POWER PVTECH

Volume 18 PV POWER PLANT TECHNOLOGY AND BUSINESS February 2019

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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, wholly owned by the LONGi Group (SH601012), has focused on p-mono for 18 years and is today the largest supplier of mono-crystalline wafers in the world, with total assets above $5.2 billion (2017). It has plans to reach 45 GW mono-crystalline wafer production capacity by 2020.

Enabled and powered by advanced technology and long-standing experience in mono-crystalline silicon, LONGi Solar shipped approximately 4.6GW of products in 2017, which is a 100% growth rate in three consecutive years. The Company has its headquarters in Xi' an, China and branches in Japan, Europe, North America, India, Malaysia, Australia and Africa.

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

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Introduction

Welcome to the eighteenth edition of PV Tech Power and our first of 2019.

The turn of year always sees competing estimates of the previous 12 months' solar installs and best guesses on installed capacity for the year ahead emerging from all the usual places. Regardless of where those figures end up come 31 December 2019, it is safe to say that the volume of both bifacial and floating solar projects will increase.

A team from the Zurich University of Applied Science and ISC Konstanz offer a comprehensive overview of bifacial system design, mounting and inverters through to those all-important LCOE calculations (p.16).

Sticking with system design, Samuel Truthseeker from TECSI Solar offers up a best-practice guide on wire management. From selection to installation and proper maintenance, errors here can have expensive consequences from short circuits to fires. Getting your wires crossed has never been so costly. Both greenfield builders and O&M firms can benefit from taking the time to understand the risks they may be exposed to (p.59).

In many markets, shifting PV project development from land to water makes a lot of sense. Momentum is building as investors get more comfortable with the concept and the base of proven projects expands. As a result, it is a string many EPCs and developers will need to add to their bow. DNV GL looks at some of the unique technical challenges of designing and building floating solar installations, including bathymetric surveys and the loads generated by wind and/or waves (p.54).

Navigating the financial, political and regulatory challenges is of course just as key to solar's fortunes in 2019. With both China and the US set for lightweight years by comparison to the very recent past, competition elsewhere is set to increase. PV Tech's Tom Kenning looks at two very different areas of focus this year. Having outlived its feed-in tariff boom Japan is struggling to redefine itself as a stable PV market. Recent auctions have delivered fewer MWs than expected and regulatory challenges remain (p.33).

Meanwhile, in Africa's Sahel region a unique secondary benefit of solar is emerging. Tom Kenning explores how solar is helping bolster attempts to combat desertification with firewood the unlikely protagonist (p.28).

We also have papers on O&M business models (p.71), the European solar finance market that is supercharging the post-subsidy pipeline (p.45), an in-depth look at Turkey from the law firm Norton Rose Fulbright (p.39) and much more. Our regular Storage and Smart Power section returns on page 85 with Andy Colthorpe at the helm as always.

John Parnell
Head of content

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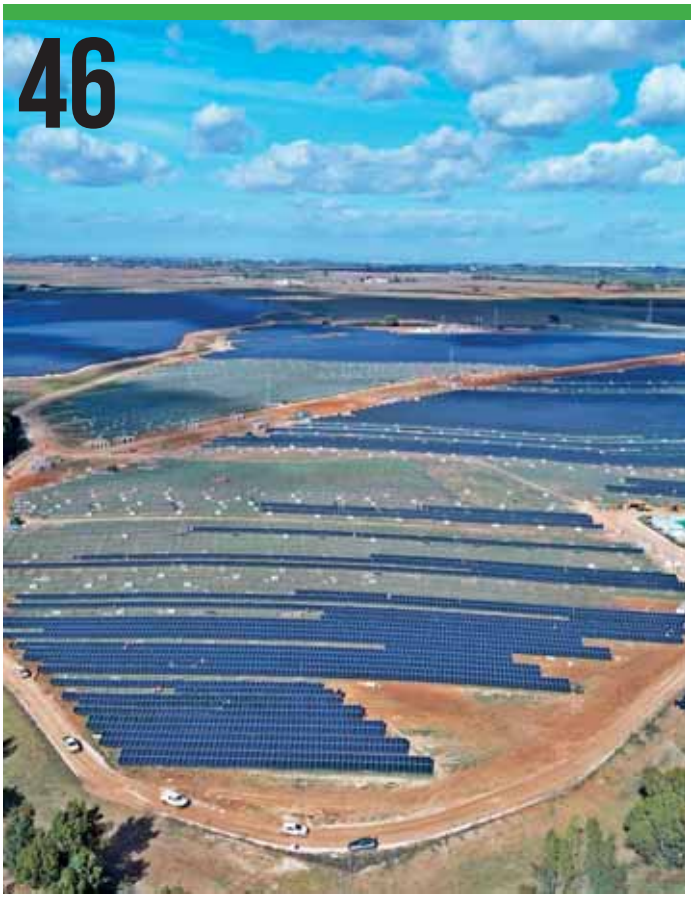

