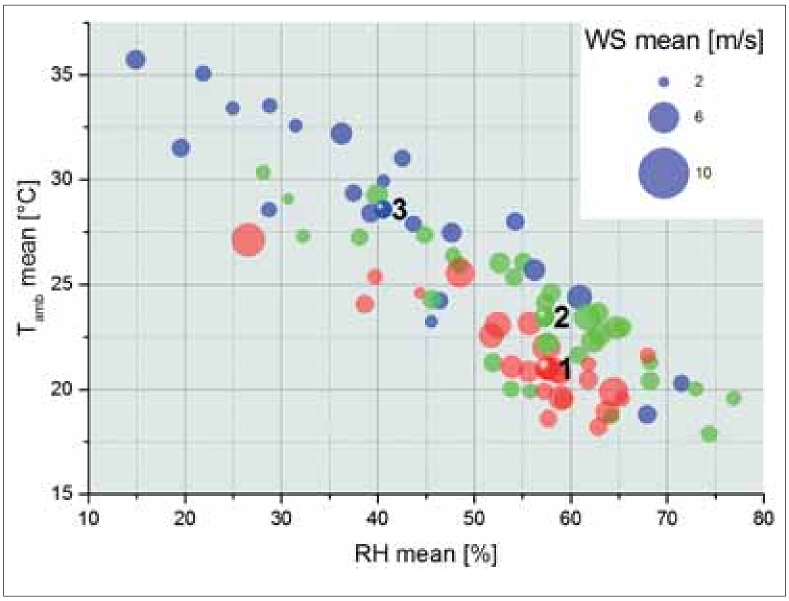


Figure 3. Variation of daily slopes between I_{sc} and irradiance for four modules with different cleaning cycles [8].



▲▼ Figure 4. Results of five-dimensional clustering of environmental data into three clusters based on daily values (cluster 1: red; cluster 2 green; cluster 3: blue) [8]



of the module (cleaning or soiling effect). This approach does not take in to account any degradation or malfunction of the PV module, the measuring equipment or the irradiance sensor (regular cleaning of the sensor was performed).

The daily slope differences (Δs_d) were calculated between one day and the day before. If Δs_d is positive, a cleaning event has occurred (natural or manual); otherwise, the soiling effect has increased.

$$\Delta s_d = s_d - s_{d-1}$$

Using this approach the resulting slopes per day for each module in the given period are displayed in Figure 3. This includes manual cleaning events for comparison. The soiling behaviour per module can be considered as the decreasing slopes, and the various cleaning events can be deciphered from the abruptly increasing slope.

An average soiling rate can be calculated by linear regression of the decreasing slopes (normalised to the cleaned state of the module) until the next cleaning event. Table 1 shows the averaged soiling rate for the four modules. Due to changes in cleaning cycles and samples, this average soiling rate was determined individually per module, according to their soiling behaviour between two cleaning events. Nevertheless, Mod_1 and Mod_3 were cleaned more frequently than Mod_2 and Mod_4. Taking the results into account, Mod_1 and Mod_3 show a higher soiling rate than the more heavily soiled samples (see Table 1). The soiling rate of the cleaned modules is close to each other and this also applies to the group of soiled modules. On the contrary, a strong effect between both glass types can't be seen.

Classification of environmental data

In order to classify the environmental parameters with their day profile and their possible interaction with each other, the k-mean clustering method was used, which is generally known for cluster analysis in data mining. k-mean clustering means that *N* observations for n parameters are divided into *k* clusters, with each observation belonging to the nearest-distance (absolute difference) to the cluster centre (centroid). These cluster centres were determined iteratively by reassigning the observations to the next nearest center in each step. After which the mean for each cluster defines a new cluster centre for the subsequent step.

The set of observations to be grouped is 75 days (*N* = 75). A suitable cluster solution for this N with three or four clusters can be selected to avoid a very small cluster division of less than 10 days per cluster. This work shows the estimation of three clusters (*k* = 3). The parameters used for clustering (*n* = 5), aggregated per day (including night values) as sum or average, are listed in Table 2.

The quality of the standard k-mean method also depends on the randomly chosen initial cluster centres before the first iteration. To ensure a reliable minimum sum of distances within each cluster, a large number of repetitions (~10,000) of the k-mean cluster were realised.

The results of the five-dimensional clustering applied to the daily aggregated environmental parameters (listed in Table 2), are shown in Figure 4. Both graphs are based on the same data and clustering process, in which the colours represent the clusters. The difference between them is due to the chosen environmental parameters and their dependency on each other in their respective clusters.

From Figure 4 it can be seen that for this particular site:

- Cluster 1 is concentrated at high *RH* and moderate temperature.
- Cluster 3 is widely spread referring to *RH* and T_{amb}.
- The amount of cumulated air dust increases with increasing T_{amb} and decreasing *RH*.
- The influence of wind speed shows no clear tendency.

The ranges between the different clusters in terms of minimum, maximum and average values are listed in Table 3. Referring to these values, because of the multi-dimensional relationship, the clusters overlap for several parameters. The clearest distinction between the clusters is shown in the accumulated dust (PM total), whose values do not overlap.

Based on these results, each further day (past/future) can be assigned to one of the three clusters, if these five parameters are known for this day.

Combination of soiling losses and clustered environmental data

In the final step, the classified days can be combined with the determined Δs_d, from one day to the other of each module. The manual cleaning events must be excluded in order to interpret the results based only on environmental impact. These results are shown in Figure 5 and in Figure 6.

In each cluster the soiling effects ($\Delta s_d<0$) have the main emphasis, but natural cleaning effects ($\Delta s_d>0$) also occur. A different soiling behaviour with respect to the cluster can be seen. Cluster 2 shows the highest level of soiling followed by cluster 3 and 1. Different soiling behaviour between the cleaned and soiled modules, as well in comparison to different types of glass can be seen in Figure 6. This figure shows the mean Δs_d per module, per cluster, with its corresponding uncertainty ($U(\Delta s_d)$, error bars), to interpret the significance of the results. The relative mean of $U(\Delta s_d)$ is approximately 5.4% with respect to all modules and clusters. The soiling behaviour of the more frequently cleaned Mod_1 and Mod_3 (ARC and non-ARC) in each cluster is worse than their corresponding soiled sample. This underlines the results of Table 1. When comparing the types of glass, the results are not as clear in the three clusters (Figure 6). In cluster 1, the non-ARC Mod_3 and Mod_4 show an advantage in contrary to cluster 2 and 3.

Which deviation in short circuit current corresponds to the determined Δs_d? Table 4 tries to answer that, by assuming different irradiance levels.

Final explanations

It is not trivial to decipher the effects of soiling based on the type of glass chosen, cleaning cycles and weather parameters. The proposed approach tries to relate them to each other. The results shown are examples of possible relationships and represent the measured site in Morocco. Other locations worldwide may have different results. The explanations before showed how the results can be handled.

The results show a different soiling behaviour between the cleaned and dirty modules and a comparison of both types of glass in the different clusters of environmental conditions per day. It is also important to note that the mean values of slope differences of each module are found by all clusters in the first quadrant 'Soiling effect', which implies the decreasing slopes for all modules. The manual cleaning events are excluded in order to interpret the results only because of environmental impacts;

Parameter	Cluster 1	Cluster 2	Cluster 3
Irradiance [kWh/m²]	5.5 – 8 (Ø 7.1)	1 – 7.8 (Ø 6.6)	4 – 7.4 (Ø 6.6)
PM total [10³ µg/m³]	10.7 – 100.7 (Ø 59.1)	108.6 – 198.7 (Ø 155.5)	206.8 – 381 (Ø 262.7)
RH [%]	26.5 – 68 (Ø 55.1)	28.1 – 76.9 (Ø 55.5)	14.9 – 71.4 (Ø 40.9)
T_{amb} [°C]	18.2 – 27.1 (Ø 21.6)	17.9 – 30.4 (Ø 23.7)	18.8 – 35.7 (Ø 28.6)
WS [m/s]	2.2 – 6.5 (Ø 4.1)	2.2 – 5.2 (Ø 3.5)	2.5 – 4.8 (Ø 3.4)

Table 3. Characterisation of clusters: minimum, maximum and mean values for each parameter and cluster

Irradiance [W/m²]	Deviation in short circuit current [mA]		
	Cluster 1	Cluster 2	Cluster 3
1000	-11.3	-43.7	-26.5
800	-9.0	-35.0	-21.2
500	-5.6	-21.9	-13.3
250	-2.8	-10.9	-6.6

Table 4. Deviation in I_{sc} determined per cluster by using mean value of slope differences (one day to the other) at different irradiances