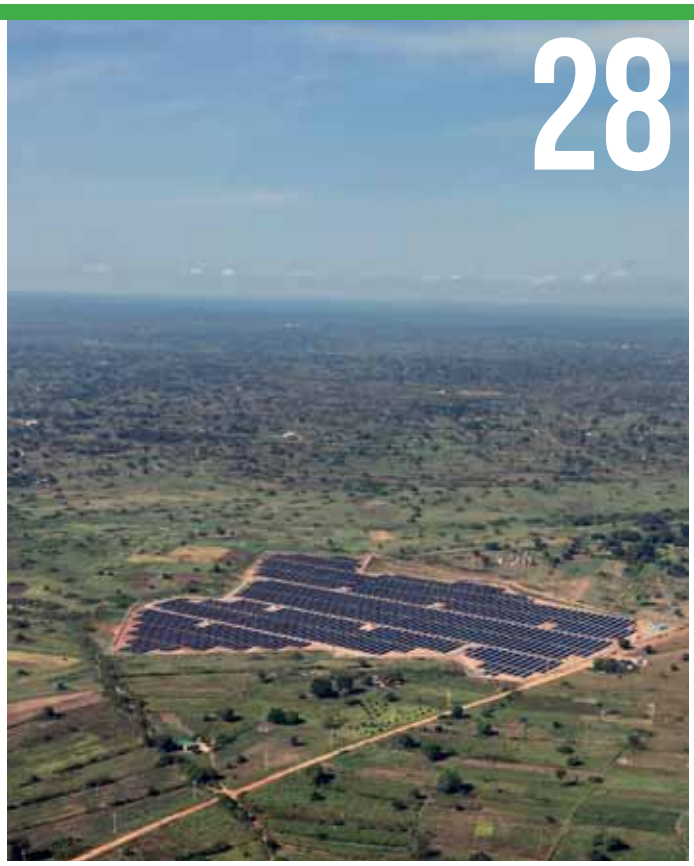


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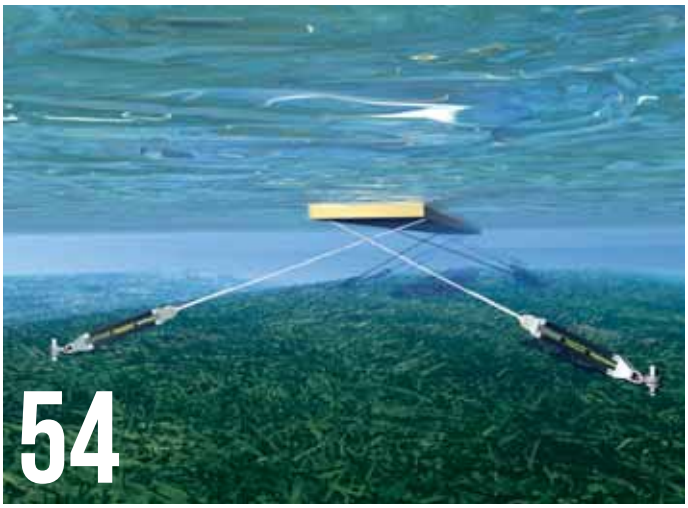

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REGULARS

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EUROPE

UK

UK post-subsidy pipeline reaches 3.3GW

The UK has a large-scale post-subsidy solar pipeline of more than 3.3GW, according to exclusive data from Solar Media's in-house market research team. The bottom-up analysis, led by Dr. Finlay Colville, tracks the progress of each project through the planning process. At the time of writing, the pipeline of 197 projects totalled 3.343GW. Around 44% of that capacity is now beyond the pre-planning phase. See page 51 for more details on how to access the full report.