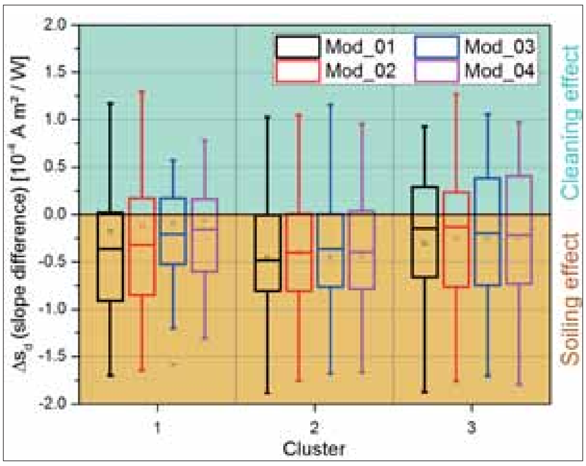


Figure 5. Slope difference Δs_d between two consecutive days; box plots (extreme values, quartile (25, 50, 75%) and mean) for each module and each cluster [8]

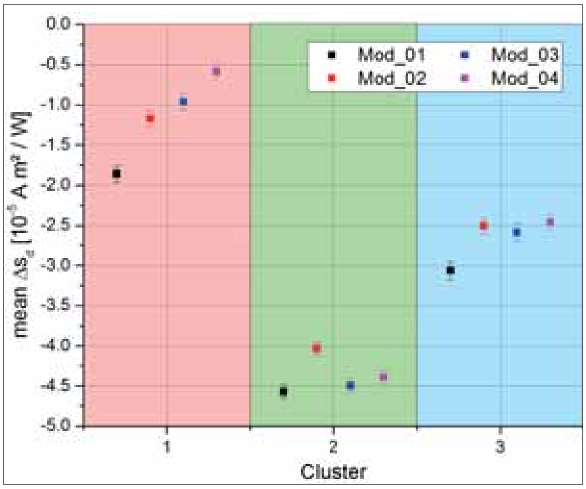


Figure 6. Mean of slope difference Δs_d between two consecutive days per module and cluster [8].

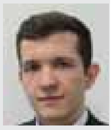
this could have resulted in higher slope differences. The soiling behaviour of the more frequently cleaned Mod_1 and Mod_3 is worse for both modules types in every cluster than their corresponding soiled sample, which underlines a hypothesis that a cleaned module surface is particularly more susceptible to soiling effects than an already soiled layer of particulate matter to attract more dust and dirt until a saturated soiled state is reached.

Another interesting point to highlight is the higher slope differences (day-to-day) of cluster 2 than those of cluster 3, despite the higher concentration of dust in cluster 3. Although cluster 2 has a lower dust concentration than cluster 3, the mean humidity in cluster 2 is higher (Table 3). On the other hand, it is assumed that increasing the density of the aerosol particles suspended in the atmosphere results in more sedimentation of dust particles on the module surface. This is an illustration of the complicated relationship between the various environmental parameters that influence soiling and the importance of the proposed method by clustering various environmental parameters and examining their soiling effects towards energy loss. Afterwards, the most important influencing parameters can be determined more precisely and then used to model the soiling effects on PV modules.

However, the end estimation of soiling losses is derived as a function of environmental parameters. Therefore, this work has the additional advantage that it can be used anywhere, if the environmental conditions are known. In a precision-based comparison, this method is very accurate in distinguishing between the module properties and the state of soiling of the modules.

Authors

David Daßler received his MSc in applied mathematics from Leipzig University of Applied Sciences. Since 2012, he has worked in Fraunhofer CSP's "Reliability of Solar Modules and Systems" group, specialising in yield analysis. In 2015 he began his PhD about yield modelling in desert climates.



Stephanie Malik has worked as an engineer in the "Reliability of Solar Modules and Systems" group at Fraunhofer CSP since 2012, focusing on outdoor measurements and yield analysis. Before joining Fraunhofer, she was active in the R&D department of Q-Cells, now Hanwha Q CELLS, for five years.

Akshayaa Pandiyan is currently working as a research assistant at Fraunhofer CSP, after obtaining her MSc in renewable energy engineering from the University of Freiburg. She shares an interest for research in renewable energy, computational programming and system modelling.

References

[1] F. A. Mejia, J. Kleissl, "Soiling losses for solar photovoltaic systems in California", Solar Energy Volume 95, September 2013, Pages 357-363.
[2] A. Sayyah et al. "Yield loss of photovoltaic panels caused by depositions", Solar Energy, September 2014.
[3] T. Sarver et al. "A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation apparoaches", Renewable and Sustainable Energy Reviews 22, 2013, pp. 698-733.
[4] H. Haeberlin, J.D. Graf, 1998, "Gradual reduction of PV generator yield due to pollution", Second World Conference on Photovoltaic Solar Energy Conversion.
[5] A.M. Pavan, A. Mellit, D. De Pieri, "The effect of soiling on energy production for large-scale photovoltaic plants", Solar Energy, 85 (2011), pp. 1128-1136.
[6] Malik, S., Ebert, M., Naimi Z., Ikken, B., "Development of outdoor research platforms and tests on photovoltaic modules in the green energy park in Morocco", Proc. of 1st Africa Photovoltaic Solar Energy Conference and Exhibition Africa PVSEC 2014, Durban; WIP Renewable Energies; pp.19-23.
[7] Malik, S. et al, "Outdoor data evaluation of half-/full-cell-modules with regard to measurement uncertainties and the application of statistical methods", 29th European Photovoltaic Solar Energy Conference and Exhibition, P. 3269-3273, 2014, Amsterdam.
[8] Daßler, D., Malik, S., Pandiyan, A., Benazzouz, A., Ikken, B., Ebert, M., "Advanced Method for Determining Soiling Losses on PV Modules in Desert Climate", 33rd European Photovoltaic Solar Energy Conference and Exhibition, Amsterdam 2017, DOI 10.4229/EUPVSEC20172017-5DV.3.31.

Cyber security: how prepared is the PV industry?

Cyber security | The digitalisation and distribution of the energy system is creating potentially more points of vulnerability for hackers to exploit. Catherine Early looks at how the PV industry is responding to ensure plants are kept safe from attack

Credit Flickr/blogtrepreneur.com/tech

A blackout forced by hackers from rogue states or criminal gangs may sound like a plot from a James Bond movie but the issue is high on the agenda of governments and electricity utilities worldwide.

Just last month – November 2017 – thousands of people working in industry or government in the US, Canada and Mexico took part in a large-scale exercise that simulated a cyber attack on electrical networks. Grid Ex IV was the fourth event of its kind run by the North American Electric Reliability Corporation (NERC) and is designed to test participants' preparation for such an event happening in reality.

Over in Europe, the EU Agency for Network and Information Security has co-ordinated similar exercises since 2010. The most recent simulation in 2016 imagined a blackout in a European country over the Christmas period, and used actors and social media to make the scenario more realistic. Over 300 organisations had to deal with a series of problems caused by malware, ransomware, drones and the Internet of Things.

The risk of cyber attacks on PV power plants and other smart grid infrastructure is attracting growing attention from industry and government

It is not just governments that are seeing the threat. In a survey of senior utility executives worldwide published by consultancy EY in November, 82% of respondents ranked business interruption from cyber attacks and storms in their top three threats.

Examples of cyber attacks specifically targeted against an electricity network so far are rare. According to the International Energy Agency, the first such incident was in the Ukraine in 2015. Attackers accessed substations' supervisory control and data acquisition (SCADA) system and firmware with a combination of malware, personnel credentials obtained through of email phishing, and Denial of Service (DoS) to prevent customers from obtaining call centre information about the blackout. Around a quarter of a million people lost power. A similar attack followed in 2016.

The threat specifically to solar PV equipment is small, but should not be ignored, according to experts. Duncan Page, a cyber security specialist at consultancy PwC, says that at the most basic level, someone could take a site offline, preventing it from generating electricity and therefore earning revenue. Taking it a step further, they could corrupt the system, blocking the utility from getting it back up and running, he says.

This becomes more serious if a utility has contracts with a grid operator to provide services such as balancing or frequency response, he adds. In future, solar farms are likely to also incorporate storage equipment and batteries with local control systems, making them more complex. This not only increases the risk of an attack occurring, but also its potential impact.

"As the grid becomes smarter and more interrelated and utilities enter into more relationships that earn money from their assets, the implications of being hacked will become greater and more complicated," Page says.

Cyril Draffin, a cybersecurity expert who advises the Massachusetts Institute of Technology energy initiative, says that hackers wanting to take down a whole grid are most likely to be acting on behalf of nation states, as major attacks take time and resources to execute. Experts estimate that hackers would have spent around six months developing the attack in the Ukraine, which the country blamed on Russian security services.

Cyber security has been a concern in the wider energy sector for some time, but the growing use of renewable energy, batteries and electric vehicles has heightened the risks. By connecting such assets to their networks, utilities are effectively exposing them to third-party access, explains Daniel Arnold, researcher and engineer at the US-based Lawrence Berkeley National Laboratory (LBNL). "These devices could be co-opted to introduce problems into the electricity grid," he says.