Credit: Lightsource BP

The UK market is poised for a rebound

Lightsource BP clinches 300MW PPA-backed UK solar pipeline

Prolific solar developer Lightsource BP is to deploy more than 300MW of utility-scale solar farms backed by power purchase agreements in the UK. The farms are to supply power to a series of as yet unnamed corporate counterparties up and down the UK, with contracts having been finalised in the last few months. Speaking to sister publication Solar Power Portal, Nick Boyle, chief executive at Lightsource BP, said that solar had been able to beat other forms of generation on price as technology costs have continued to slide. Shortly after a 100MW deal with brewer AB InBev was confirmed.

Central Europe

Masdar partners with Taaleri for solar and wind projects in Central and Eastern Europe

Finnish renewables developer and fund manager Taaleri Energia has formed a joint venture with Masdar, the Abu Dhabi Future Energy Company, to develop solar and wind projects in Central and Eastern Europe. The JV aims to build upon of the success of Masdar and Taaleri's ongoing activities in the Western Balkans and to capitalize on projected clean energy growth in the central and Eastern Europe-an region, such as in Poland where more than 3GW of new onshore wind capacity is expected to be added over the next few years.

ReneSola bags funding for 96MW of solar projects in Hungary and Poland

China-based PV firm ReneSola has secured a €13.4 million bridge financing agreement with Eiffel Energy Transition Fund for solar projects including 41.3MW in Hungary and 55MW in Poland. Xianshou Li, chairman and CEO of ReneSola, said: "This facility demonstrates the confidence that the capital markets put in our ability to successfully develop projects in international markets. We continue to expect both Hungary and Poland to be growth markets in the years ahead, and we look forward to further supporting solar deployment in these geographies."

Iberia

Spain solar deployment doubles year-on-year in 2018 driven by self-consumption

Solar PV installations increased by 94% in 2018 compared to the prior year, according to the data registered by Spanish solar association, UNEF. Last year 261.7MW of new capacity was installed, a strong upwards growth from 135MW in 2017, 55MW in 2016 and 49MW in 2015. Around 90% (235.7MW) of last year's deployment was in the rooftop self-consumption segment, with the other 26MW in ground-mount projects.

Subsidy-free potential spurs Audax on to record solar play

The aggressive solar push by until-now wind specialist Audax Renovables is being driven by a bullish outlook for subsidy-free projects in Southern Europe, the firm told PV Tech. Grid parity, irradiation levels and solid power prices in the region have spurred the Catalonia-headquartered utility onto a large-scale PV build-up, starting with a first 708MW foray across Portugal and Spain. "There's a perfect storm in the global energy sector," said Audax global head of strategy and M&A Jaime Jaquotot when quizzed over the deal.

Allianz acquires giant subsidy-free solar plant in Portugal

Investor Allianz Capital Partners agreed the acquisition of what is expected to be Portugal's largest unsubsidised solar project, continuing the positive signs that Europe's solar industry is adapting to a post-subsidy environment. The investment arm of the Munich-based insurance group today announced that it will acquire the 218.8MW Solara project in southern Portugal, expected to become the country's largest PV power plant both without public subsidy and overall.

Finance

Standardisation a 'long way off' from solving the 'gulf' in corporate PPA understanding

The corporate power purchase agreement (PPA) market is currently struggling from a "large gulf" in understanding that standardised contracts could solve, but the industry is still a "long way off" from introducing them. A panel at the Solar Finance and Investment conference in London in January discussed the scope of post-subsidy developments throughout Europe, including the potential for long-term corporate PPAs to help projects receive financing in the absence of stable, subsidy-backed revenues. However, there has yet to be a tangible, significant movement towards corporate PPAs and the panel discussion concluded that this is predominantly down to a "large gulf in understanding" of such agreements.

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AMERICAS

Jobs

US solar jobs fell by 8,000 in 2018

Employment in the US solar sector declined by 8,000 in 2018, or around 3.2%, according to the latest Solar Jobs Census. Overall, solar jobs totalled 242,000, down from around 250,000 in 2017. Losses were largest in California (-9,576) and Massachusetts (-1,320) with Florida (+1,769) and Illinois (+1,308) offering up the largest gains. The latest iteration of the annual report by the Solar Foundation also recorded a fall in manufacturing jobs of 8.6% from 2017 to 2018. An increase is forecast for 2019 taking 2018's tally of 33,726 to 34,949. The survey includes any job that is solar related for 50% of the time.