A vulnerability hackers could exploit is the inverters used in PV systems, Arnold says. "There are autonomous control functions on these devices that are meant to regulate their power output for system safety and reliability. They can be changed in a way that could cause problems for the grid in terms of voltage oscillations if enough devices were affected," he says.

However, Arnold also sees the connection of third-party devices to the grid as an opportunity as well as a risk. He is leading a major government-funded project at the LBNL which is developing ways to use these devices to fight off attacks (see box, next page).

> "There are autonomous control functions on inverters that are meant to regulate their power output for system safety and reliability. They can be changed in a way that could cause problems for the grid in terms of voltage oscillations if enough devices were affected"

Detlef Beister, business development manager at German inverter manufacturer SMA Solar Technology, says that distributed energy systems have advantages over traditional centralised power stations in terms of cyber security. "It's much harder for hackers to damage distributed supply as they would have to attack a large number of devices, which would take a lot of time and money to do," he says.

However, having multiple small sites can also be a challenge to protect, Page warns. When dealing with attacks, companies tend to fall down on the application of security, rather than lacking security tools and technologies, he says. For example, solar farms tend to be small and unmanned, so it is harder to keep up to date with security patches.

"Operators need to make sure that their security frameworks are just as good at protecting small sites as they are at controlling the central IT estate," he says. Once a vulnerability has been identified, it would be relatively easy to scale up an attack with a large number of small sites, he adds.

"There is no substitute for thinking about security at the design stage; then there should be enough tools and techniques available," he says. This is one advantage the solar power industry has over more traditional energy plants, since most equipment has been installed relatively recently, he says.

Industry and government action

Manufacturers also have a part to play. SMA has several strategies to deal with cyber security, according to its information security manager Marek Seeger. It has a team of people who work on ensuring that its products are certified to security standards and pass security tests. They are also tested by independent companies who employ hackers to test for vulnerabilities.

The company's products were recently criticised by Dutch cyber security engineer Willem Westerhof, who claimed that its inverters were vulnerable to attack. SMA acknowledges some problems exist with four older models of inverter, the Sunny Boy models TLST-21 and TL-21, and Sunny Tripower models TL-10 and TL-30.

However, the company stresses that even if operators use these inverters, a potential hacker would need to have extensive expertise to hack. It denies Westerhof's claims that there are a potential 17GW of solar inverter power at risk, saying that this figure represents its entire sales, not sales of the affected products, which is a fraction of this.

"We see absolutely no danger to grid stability even in the extremely unlikely event that all inverters should be successfully attacked at the same time," the company states.

The company publishes guidance for its customers to help them implement robust security measures. According to the guidance, when a PV system is being connected to the internet, the system operator or network administrator must have knowledge of all devices active in the network, including their communication requirements and features and possible vulnerabilities. They should also know all accounts that access the systems, how to limit access to the network and devices, and they should have installed all security tools such as a firewall and proxy server.

"Manufacturers and customers need to work together to stay up to date and secure on cyber security," Seeger says.

String inverter manufacturer SolarEdge says it is also taking the threat seriously. Lior Handelsman, vice president of marketing and product strategy at the company, explains that it embeds information security into all product development, runs stress tests on its security systems and encrypts and authenticates communication channels. If an attack did take place, it has backup protection and restoration plans to minimise potential damage, he says.

However, Handelsman believes that more needs to be done industry-wide. "The entire energy industry, including solar, needs to view cyber security as a necessity. As such, we have called for the creation of an industry-wide body that includes all stakeholders to share information in order to prevent attacks and help prevent PV's collective brand from being damaged," he says.

Such a body would mean that the whole sector was working together to identify risks, and could create unified standards and regulations on encryption, backup, reporting breaches, protocols, endpoint security, penetration testing, server security and hardening, hosting security and database security, he says.

Other industry players have also been thinking about standards and regulations on cyber security. In Europe, PV trade association Solar Power Europe has set up a task force on digitalisation covering all aspects of how smart grids, buildings and meters will affect the sector's operations. The task force is being led by SMA, and its 30 members include manufacturers ABB, Siemens and utilities Centrica and RWE.

The task force has called on policy makers to support the PV industry in its transition to full digitalisation, and has highlighted cyber security as one of the 10 aspects of regulation that it wants addressed.

A lack of internationally binding standards or requirements mean that it is up to manufacturers how seriously they take cyber security and whether their products adhere to any of these standards, the task force says. It therefore wants internationally binding, consistent and modern cyber security regulation.

In turn, the task force has produced seven commitments on digitalisation that its members have signed up to, including championing data protection and putting in place stringent cyber security measures.

Meanwhile, the EU is working on strengthening its cyber security strategies and policies. The bloc's first legislation on cyber security, the Network and Information Security (NIS) Directive, was adopted by the European Parliament in July 2016. It requires member states to adopt a national strategy for NIS security and to designate responsibility for the issue to a national authority. It also enhances cooperation on cyber security among member states through a dedicated group on the issue.

In September 2017, the European Commission stepped up its action by proposing an EU cyber security agency to help member states in dealing with attacks, as well as a new European certification scheme to ensure that digital products and services are safe to use.

In the US, multiple organisations have responsibilities for cyber security, ranging from the Federal Bureau of Investigation to individual state government. Cyber security in the energy sector is led by the Department of Energy (DoE). It has developed strategies to coordinate public and private initiatives for resilient energy systems, and in 2013, launched public-private partnership the Cybersecurity Risk Information Sharing Programme to provide the electricity sector with near-time cyber threat information and analysis. The US also works with Canada on standards to maintain critical infrastructure within the North American Electric Reliability Corporation (NERC).

Some countries obligate organisations that provide critical infrastructure to comply with standards such as ISO/IEC 27001, which sets out best practice for management of information security. Product standards include ISO/IEC 27032, PAS 555, UL 2900 and IEC 62443. There is also the US National Institute of Standards and Technology (NIST) Cybersecurity Framework, which comprises voluntary guidance to organisations on reducing cyber security risks.

"There is a well organised overall direction, but responsibility for cyber security and response to attacks resides with companies, individual government agencies and organisations, and some are much better prepared than others," Draffin says.

Large solar PV systems owned by electric utilities do have to meet NERC critical infrastructure protection standards, but there are no regulations that apply to small solar PV. Draffin believes that regulations should be mandated for all solar PV systems connected to the grid, and all should use best practice.

However, he warns: "Just as it is impossible to stop all crimes, it is impossible to have fully effective cyber defences, because adversaries are constantly improving their attacks and approaches, and new software with vulnerabilities are being introduced." ■

Catherine Early is a freelance journalist specialising in energy and the environment

Inverters the focus of efforts to beat hackers at their own game

"Utilities connecting third-party devices to their systems are simultaneously creating a vulnerability and an opportunity for better defence," says Daniel Arnold, a researcher in the Grid Integration Group at the Lawrence Berkeley National Laboratory in America.

Arnold is exploring ways to use this theory to develop defences against cyber attacks on inverter technology. In September, his project was one of 20 awarded up to US$2.5 million funding by the US Department of Energy, which is seeking innovative, scalable and cost-effective solutions to deal with cyber security issues. The three-year project will test ways of enabling electricity grids to resist cyber attacks by developing adaptive control algorithms for distributed energy resources, voltage regulation and protection systems.

Industry and government are developing standards for how solar inverters communicate with the grid so that the PV modules can adjust their power levels accordingly. "It is this standardisation that presents a vulnerability," says Arnold.

The project will develop algorithms to use the system in the same way the hackers might do, but will nullify the attack by sending the opposite signals. "If an attacker tries to manipulate the settings in a number of PV inverters, we'll observe these manipulations, then identify the settings in PV inverters that have not been hacked, and finally, dispatch the appropriate settings to the inverters deemed safe in order to counter that attack," explains Arnold.

LBNL's approach is to consider what would happen if all existing cyber defence tools such as encryption fail and a hostile entity gains control of a PV system. "We're putting ourselves in the perspective of the hacker to understand what defences we should deploy to fight off these attacks," he says.

The team has discovered several methods by which control systems could be manipulated to create a problem, and it has also discovered ways in which it could counteract these attacks. One challenge for the project will be how to fully test the algorithms, Arnold says.

"It's very difficult to trial on a real system as we'd have to fall victim to an attack, and defend against it, or we'd have to simulate an attack ourselves, which utilities aren't exactly keen to do. So although we're going to deploy this on real networks, we'll have to be creative in how we test it," he says.

Partners on the project include trade bodies the SunSpec Alliance and HDPV Alliance, manufacturers SolarEdge and Siemens, and Arizona State University.

The ultimate aim is to develop algorithms that can monitor the grid to provide advanced warning to a utility operator of a possible emerging attack.

Presented to you by: Energy Storage NEWS

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Energy Storage NEWS

Introduction

Welcome to this sophomore edition of Storage & Smart Power, brought to you by the team at Energy-Storage.News.