Credit: SolarWorld Americas

A worker in the SolarWorld Americas plant, which is currently ramping after its purchase by Sunpower

US pipeline

100% renewable energy plan for Illinois tabled including 6GW of solar

Illinois State Representative Will Davis announced the "Path to 100 Act", which will introduce new legislation that would bring the state to a 100% clean energy mix. The Path to 100 Act builds on the efforts of the Future Energy Jobs Act (FEJA) to spur renewable energy deployment across the state. The key items in the "Path to 100 Act", which will be introduced in the coming days and sponsored by US State Senator Bill Cunningham, include a measure to drive procurement of 6GW of new utility-scale PV power, 6.5GW of new wind power and 7.5GW of new residential, commercial and community-scale solar.

NextEra Energy in talks to develop 423MW PV project in Nebraska

NextEra Energy is reportedly in talks to also develop a large-scale PV project in the northeastern part of Nebraska. Company spokesman Bryan Garner told The Lincoln Journal Star that the company is in the "very early stages of looking at the viability of solar projects in Nebraska". Specifically, the proposed solar installation discussed would have an installed generation capacity of 423MW, which would not only be the largest PV project in Nebraska, but the largest in the Midwest US.

Invenergy plans to develop 180MW PV project in Western New York

Invenergy is taking steps toward developing a 180MW PV project located in Caledonia, a town in Western New York. In a public involvement programme plan released back in November, Invenergy announced that it was keeping tabs on 971 hectares of land to develop the installation, named Horseshoe Solar.

EDF Renewables to build 170MW solar plant under NYSERDA contract

EDF Renewables North America was awarded a contract from the New York State Energy Research and Development Authority (NYSERDA) to build a 170 MWac PV power plant near the town of Mount Morris, New York state. EDF Renewables noted that the project would occupy around 1,000 acres and was to meet the electricity consumption needs of over 39,000 average New Yorkers. It is expected to be fully operational by the end of 2022.

Corporate power

BNEF: Corporate renewable energy buying power swelled in 2018

Corporate power purchase agreements (PPAs) for renewable energy swelled to 13.4GW in 2018, according to Bloomberg New Energy Finance (BNEF). The tally dwarfs the 6.1GW figure of 2017 with the US market dominating. Almost two-thirds of the global total for 2018 was contracted in the States (8.5GW).

Google to develop 413MW pipeline of PV projects in Tennessee, Alabama

Already busy developing a pair of energy-efficient data centre campuses in Tennessee and Northern Alabama, Google announced an even grander plan to develop a 413MW pipeline of PV projects within both states. It will purchase the output of several new solar farms as part of a deal with the Tennessee Valley Authority (TVA). The two largest PV projects are located in Hollywood, Alabama and Yum Yum, Tennessee, with each installation boasting an installed generation capacity of 150MW. These will be the largest PV projects ever built for Google, as well as some of the larger renewable-energy installations developed in the Tennessee Valley region.

Brazil

Grupo Interalli earns approval for 540MW PV project in Brazil

Brazilian energy developer and port company Grupo Interalli received government approval by the State Secretariat for the Environment of Piauí (SEMAR) for the development of the Marangatu Photovoltaic – Complex a 540MW solar park. The project will be developed atop an area of 2,100 hectares near the city of Brasileira in the state of Piauí. Work on the site is expected to begin in the second half of 2019. Fabrício Slavieiro Fumagalli, CEO of Grupo Interalli, noted that the development of a PV project of this magnitude is positive for Piauí as a whole.

Atlas Renewable Energy completes 67MW PV project in Brazil

Atlas Renewable Energy inaugurated its first operational PV project in Brazil, with the company completing the 67.1MW São Pedro solar plant in Bom Jesus da Lapa, located within the state of Bahia. Construction began in January 2017 for the installation, which is split between a pair of sub-plants. Financing for the site was secured through the Banco do Nordeste (BNB), along with an equivalent sum of commercial bank guarantees from BTG Pactual, Banco ABC Brasil, and Banco Bradesco. The project has a 20-year PPA Chamber of Electricity Commercialization (CCEE) through the Brazilian government's energy auction in 2015.