As we approach the end of 2017, without even looking through the statistics I can tell you that we've had our busiest year ever, and while much of the action has been concentrated in the key markets you might expect, there have been a fair few surprises too.

Over the past year or so we've seen institutional investment start to trickle into the sector, we've seen commercial and industrial markets really open up in the US and Canada, we've seen grid services markets launch in Europe. We've seen battery storage projects delivered in record time, we've seen third-party project financing kick off and we've seen behind-the-meter systems coordinated to create virtual power plants in numerous territories.

Yes, we still see the same lack of understanding in the mainstream press, when a story occasionally breaks through. The public is still hungry to learn more about what energy storage can do, especially in its relationship with renewables, but as we've seen in solar before, it takes some time, a lot of deployment and a fair bit of money to come in before potentially world-changing new technologies gain acceptance.

With this in mind, we hope that the three special feature articles we've brought you this quarter each touch on or confront some of the biggest talking points in energy storage today:

Navigant Research analyst Alex Eller, whom some of you will know from previous contributions on the importance of energy storage software and other topics, has written about the case for energy storage as an alternative to transmission and distribution (T&D) infrastructure spending. At utility or grid-planning level, 'non-wires alternatives' could have a big impact on network modernisation. Alex writes about exploring this use case.

There's not been a 'buzzier' buzzword this year in energy – or in fact, in IT and a few dozen other sectors – than "blockchain". The digital ledger system is transforming the use of data across the world, seen as a near-foolproof way to create and document thousands of transactions every minute. Dr. Carsten Reincke-Collon of Younicos writes about how it can be used – and what its limitations are. Also contributing to that piece is Sonnen's new chief of e-services, Jean-Baptiste Cornefert, who writes about the German company's first-hand experiences with the technology.

Finally, who better to reflect on the changing ways in which storage and other clean energy technologies are funded and deployed than solar finance guru Jigar Shah? We interviewed Shah, who says a recent US$200 million investment gives his company, Generate Capital, "complete freedom" to invest, from the "misunderstood" frontier of clean energy.

Whether you've picked this journal up at a trade show, you've been sent it in the post or you're reading online, we hope you enjoy our exclusive content and find it informative and useful.

See you next year!

Andy Colthorpe
Solar Media

Tesla makes good on '100 day' battery promise

Credit Tesla

Tesla has promised to deliver a 100MW li-ion battery in South Australia within 100 days

Tesla's work on a 129MWh energy storage system in South Australia appears on track to be completed in time.

South Australia's government turned to the idea of a giant lithium-ion battery storage system backed with diesel following major blackouts in September 2016.

Tesla CEO Elon Musk famously ended up promising to deliver a 100MW/129MWh project within 100 days of contracts being signed or deliver it for free.

Tesla switched from its usual battery cell supplier Panasonic to Samsung SDI, in order to expedite deliveries and construction. At the time of going to press, the system was about to enter a phase of regulatory testing ahead of it being put into use.

Australia's first unsubsidised grid-scale battery helped by CEFC debt-financing

Australia's Clean Energy Finance Corporation (CEFC) will help finance the country's first "unsubsidised large-scale grid-connected battery", co-located with a wind farm in South Australia.

Lincoln Gap wind farm is currently being developed in Port Augusta, South Australia and will host a 10MW/10MWh battery energy storage system, which is expected to assist the integration of renewable energy and perform some grid-balancing services.

CEFC will provide AU$150 million in debt financing for the first phase of construction – including a portion of the storage system's costs. Stage one of construction is worth about AU$300 million and comprises 126MW of the wind farm's generation capacity.

Chinese government's strategic push for energy storage to yield large flow battery projects

A project demonstrating the integration of energy storage onto grid networks in Hubei, China, will see the first phase of a 10MW/40MWh project built by Pu Neng, a vanadium flow battery manufacturer.

According to Pu Neng, the 40MWh project itself will soon be superseded in size in Hubei by a mammoth 100MW/500MWh energy storage system that is expected to "be the cornerstone of a new smart energy grid" in the province.

In September the China National Development and Reform Commission (NDRC) called for more investment in energy storage, including flow batteries. A 200MW/800MWh vanadium energy storage project is being built in Dalian, by Rongke Power and UniEnergy Technologies.

Centrica reveals early stage plans for a 100MW battery in Ireland

Utility Centrica has revealed plans to build a single 100MW battery energy storage system in Ireland to take advantage of capacity market and grid services opportunities currently under development.

The project is said to be at the early stages of development, with planning documents submitted in three locations – Kilkenny, Athlone in Westmeath and Cahir in Tipperary – by Bord Gáis, the previously state-owned power and gas company bought by Centrica in 2014.

Centrica's project manager Chris Read explained that one of the sites could see the huge battery built, with the potential for a reciprocating gas engine and gas turbine at the others.

'World's tallest' wind turbine gets 70MWh of pumped storage

The world's tallest wind turbine to date will be paired with 70MWh of pumped hydro energy storage onsite.

Four turbines of 3.4MW rated capacity each are being installed in Gaildorf, near Stuttgart in southern Germany, by Max Bögl Wind.

The wind farm includes one turbine with a height of 246.5 metres, to date the world's largest on-shore wind turbine. This impressive height was only achievable due to the incorporation of a pumped hydro storage into the wind farm, because its foundations stand inside a natural reservoir used to store water before it is dropped down a hill through more turbines into another pool, generating electricity in the process. The depth of this reservoir adds another 40 metres to the height of the turbine.

The 'world's tallest' wind turbine has been completed along with 70MWh of pumped hydro storage

Credit Max Bögl Wind

Dominican Republic energy storage stayed resilient during Hurricanes Irma and Maria

AES claims that 20MW of energy storage it deployed in the Dominican Republic just a few weeks before Hurricane Irma assisted the island nation in keeping power supplies running even as devastation struck.

In late August, local subsidiary AES Dominicana commissioned two 10MW energy storage facilities using lithium-ion batteries. Both are able to store energy for 30 minutes duration.

AES said the Andres and Los Mina DPP projects, "played a key role in maintaining grid stability" as Hurricanes Irma and Maria struck. The plants provide frequency control services. They also support the operation of the Republic's interconnected electricity system, SENI.

AES said no outages were experienced at either array, with both maintaining their full operational capacity throughout.

Mahindra wins India's first large-scale solar-plus-storage auction

Indian state-run coal mining and power firm NLC India auctioned a 20MW solar PV project to be combined with 28MWh of energy storage capacity in the Andaman and Nicobar Islands in October.

This is the first time such an auction for utility-scale storage has been completed in India with bids announced.

The NLC tender includes EPC and O&M services for 25 years and Indian firm Mahindra Susten won by quoting a price of INR2.99 billion (US$46 million). Other bidders included Adani, Sterling & Wilson, Ujaas, Exide, Hero and BHEL.

Distributed energy technologies challenge conventional thinking around grid planning

Grids | New storage and renewable energy technologies offer a potentially disruptive alternative to costly, unpopular investment in grid infrastructure improvements. Alex Eller looks at the opportunities for non-wire alternatives to maintaining transmission and distribution networks

Credit Scott Dreger/Southern California Edison

Innovations in new distributed energy technologies are challenging conventional thinking around the most effective ways to serve electricity customers and utilise grid infrastructure. These innovations in hardware, software and business models are helping to drive the overall transition to a more resilient and intelligent energy system that aims to deliver cleaner and more efficient electricity to an increasingly engaged customer base.

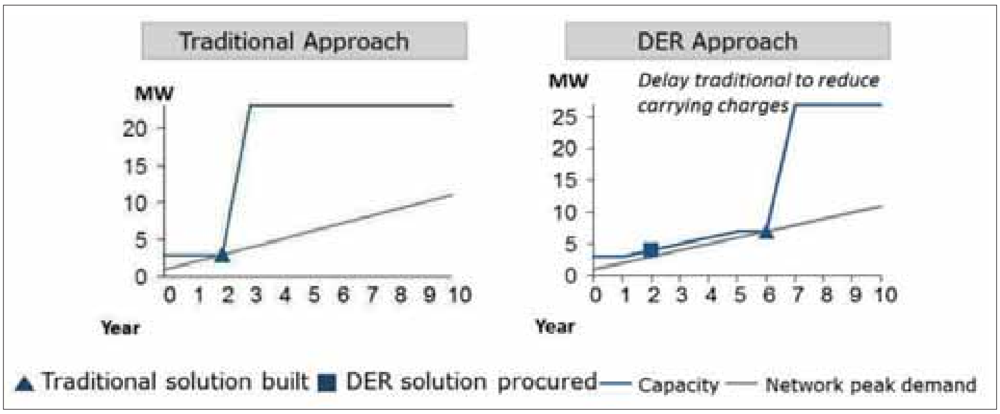
Maintaining and upgrading transmission and distribution (T&D) networks represents one of the most significant expenses for electric utilities and traditionally there were few alternatives to costly investments in expanded capacity. The new generation of less expensive and more intelligent distributed energy resources (DER) and energy storage technologies located on both the T&D grid and customers' properties has opened the door to a compelling array of new options for how to best utilise existing infrastructure. These technologies will disrupt the conventional T&D industry by maximising the value and efficiency of existing grid assets while empowering customers to participate in the management of the grid. This article will explore the overall drivers of T&D upgrades and the challenges facing these projects as well as new alternatives, with a focus on diverse non-wire alternative (NWA) projects, their benefits and challenges and the emerging trend of using purely energy storage to defer costly upgrades [1].

Energy storage is among the emerging technologies challenging conventional thinking on grid improvements

A need for upgrades

The electric T&D system is a constantly evolving machine that requires continual monitoring, maintenance and upgrades. Traditionally, the required upgrades to the T&D system were relatively easy to predict and could utilise a consistent and standard set of grid equipment and infrastructure to meet growing electricity demand. Rapidly evolving technologies and evolving customer demands have made predicting and performing grid upgrades much more complex in recent years. There are three primary issues driving the need for T&D upgrades:

- **Congestion and generation curtailment:** The growing amounts of variable renewable generation have exacerbated



Source: Consolidated Edison

Figure 1. The value of a non-wire alternative or energy storage/DER approach to defer T&D upgrade

congestion challenges in many areas, leading to the curtailment of energy. Actual rates of curtailment vary considerably in markets around the world. The highest average curtailment rates have been seen in China, where some provinces have wasted nearly 39% of wind generation due in part to limited transmission capacity [2].

- **Load and peak demand growth:** Typically, increasing demand for electricity and load growth has closely followed overall economic development. However, load growth rates have decreased or remained flat in many developed economies in recent years, while the dynamics of peak demand periods on the grid continue to evolve. Some utilities are experiencing decreasing overall load growth rates, yet increasing growth in their peak demand. New sources of load, notably EVs, are expected to reverse the trend toward decreasing electricity demand growth over the coming years. This new load growth will be variable and often concentrated in specific areas, providing an advantage for more flexible NWA-type solutions.
- **Reliability:** Improving reliability is a particular concern for commercial and industrial (C&I) customers, which often place a premium on reliability as they risk significant financial losses from an outage. Utilities are increasingly focused on improving reliability in the face of competition from third-party energy service providers targeting C&I customers. Furthermore, the overall resilience of the grid is becoming a greater focal point for governments and regulators in the face of both natural disasters and physical and cyber security threats. The diversification and expansion of the grid can reduce the potential effects of these events.

Building new T&D infrastructure has been the default solution to issues facing the electricity grid for decades. However, there are many challenges to upgrading grid infrastructure, particularly large-scale transmission projects. These challenges include concerns from local communities, the time required to develop and build projects, uncertainty around future load growth and demand patterns, and the rising costs to build new infrastructure in both urban and remote areas. Given these challenges, the falling costs of energy storage and DER technologies are presenting an increasingly economical alternative to conventional T&D projects.

Innovations in grid management and DER technologies have presented a new set of possibilities to maximise the use of existing grid infrastructure and defer or entirely avoid costly upgrades. At the same time, many utilities are seeking to engage customers and provide more value-added services in response to growing competition. Creative solutions to address infrastructure needs at a lower cost with greater customer and environmental benefits, known as NWAs, are being tested around the world. Navigant Research defines an NWA as:

"An electricity grid investment or project that uses non-traditional T&D solutions, such as distributed generation, energy storage, energy efficiency, demand response (DR), and grid software and controls, to defer or replace the need for specific equipment upgrades, such as T&D lines or transformers, by reducing load at a substation or circuit level."

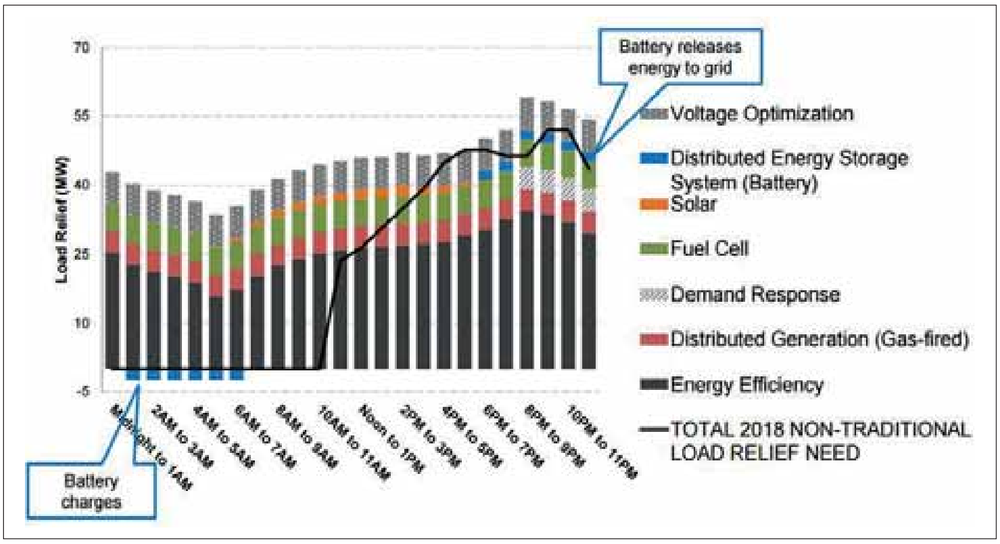
Overall, the major advantage is the greater flexibility provided by NWAs compared to traditional investments. A DER-based approach to meeting load growth can more closely match actual conditions on the grid without unnecessary investments. The graphic below illustrates how a DER approach can better match growing demand and defer a much larger investment.

Driving growth

Although there is a wide range of specific factors leading to the development of NWA projects, there are five primary drivers in the market which also represent some of the fundamental changes underpinning the shifts in this industry and the challenges to the traditional utility business model. These drivers include:

- **Regulatory policies:** Regulations and policies can provide incentives to utilities to implement more NWAs, such as allowing the sharing of economic benefits between customers and shareholders rather than all savings going to customers. Many of these policies are designed to reduce the environmental impact of electricity generation and usage by limiting the need for new power plants and T&D infrastructure.
- **Economics:** By far the most significant economic benefit of an NWA is the deferral benefit of the large capital investment. Traditional T&D upgrades have risen in cost and complexity in recent years, while DER technologies and grid management software and communications have seen dramatic price decreases.
- **Utility customer engagement:** Faced with competition from customer-owned DER technologies and third-party energy service providers, utilities are working to offer new solutions and improve customer engagement.
- **Load growth uncertainty:** Short-term investments in NWAs can defer much larger infrastructure investments, giving a utility time to assess whether the infrastructure investment is truly required and to investigate other potential options.

To date, most NWA projects developed have been in the US and the list of projects is expected to grow quickly. New York utility Consolidated Edison (Con Edison) was one of the early pioneers of NWA strategies. The utility began geographically targeting energy efficiency investments in 2003 when growing demand caused several distribution networks to approach peak capacity. These efforts evolved into the well-known Brooklyn Queens Demand Management Programme (BQDM) [3]. This programme intends to use many forms of DER to defer or avoid costly T&D infrastructure projects, specifically a new US$1 billion substation for the Brooklyn/Queens area, a region



Source: Consolidated Edison

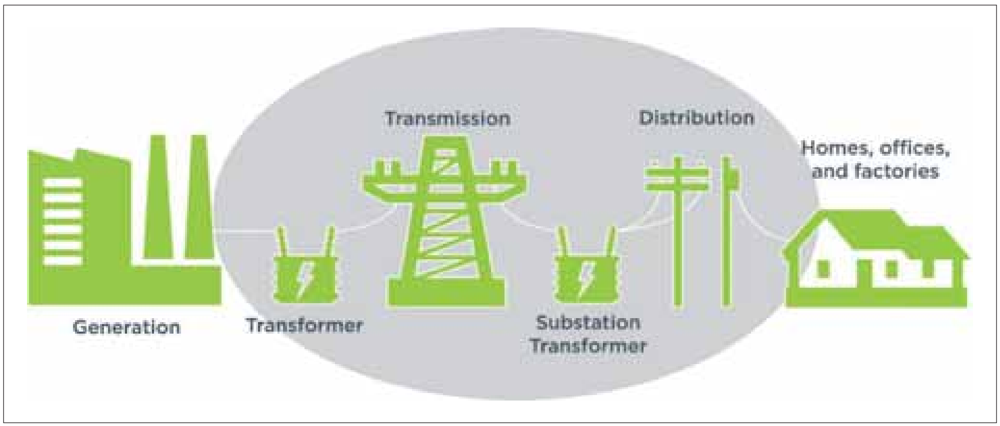
Figure 2. Anticipated BQDM 2018 Portfolio.

expected to see significant demand growth. The BQDM programme is expected to spend US$200 million on demand-side load management (DSM) programmes to shed 52MW of load – 41MW from the customer side and 11MW from non-traditional, utility-side measures. Figure 2 illustrates the anticipated resource portfolio of the programme in 2018, highlighting the diversity of DER being utilised.