MIDDLE EAST & AFRICA

Tenders

Abu Dhabi launches 2GW tender

The Emirates Water and Electricity Company (EWEC) launched a 2GW solar tender in February. Developers were given until 5 March to express interest in taking a 40% share in a special purpose vehicle with EWEC, which will also be the offtaker. The emirate has already built the 1.2GW Sweihan complex, which was built by Indian engineering, procurement and construction firm Sterling & Wilson with JinkoSolar supplying modules.

Credit: Sterling & Wilson

The new tender eclipses the 1.2GW Sweihan project

Saudi Arabia launches 1.5GW solar tender

Saudi Arabia has launched the second round of its solar power tender programme with a request for proposals for 1.5GW of solar. The capacity is split up between seven projects ranging from 20MW to 600MW. Initial expressions of interest in participating in the tender are required by 14 February 2019. Bidding on a further +700MW will be opened later in the year.

Emirate reveals 1.2GW solar ambitions as it launches sustainable building code

Ras Al Khaimah, one of the seven emirates making up the UAE, has revealed a 1.2GW solar ambition. At the launch of the new sustainable building programme dubbed Barjeel, Ras Al Khaimah's municipality said it would look to build out 600MW of rooftop solar and 600MW of utility-scale projects. The RAK Municipality has a 2040 objective of 30% energy efficiency improvements, 20% water savings and 20% renewable energy generation.

Mines

South African mining giant mulls PV plant to escape utility fallout

Talks are underway at Harmony Gold Mining Company on whether to develop 30MW of solar in South Africa to help shield the firm against ongoing turmoil at state-owned utility Eskom. The mining giant confirmed the potential solar play during a Q2 2019 earnings call held on Tuesday, after it emerged its net profit had nosedived to US$5 million in H2 2018 from US$65 million in H2 2017.

Univergy and Rioenergy to set up 180MW of solar for Zimbabwe mines

Zimbabwean mining firm RioZim contracted Spanish-Japanese renewable energy company Univergy International and power firm RioEnergy to develop, build, operate and maintain four solar PV plants totalling more than 180MW capacity to supply cheaper power to four of the country's largest mines, according to a filing on the Zimbabwe Stock Exchange (ZSE). Through a power purchase agreement (PPA), Renco Mine in Nyajena, Dalny Mine in Chakari, Cam and Motor Mine in Kadoma, and Murowa Diamonds Mine in Zvishavane, will all receive power from the solar projects, each with a capacity of around 45MW.

Africa prospects

Kenya's 2022 total electrification plan highlights off-grid solar and mini-grids

Kenya's government launched a plan for total electrification in the country by 2022, which acknowledges the role that off-grid systems, mini-grids and stand-alone solar plants can have in complementing extensions to the grid and mitigating higher loads. Power in Kenya has been touted as a US$14.8 billion opportunity over the next five years across power generation, transmission, distribution, off-grid electrification, mini-grids and solar systems for homes and institutions.

Chad signs MoU for 120MW solar project

Representatives from both the Republic of Chad and UAE-based renewable energy developer Amea Power signed off on a Memorandum of Understanding (MoU) for a 120MW PV project. The MoU was signed by Amea's chairman, Hussain Nowais, and Chad's minister of petroleum and energy, Mahamat Hamid Koua. Former Chadian prime minister Kalzeubet Pahimi Deubet was also in attendance for the signing.

GCF backs solar mini-grids for 100 villages in Burkina Faso

The Green Climate Fund (GCF) is providing nearly half the funding necessary for a scheme to deploy solar mini-grids across 100 villages in Burkina Faso. The €24.3 million funding will contribute to the €53.1 million programme, which aims to reduce the West African country's reliance on fossil fuels and alleviate what are some of the highest power tariffs in the region, is also focused on improving power access, given just 3% of Burkina Faso's rural areas are electrified.

ASIA-PACIFIC

India

Indian manufacturers 'elated' with 12GW domestic content solar scheme

India has approved a 12GW solar scheme for central public sector undertakings (CPSUs), which are state-owned enterprises, spanning the military, health, energy, government and mining sectors, among others. Importantly, the scheme mandates the use of domestically sourced solar cells and modules. The government is trying to appease demand at home not just to support solar PV deployment but also to foster a domestic manufacturing industry and reduce the dependence on Chinese imports. The proposed 12GW CPSU scheme will come with significant Viability Gap Funding (VGF) subsidy support of INR85.8 billion (US$1.2 billion).

Indian renewables deployment to grow sharply after 'forgettable' 2018

India's renewable energy deployment is expected to grow by 50% year-on-year in 2019 with a total of 15,860MW of installations, according to the 'India RE 2019 Outlook report' by consultancy firm Bridge to India. It described 2018 as a "forgettable year" for the Indian renewables sector, lifted only by a surge in auctions with more than 20GW of capacity awarded, however, there were also several major tender cancellations in the year. Utility-scale PV deployment is set to hit 10,902MW in 2019, surpassing 10GW in a single year for the first time, and well up from 6,833MW in 2018.

India's SECI tenders 7.5GW of solar in Ladakh

Credit: flickr/Kiran Jonnalagadda

India has huge PV ambitions for the desert mountain region of Ladakh

Solar Energy Corporation of India (SECI) has tendered for 7.5GW of grid-connected solar PV projects, including implementation of power transmission and evacuation infrastructure, in the high altitude Leh and Kargil districts of Jammu & Kashmir state. This includes three packages of 2.5GW each in the Ladakh region. This is part of the central government's scheme to set up 23GW of solar across the state. Ministry of New and Renewable Energy (MNRE) is also planning two hybrid projects with a combined total of 14MW solar PV and 42MWh of battery energy storage in Leh and Kargil.

India plans 60GW of solar tenders by March 2020 in push to hit targets

India plans to tender 30GW of solar in each of the next two years to give developers time to complete projects ahead of the flagship 2022 targets. The government wants to give assurance to renewable energy developers and the investor community about its long-term commitment to the clean energy sector and is encouraging them of the ability "to make risk-free investments in the country". On the last day of 2018, SECI tendered for 1.2GW of wind projects and 1.2GW of ISTS-connected solar PV projects. It also announced tender plans for 1.2GW national grid-connected wind-solar hybrid projects, while several states followed with their own gigawatt-scale tenders.

Southeast Asia

Vietnam FiT extension

Vietnam's Ministry of Industry and Trade has issued a draft policy to extend the solar feed-in tariff (FiT) by two years up to until 30 June 2021. The new FiT, which has lower rates, would also alter in relation to the region a project is located, based on solar irradiance, type of installation and COD, in an attempt to spread solar PV across the country. In other news, Vietnamese conglomerate Sao Mai Group has signed an agreement with local financier HD Bank to jointly work on a 210MW solar PV project.

China

China reveals new subsidy-free solar and wind policy

Credit: Panda Green Energy

China has moved into a new phase of renewable energy policy

China's top planning organisation revealed new solar and wind policies for subsidy-free projects. Feed-in tariff (FiT) support was cut in May 2018 but under new plans, all relevant bodies will be asked to clear obstacles for those projects that can undercut coal (coal-fired benchmark on-grid price). Local governments will be allowed to subsidise projects if they choose but the policy states that those subsidies cannot be used to prop up local manufacturers. Support cannot be offered with local content requirements either. This tallies with previous indications that struggling solar manufacturers should not be offered artificial support. The plans also include the use of Green Certificates, linked to renewable power generation that can then be traded. China carried out a trial of the scheme in 2017. In addition, strenuous efforts to reinforce grid infrastructure will be made to reduce curtailment. Projects that cannot show that the power can be efficiently distributed will not be approved. Provinces will also be encouraged to trade more power across their respective boundaries. Tighter requirements on project design and siting are also introduced. Projects will be encouraged on unused state-owned land. The policy stands until the end of 2020.

Central Asia and Australia

Deadline approaches for 2GW Afghanistan solar EOI

The government of Afghanistan has invited expressions of interest for up to 2GW of solar as part of an effort by the Central Asian country to boost its energy self-reliance and meet growing electricity demand. Interested parties were able to submit proposals to build up to 400MW of grid-connected PV in each of the five Afghani provinces of Kabul, Jalalabad, Kandahar, Herat and Balkh. Both the World Bank and its subsidiary the IFC have separately backed solar initiatives in Afghanistan in 2018.