On the West Coast of the US, two of the largest grid operators and electricity providers, Bonneville Power Administration (BPA) and Pacific Gas & Electric (PG&E), are also exploring NWAs [4]. While BPA has been evaluating NWA options for many years, its first commercial project was announced in May 2017, aiming to avoid replacing a large and expensive transmission line in Oregon and Washington. After almost 10 years of planning the upgrade with strong public opposition and increasing project costs, BPA decided instead to implement various NWA options, including energy efficiency, DR, rooftop solar and possibly energy storage to avoid the large transmission system investment. PG&E in California has also been experimenting with NWAs for many years, with a focus on targeted DSM efforts. Using DSM to defer investments in T&D capacity frees up constrained capital to fund other, more valuable projects for its system. Furthermore, PG&E believes that engagement with a DSM programme significantly increases customer satisfaction.

Risk aversion hinders widespread adoption

Despite the advantages and growing popularity of NWA programmes, significant barriers remain to more widespread adoption. As with many new electrical grid technologies, the level of confidence utilities have in the new programmes is crucial. Although early results have been promising, many utilities do not yet have enough faith in NWA programmes to overcome the traditional preference and expertise with T&D investments. This lack of faith is the result of both an institutional resistance to change within many organisations and the fact that prevailing rate recovery mechanisms for utilities typically do not encourage alternatives and innovation. If there is no regulatory pressure in place, there are few reasons why a utility would pursue an NWA. There is a higher perceived risk associated with these types of short measure life projects



Source: Navigant Research

Figure 3. Transmission and distribution breakdown

compared to a traditional equipment upgrade that is built to last 20 years or more. In addition, a T&D upgrade aligns with the historical experience of a utility. Thus, they may be more comfortable implementing a poles and wires upgrade.

Much of the hesitation to embrace NWAs stems from the challenges with engaging customers and being able to effectively guarantee a necessary amount of load reduction. Investments in energy efficiency, DR and solar PV have proven effective at reducing load in select areas; however, they do not guarantee the level of reliability and control that utilities demand. Although customers may typically respond to a DR signal to reduce demand, they often can override that signal and continue their normal operations. Due to this inherent unreliability, new technologies such as distributed generation and energy storage have emerged as more expensive but advantageous components of an NWA portfolio.

The increasing popularity of energy storage in NWA programmes and as a single-technology alternative to conventional T&D investments stems from the reliability and flexibility of storage systems on the grid [5]. Utilities prefer direct control over critical assets that are used to serve peak demand and ensure the capacity of grid infrastructure is not exceeded. As a result, energy storage is typically seen as a more reliable form of load reduction compared to NWAs composed of customer-side DER. Centralised, utility-scale energy storage systems (ESSs) in particular fit more with traditional utility investment models and technical expertise. ESSs provide added flexibility with the variety of services they can provide when not needed to support T&D infrastructure, including frequency regulation, voltage support, spinning reserves, outage mitigation and effectively integrating renewable generation. Another advantage of energy storage is that the technology can be sized appropriately to meet grid needs and can be sited in numerous locations to deliver maximum benefits—either in front of customers' meters on the T&D grid or behind-the-meter (BTM).

Transmission-level ESSs designed to relieve congestion have been relatively rare to date due to the large storage capacity required to alleviate these issues. Distribution-level ESSs have been the most common type of T&D deferral projects to date. These systems are frequently built at substations or specific points of congestion on the distribution grid to defer investments and improve reliability by isolating outages. Many distribution-level systems have been relatively small pilot projects initially, but utilise modular designs allowing for storage capacity to be expanded over time.

BTM energy storage to defer T&D investments is more complex and dynamic than transmission or distribution-level systems, although it has the potential to be far more disruptive to the industry. BTM energy storage for T&D deferral includes systems located in both C&I and residential buildings that utilise advanced software and virtual aggregation to provide targeted congestion relief for grid operators. The primary advantages of BTM storage providing T&D deferral are potentially lower costs to utilities and the ability to offer more visibility and control at the edges of the grid. BTM storage for these applications is currently a nascent market, with several key challenges including:

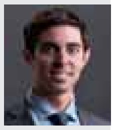
- Relatively high upfront costs for customer acquisition in some situations
- Small amount of storage capacity per system
- Concerns regarding the reliability of load reduction with customer or third-party owned systems.

Momentum evident, despite barriers

As with NWA programmes in general, there are several barriers standing in the way of energy storage being widely used to defer T&D investments. Despite recent advances, the technology and market remain quite new and immature, resulting in a conservative approach from often risk-averse utilities. Fully understanding and analysing the value of these energy storage projects is also challenging as the complex nature of the technology –including its ability to provide multiple services at different times – is not captured in many grid modelling and simulation systems. Furthermore, there is a major variation in the costs to upgrade T&D infrastructure. Energy storage and NWAs are typically only a cost-effective alternative when T&D projects face high costs due to challenging terrain, population density, real estate costs, weather constraints and other issues.

While barriers to widespread growth remain, both NWAs and storage-specific projects to defer T&D investments are gaining significant momentum with a variety of new projects being developed around the world. In addition to the NWA projects already discussed, energy storage projects for T&D deferral are growing in popularity and have recently been announced in Arizona, California, Massachusetts and Australia. These new projects are utilising several different business models to match the necessary technical and financial solutions with a customer's needs and available resources. The innovations happening in this market are helping drive the overall transition to a more intelligent, dynamic and distributed energy system the promises to improve efficiency, empower customers, and reduce environmental impact.

Author



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References

[1] https://www.navigantresearch.com/research/non-wires-alternatives
[2] https://www.chinadialogue.net/article/show/single/en/8965-Blowing-in-the-wind
[3] https://conedbqdmauction.com/
[4] https://www.utilitydive.com/news/non-wires-alternatives-whats-up-next-in-utility-business-model-evolution/446933/
[5] https://www.navigantresearch.com/research/energy-storage-for-transmission-and-distribution-deferral

Look beyond the hype: to really disrupt the energy world, we need a Yin to blockchain's Yang

Smart grid | Blockchain technology is being touted as the next big step forward in the digitalisation of the energy system. But storage and storage management software are the critical pieces of the puzzle needed to maximise its potential, writes Carsten Reincke-Collon

Credit deavmi/Wikimedia Commons

Not a day goes by without another article, conference, LinkedIn post or tweet, praising the revolutionary nature and countless blessings of introducing "blockchain" into the energy sector. And yes, the technology behind the Bitcoin cyber-currency has the potential to fundamentally alter the way energy is being procured and traded. But for all its potential, blockchain is, and always will be, limited to the purely commercial aspect of any energy transaction. To be truly transformative, the $-bits need to be matched by software that links it the other side of the proverbial energy coin: the physical world of electrons.

What blockchain does do is bring the market much closer to the electrons – and thus the economic and physical dimensions of the energy world closer together. Remember that essentially the energy world is split in two. First, it has a physical dimension, in which electricity is being generated and distributed through an infrastructure we call the power grid. For electricity to be transported safely, this grid must be kept in balance at all times, which essentially means that power production needs to equal load demand every instance.

Blockchain has been greatly talked up for its use in the future energy system

On the other hand, there is a market – or some other arrangement – by which those that consume power pay for its production and safe transport. Generally, payments are made to a utility. This utility in turn either produces power or procures it – and, depending on where you are in the world, either pays a grid operator or maintains grid stability itself.

Today, the commercial transaction is only very indirectly linked to what happens in the physical world. That's because electricity is essentially being traded via the great "ocean" that is the grid. Yes, producers feed an agreed amount into that ocean at any given time, typically in hourly intervals, and consumers pay for the amount of energy they use, but it's impossible to say where the kilowatt-hour (kWh) of power that just kept your lights on really came from. Most likely it just comes from the closest power plant.

Blockchain changes that – to a degree.

The ABCs of blockchain

What is blockchain? Well, it's basically a continuously growing list of records, or "blocks", which are linked and secured using cryptography. Each block typically contains a link to a previous block, a timestamp and transaction data. That makes blockchains inherently resistant to modification of the data.

A blockchain can serve as "an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way" according to the Wikipedia definition [1]. "For use as a distributed ledger, a blockchain is typically managed by a peer-to-peer network collectively adhering to a protocol for validating new blocks. Once recorded, the data in any given block cannot be altered retroactively without the alteration of all subsequent blocks, which requires collusion of the network majority."

Blockchain became famous as the technology behind the Bitcoin digital currency. But its decentralised nature, fault tolerance and security also make it suitable for many other applications, ranging from identity management to food traceability.

Energy trading is a great fit too. Blockchain allows for the creation of an automated trading platform that links producers and consumers in real time and lets them engage – via "smart contracts" – in a (quasi-) direct transaction.