Large-scale plants roll on in Australia

The Australia solar market has continued to churn out news related to utility-scale solar plants. UK firm Octopus Investments and Edify Energy have closed finance on a 333MW project in Australia. Canadian Solar is partnering with Signal Energy for an EPC and module supply contract for ESCO Pacific's 175MW Finley Solar Farm in New South Wales. Meanwhile, Pacific Hydro Australia has secured local planning permission for two solar projects representing 555MW in capacity. Both major parties in the election race for New South Wales have also put forward plans focusing on solar and storage for households.

Despite political changes, big plants keep coming in Australia

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"This year's conference agenda was once again very informative and the range of speakers very good. It's very helpful to be able to attend a meeting which provides such a good overview of the different dynamics of the solar PV market across so many countries"

Philip Bazin, Triodos Bank

lss.solarenergyevents.com

Product reviews

Inverter — Hoymiles HM-1200 microinverter first designed for four solar panels and reactive power control

Product Outline: Hoymiles is unveiling its 4-in-1 microinverter, the HM-1200, which is the first designed with reactive power control for four solar panels. It still offers the same features as Hoymiles's previously released MI-1200, with wide DC input operating voltage range (16-60V) and low start-up voltage (22V only).

Problem: With the increasing proportion of photovoltaic power generation in the power grid, the influence of PV systems on the power grid is gradually increasing, and when a PV system provides active energy to power grid, it will also bring harm to the safety of the power network. PV inverters, notably microinverters should have reactive power control.

Solution: When the capacity of the PV system is large, and the dot voltage fluctuates, the HM-1200 can output reactive power to solve the voltage fluctuation overload problems. When the external environment changes, the active output of the PV system fluctuates, and it will properly adjust the reactive power export stability and dot voltage. When the PV system grid-connected side fails and the dot voltage drops, the system can adjust its reactive power output to provide voltage support.

Applications: HM-1200 is adapted to both 60-cell and 72-cell PV panels (200~380Wp).

Platform: HM-1200 offers a module-level, in-parallel solution, dual module-level MPPT and module-level monitoring for real-time monitoring and maintenance, which ensures 100% safety of both installers and users. The HM-1200 comes with a 6,000V surge protection, MTBF (mean time between failure) >550years, yearly failure rate <0.18% and lower LCOE with industry-leading warranty of up to 25 years.

Availability: Available for batch order from 1 April 2019.

Module — Jolywood's bifacial 'paving' module boasts front power of 430W, efficiency of 20.5%

Product Outline: Jolywood (Suzhou) Sunwatt Co has launched two differentiated high-efficiency n-type mono PV modules. The new products, the JW-HT&HD Series 'Paving' module boasts a front power of 430W, efficiency of 20.5%, integrated power of 530W with efficiency of 25.4%, as well as a rear power gain of 30%.

Problem: The need to reduce the levelised cost of energy (LCOE) continues to drive cell and module conversion efficiencies, while achieving cost-effective manufacturing at scale. The adoption of large-area, high-purity wafers and multi-cut cell configuration and bifacial cells further increase efficiencies.

Solution: The n-type monocrystalline, high-efficiency bifacial paving module developed by Jolywood uses flat ribbons to link up each cell, which is an innovative solution to avoid cells being covered by ribbons and narrows the distance between cells. This increases the module conversion efficiency and reduces the LCOE). Compared to modules with the same cells, the n bifacial paving module has a typical power gain of 15W to 20W, increasing the conversion efficiency by 1.5%.

Applications: The JW-HF Series can be used in a variety of situations, such as a rooftop with low load-bearing capacity or the exterior of a building. The JW-HT&HD Series bifacial modules can be used for commercial rooftop and utility-scale projects.

Platform: The n-type TOPcon (tunnel oxide passivated contact) cell technology was developed at Fraunhofer ISE and is based on an ultra-thin tunnel oxide in combination with a thin silicon layer and enables excellent charge carrier selectivity, using high-quality wafers.

Availability: Available since January 2019.

Products in Brief

Delta PV inverters achieve US rapid shutdown requirements with Tigo's UL Certification

Tigo Energy has received Underwriter Laboratories (UL) certification for its TS4 Platform Rapid Shutdown Systems (RSS) with Delta Group. The partnership fulfills the mandatory NEC 2017 Rapid Shutdown specifications for US residential and C&I rooftop solar installations. The Delta inverters (M36U, M42U, M60U, M80U, TS4-O (Optimisation) and TS4-L (Long Strings) were successfully certified with Tigo's RSS solutions: TS4-F (Fire Safety), TS4-O (Optimisation), and TS4-L (Long String). Tigo is currently shipping with Delta and more tier-one certified inverter manufacturing partners throughout the U.S.