The electrons thus sold still don't go straight to the buyer, but both parties know that at the (exact) time in question, one party is producing just the amount of energy that the other party needs. Provided both parties are also physically close (which is a big if), this transaction has relatively little impact on the grid.

As almost all contributions on the subject point out, blockchain has the potential to make a utility redundant by enabling consumers and (independent) producers or prosumers to trade directly without any intermediary.

While it's hard to argue with that, sceptics try to temper the hype around blockchain by pointing to (i) the volume of data storage required, (ii) the correspondingly huge requirement for energy that would be needed, as well as (iii) the absence of any industrial standards. There's also the ubiquitous complaint that "the current legal and regulatory framework in no way matches the requirements of a decentralised energy grid".

And, indeed, at present the energy aspect of blockchain is, unfortunately, a reality. To be disruptive, blockchain will have to become a lot leaner: right now a single transaction "costs" the equivalent of a full charge of an electric vehicle. Obviously, "paying" in energy the equivalent of a full Tesla charge is not sustainable. But the good news is that there are many promising avenues to significantly reduce the energy cost of using blockchain in grid transactions. It's much easier to limit and validate participants, for instance. Given sufficient interest, it seems certain that blockchain will scale – just as emails did – even though there were many that warned sending an email would prove to be much costlier than sending a fax [2].

Blockchain's stumbling block

There is a much bigger obstacle out there, however, that gets far less attention. Someone – or something – needs to make sure that the energy being transacted actually moves from A to B – and that it doesn't tear down the "roads" it travels on, i.e., the grid, in the process. So, yes, blockchain might make the utility superfluous – but only insofar as the utility acts as a commercial intermediary between consumers and producers. While blockchain brings the physical and the economic dimensions of electricity much closer together, it doesn't – and will never – "fuse" them in any shape or form, even if some would have us believe that.

To truly link kilowatt-hours to dollars (or euros or renminbi) in the same virtual dimension, another piece of equally ingenious code is required: energy management software in general – and energy *storage* management software in particular.

Why? Think about it: in a way, the ability to store something has always been a pre-requisite for trading it. If you have to pass the "hot potato" immediately, you're not in a very good position to make demands about price. In fact, that's the reason the shortest interval in energy markets today tends to be 15 minutes – because that is exactly the time it takes a (warm) gas turbine to power up to cover added demand. In deregulated energy markets, anything less than 15 minutes is usually organised in balancing markets or through "re-dispatch", where those resources that – either via power up or down – provide short-term grid stability get compensated by some type of grid operator or regulator. In monopolies, the incumbent utility balances supply and demand directly, but of course that's not really a market at all.

> "The real value of storage and distributed energy resources management systems software is that they enable applications like blockchain-based trading"

Gas turbines used to be the fastest units in the energy system. But just as email has replaced fax machines, we now have much faster units for moving energy. The power electronics embedded in solar PV and wind turbines allow for partial – that is, "downward" or limiting, but nonetheless real-time – control of these decentralised clean energy generation assets. Add battery energy storage to that mix and it becomes possible to balance short- and medium-term fluctuations within milliseconds, and do so fully automatically.

This ability to effectively stop and control electrons or, in more common terminology, store them, enables us to trade energy in real time. Unless you can "hold back" power in some way, you're required to sell it (or lose it) at the moment it's produced. Conversely, if you don't need to sell at the exact moment you produce, you have a lot more control over the market. This flexibility allows you to exactly match a given customer's demand profile, for example, and likely extract a higher price for such precise targeting and delivery.

Of course, having this level of control in turn requires software that manages both the storing and provision of power within milliseconds. But that is only the beginning. The real value of storage and distributed energy resources management systems software (DERMS) is that they enable applications like blockchain-based trading in the first place. DERMS provides blockchain applications with an interface into the physical world, which they need to translate the cyber revolution into the real world. DERMS is the Yin to the Yang of blockchain – or indeed any other automated energy trading protocol.

Both technologies, or rather types of software, have high value in and of themselves. But only when you take them together can they become truly disruptive – and dramatically increase the efficiency of how energy is being supplied. Put these pieces of the puzzle together and it becomes possible to trade energy peer-to-peer and keep the grid stable at the same time. That combination, indeed, has the potential to set off a "chain" reaction that will transform the utility industry.

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References

[1] See https://en.wikipedia.org/wiki/Blockchain

[2] see http://www-formal.stanford.edu/jmc/harmful.html

Blockchain in action: stabilising the grid in Germany and the Netherlands

Case study | Blockchain technology is being put to the test in northern Europe, writes Jean-Baptiste Cornefert

A quick view into the future: it is the year 2030 and Paul, a homeowner with his own photovoltaic system and battery storage, checks his electricity bill. His neighbour Sam got 12kWh of solar power from Paul's house roof today. Amanda, the elderly lady a few blocks away, has consumed 5kWh of solar power from Paul. Both charges Paul sees on his online portal. The transactions are registered with a blockchain and the compensation is immediately credited to Paul's bank account.

Those energy transactions happen thousands of times every second, and are continuously and consistently registered on a myriad of single computers around the world with a blockchain. A blockchain is a database that is organised decentrally. A main server that stores all operations is no longer needed. All distributed computers store the information that Sam got 12kWh of solar power from Paul. After a certain time, all accumulated information is then combined into a block and provided with a kind of checksum. This checksum is then included in the data of the next block. This makes the blockchain very secure against subsequent manipulation. If an individual transaction is subsequently modified on a computer, this is immediately noticeable because a whole chain of checksums is no longer correct.

For the energy supply of the future, the blockchain is the key technology. It digitally links up millions of decentralised generators of clean energy and documents their output, even at the smallest level between Paul's PV system and his neighbour Sam.

Finally, Paul produces and consumes his electricity himself and sells the surplus energy that he does not need himself. Miles of transmission networks that transport electricity over long distances are needed in a much lower scale.

Electricity is more and more being produced in decentralised and climate-friendly ways. Instead of individual large power plants, energy is generated where it is being consumed: for example on private houses with photovoltaic systems. Of course, there are also wind turbines, on land and at sea, hydroelectric power plants and biogas plants. All contribute to the sustainable electricity mix that supplies society, industry and consumers.

This decentralised generation has a positive effect on our energy system in many ways. Electricity is produced and consumed directly or stored in batteries for later use. As a result, the necessary basic supply in the power grid is drastically reduced, which in turn means only a few central power plants are needed.

Nevertheless, the switch to renewable energy also has its own challenges. A nuclear or coal-fired power plant can theoretically deliver constant power around the clock. Wind and solar power, on the other hand, are influenced by external circumstances. If there is a lot of sun, the share of solar power is correspondingly high. At night, this will disappear completely. Wind energy depends on the weather. This wind is sometimes constant, sometimes it fades and in a storm, a lot of electricity is produced.

Such fluctuations are referred to in the jargon as volatility. The energy transition, and thus the change to a decentralised supply, is still a few years away. But the more renewable energy is integrated into the electricity mix today, the greater the need for solutions, so-called grid services, for this new form of electricity production.

A pilot project for offering grid services in whole new way has just started in Germany. In a cooperation between IBM, German transmission system operator, TenneT, and battery supplier, sonnen, decentralised home storage systems are being integrated into the power grid with a blockchain for the first time.

What does a grid service via blockchain look like? Imagine a windy day over

Credit TenneT

German TSO, TenneT, is one of the partners in the blockchain trial

the North Sea that makes the wind turbines in the area rotate heavily and produce large amounts of electricity. Now there are two problems: the power consumption in northern Germany is not high enough to take all that electricity. Secondly, the power lines to southern Germany or other parts of Europe are not strong enough to transport that huge excess of energy. To bridge that bottleneck the grid operators have to act with the so-called 'redispatch'. Usually they turn off the wind turbines in the north and activate gas or coal fired plants in the south for keeping the balance.

The pilot project with TenneT and sonnen has found a new approach. If too much wind energy is produced in the north it is stored in the virtual connected battery storage systems in that region. At the same time, decentralised storage systems in the south discharge energy into the grid for compensating the lack of energy from the north. So the bottleneck is bypassed via a virtual power line that is by the way the first green solution for the redispatch.

The amount of energy each individual decentralised battery has charged or discharged is registered and stored by a blockchain. The process starts automatically within seconds, no phone calls between grid operator and power plants have to be made. The collected information is encrypted and stored on thousands of computers. Every participating party, such as storage providers or grid operators, has full access to all data, making it very transparent.

sonnen is providing its virtual battery pool that can deliver exact forecasts how much energy will be available in a certain region and within a certain time.

For the grid and society, this form of redispatch has significant advantages. On the one hand, the decentralised storage units are already available to homeowners and serve as a battery for their own energy supply. In addition, all people benefit. Less wind energy has to be wasted and the costs for grid operations like the redispatch can be reduced significantly.

In addition to their own, clean and free electricity production, the individual owners of the storage are looking forward to additional revenue they can obtain by participating in those scenarios. ■

Author

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Life at the frontier of g

Storage finance | Clean energy entrepreneur Jigar Shah, one of the pioneers of solar finance, is turning his attentions to other low-carbon energy technologies such as storage. He tells Andy Colthorpe about his latest equity round and the freedom he enjoys to back projects he thinks will have greatest impact

At Energy-Storage.News, we have seen the industry rise and rise, driven on by specific geographies and higher-value applications. Analysts tracking energy storage, such as Mercom Capital, which issues quarterly reports on mergers and acquisitions and venture capital funding, have found significant sums of capital being put forward for new technologies and latterly for project financing, with increasing frequency.

As solar PV went through the learning curve of its boom years, capital first came mostly from private investors and risk-hungry venture capitalists. Only as the market matured did longer-term, institutional investors start to get involved. While the likes of superstar clean-tech VC investor Nancy Pfund have told us that the energy storage space is getting ripe for big money, with institutional investors eyeing opportunities closely, hands have not yet gone into pockets on a grand scale.

In late October, Generate Capital, led by an executive team that includes SunEdison founder Jigar Shah, raised about US$200 million in equity investment, with input from the Alaska Permanent Fund Corp (APFC).

Both the sum of money and the fact that a large chunk of it was sourced from an institutional investment group – APFC is a sovereign fund for the state of Alaska – are notable. Generate prides itself on finding opportunities across the whole spectrum of clean energy. While best known for his pioneering work in solar finance, Shah and the Generate board appear just as excited these days about the potential for other technologies too, from batteries to anaerobic digestion, fuel cells for forklifts, to low carbon solutions for purifying drinking water.

Speaking to Shah over the phone, it's obvious that he relishes what he calls the "complete freedom" to invest where Generate thinks it can make the most impact, be it "water, agriculture, waste, battery storage" or other options.

It's a question of being trusted to take calculated risks, Shah says, of negotiating a frontier that is littered not just with potentially 'good' deals and 'bad' deals but more commonly also includes "misunderstood" technologies or business ideas. He explains that, for example, through the recent history of the energy storage industry, the thought of funding the technology had "traditional finance providers very scared, initially".

Generate, on the other hand, was experienced with renewables and clean tech and convinced of their potential. This has led to the company "providing a lot of capital" to a series of solar-plus-storage and behind-the-meter energy storage projects already.

For Generate Capital, there will always be a "frontier of deals that are misunderstood", Shah says.

"That problem will never get solved. There will always be someone that has to go first, or second, or third, in helping a technology that has proven itself on a technology basis but has not proven itself on an institutional infrastructure basis."

Gradually we have seen banks and other financiers starting to become comfortable with solar PV, especially in North America. Yet according to Shah that reluctance still exists when it comes to more advanced technologies and Generate Capital sees itself as a conduit for cashflow into less traditional areas of clean infrastructure investment.

"Generate is really about serving the market, before sort of the commodity capital sources start streaming in," he explains. "Once you feel you can get 5% money from Deutsche Bank, Generate is no longer as competitive. Right now, there are a lot of applications of storage that continue to be misunderstood by the broader finance community."

> "There will always be someone that has to go first, or second, or third, in helping a technology that has proven itself on a technology basis but has not proven itself on an institutional infrastructure basis"

Examples where the funder stepped in where banks feared to tread have included solar-plus-storage projects, behind-the-meter applications, or even energy storage projects in Ontario planned to mitigate the effects of the Canadian region's Global Adjustment Charge, payable by electricity ratepayers to finance conservation and demand management programmes.

Institutionalised?

As for the advent of institutional investment in energy storage, there have only been one or two blips on the radar until now. Swiss group SUSI Partners created SUSI Energy Storage Fund, reaching its first closing in April this year at just over US$70 million, with backers including pension funds and insurance companies. While it's obvious that just as with banks, institutional investors will start to get comfortable with energy storage, Generate's opportunity to work with the Alaska Permanent Fund's capital is one of only a handful of other examples.

There has been little pressure on pension funds and others to see energy storage, or even solar-plus-storage, as a viable divestment option from fossil fuels. While it might seem also that institutional investors would err on the side of conservatism in deploying their capital, this isn't necessarily the reason why many haven't bought into the storage revolution yet.

reen investment

"[Institutional investors] invest in hedge funds, private equity funds. They invest in a lot of things that you might privately think are risky. The hook at this point is that for many of these companies, or investors, they're really focused on oil and gas investing. And you know, oil and gas investing has been quite volatile as of late," Shah says.

'Energy as infrastructure'

The point is that oil and gas, while risky, can make 25% returns; wind and solar typically create closer to 6% to 10% returns, on the proverbial good day. Investing in renewables, Shah says, is closer to infrastructure investing – "if they buy an airport, they might get a 6% to 10% return" – than it is to the traditional fossil fuel market gamble. The money institutional investors would put into wind, solar or latterly energy storage projects therefore would probably not therefore represent a divestment and would come from separate funds to those oil and gas holdings, Shah argues. As he showed through years of reinventing solar finance, however, it's still all about scaling up.

"The big thing for these institutions is that they can't dive in to deals unless it's a large cheque. So if someone comes to them with a US$25 million opportunity in battery storage, they just can't do a US$25m deal. They really need to put their money out the door in larger quantities. So if they're going to do deals directly, they'll do solar and wind where they might be able to do a US$100 million deal, so they're not going to smaller deals directly. So I don't think it's about risk as much as it is about comfort, and size."

Shah remains passionate about solar. He says Generate is one of very few financiers investing in community solar, a state of affairs that he says he finds "weird".

"Every community solar deal today has been forced to find institutional off-takers. Why don't you get Walmart, or this local school district to actually buy the power? Well, because those guys are not the ones the community solar statute was written for. Something as simple as that was basically blacklisted by the entire finance industry, and it wasn't until we started coming in and funding it that people started opening their eyes."

While there is some risk associated with low-income customers and residential renters who may not live in one place for the long haul, this calculable risk can be built into the business proposition. Of course, in energy storage, the long-term value of a deal can be harder to figure out.

"It's about figuring out what we can charge for," Shah explains. "It's saying, 'What benefits will the industrial customer, or commercial customer pay for?' Will they pay for it as a fixed payment because they believe it's real and will occur every month? Or are they paying for it on a performance basis, where they say, prove to me at the end of the month that you'll save me demand charges and then I'll pay you 80% of what you show me.

"Those are two different risk profiles. In one case they've agreed that it works and they're just paying us a fixed payment every month. In another application, like if the software fails to operate correctly, then we don't get paid."

Separate to that risk, Shah says, is regulatory risk. Many markets do not yet value the services batteries can provide, meaning that even where the demand exists, the regulatory space is yet to catch up.

Modelling the risk

Evaluating and finding ways around these risks is tricky. UK transmission network operator National Grid recently said developers should not bank on revenues from providing frequency regulation services and should find ways to 'stack' multiple revenues for providing different services, behind and in front of the meter.

"If someone calls us up now and says they've included X number of dollars for grid services, we're going to say 'wait a second, we don't think you're going to get them until 2019 or 2020, and when you do get them it's going to be this amount, not that amount'. We're not miracle workers. We can't just assume that these revenues are going to magically appear.

"You have to be able to model it. You certainly can get frequency regulation revenues for two years and those are pretty lucrative and could give you almost half your money back, which is great, or more. But then the question is what do you do next? What markets do you participate in next? And you just have to keep revenue stacking and modelling it.

"The other alternative with battery storage is that you could also potentially afford to just pick it up and move it! You could say for two years I'll get this revenue and then move it to another place. So I certainly believe there is a rational way to finance projects with short-term revenues – but then the returns have to be similar to independent power producer returns, which are more in the 20% range."

2018: The year utilities break through?

Asked what next year might hold, Shah's answer is perhaps surprisingly downbeat, although laced with his usual fighting spirit. Utilities are quickly becoming wise to the value of energy storage, Shah says. It took many North American utilities several years of the solar market boom to realise they could not ignore it and hope it would go away. Nowadays utilities are presenting a multitude of approaches to encouraging, accommodating or in some cases even pushing aside PV. Some utilities are now keen to own solar assets. Jigar Shah is expecting to see a similar dynamic in energy storage next year.

"Energy storage has broken through such that utilities [in the US] admit that their value is very high, at least to a 3.5% penetration. The fight now is really about who owns the storage – I am inclined to believe that the utility companies will win that battle," Shah says.

"They will make sure that private owners of batteries don't get paid a fair return – similar to what has happened to the demand response markets."

While Shah thinks utilities will not be able to achieve a takeover of the market in 2018, they will "all decide that is the strategy", he says. Yet he is not defeatist. I ask if that means it will be harder for the likes of Generate to keep making plays for the projects and technologies it wants to.

"It means that we have to innovate on our side to be able to continue to put our money to work," he says. ■

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