REC Group to produce heterojunction modules with Meyer Burger's 'SmartWire' technology

REC Group has said it has invested US$150 million in developing and rolling out into volume production a new n-type monocrystalline-based heterojunction (HJ) cell that will use Meyer Burger's 'SmartWire' (SWCT) cell connection technology. REC said that the new high-performance module would be first showcased at this year's Intersolar Europe, being held in Munich in mid-May, 2019. REC Group touted that HJ modules were manufactured without the higher temperatures of other methods, which simplifies the process and reduces manufacturing energy consumption.

O&M | Mondas launches novel analytical software for solar power plant O&M

Product Outline: Fraunhofer ISE spin-off, Mondas has launched a novel analytical software system for a broad range of applications, including solar power plant O&M. The 'Mondas' System Platform is a web-based tool designed for the collection and analysis of data enabling the monitoring of a large number of similar energy and production plants and to manage building commissioning in a time- and cost-effective way.

Problem: Many energy plants are believed to operating far below optimal performance but the challenge is raising performance without data-driven technology, yet this requires the ability to handle a large number of systems.

Solution: Mondas records all relevant system data such as operating temperatures, running times or rpm and analyses them in real time. In the critical operating state, the system sends the error analysis to the customer. As a result, the number of breakdowns decreases significantly, maintenance trips can be saved or carried out more efficiently. This significantly improves the energy yield and thus the profitability of combined heat and power plants or solar parks, according to the company.

Applications: Typical plant applications are combined heat and power plants and photovoltaic systems, but also compressed air stations or chillers.

Platform: The Mondas platform is designed for the collection and analysis of data enabling you to monitor a large number of similar energy and production plants and to manage building commissioning in a time and cost-effective way. The underlying HDF5 data format processes large data volumes and is by several orders of magnitude faster than for example SQL data bases.

Availability: February 2019 onwards.

Repowering | SMA Solar offering 'Repowering' packages for PV power plants

Product Outline: SMA Solar Technology is now offering its SMA 'Repowering' packages featuring customised solutions for modernising PV power plants worldwide. The packages include state-of-the-art hardware and software along with enhanced servicing and maintenance programmes.

Problem: PV power plant technology has advanced at a rapid pace over the last few years, highlighting that an increasingly number of older PV power plants no longer satisfy all the requirements of modern and future-proof energy generation. This can be down to poor quality, outdated technology, insufficient maintenance or a shortage of spare parts. Manufacturers withdrawing from the PV business is often a factor in the need for repowering PV power plants

Solution: System availability is a key factor in PV system profitability – and it can be improved significantly through modernisation. In addition to enhancing performance and increasing energy yields, modernisation not only equips PV power plants with modern energy management functions, storage integration interfaces and energy trade connection interfaces, but also upgrades them in line with the latest cybersecurity standards. A PV power plant that has been modernised by specialists is longer lasting and, in turn, much more profitable. Modernisation also avoids servicing costs and output losses caused by aging components.

Applications: Repowering PV power plants.

Platform: SMA is now offering the new Engineering Services to determine modernisation requirements across the globe. The Engineering Services experts ensure that new components, services and software solutions are customised to the specific PV power plant and ambient conditions. Country-specific requirements of, for example, grid operators are also taken into consideration.

Availability: Currently available.

Vikram Solar's mono-PERC half-cut-cell module improves output by 15Wp

Vikram Solar has introduced a new mono-PERC half-cut-cell module consisting of 144 and 120 half-cells instead of 72 and 60 full cells, yet keeps nearly the same dimension as standard 72 and 60-cell modules, providing and increased output of ~15Wp per module compared to standard PV modules. The design minimises shadow-loss through a series-parallel cell connection, when one-half of the modules are affected by shading. Module power mismatch loss is reduced by a factor of four as power loss is proportional to the square of the current. No hotspot degradation is expected on the modules and a split junction box design provides better heat dissipation, improving the life of the module.

Alion Energy's 'Storm Tracker' provides ballasted single-axis tracker with automated cleaning robots

Alion Energy has developed the 'Storm Tracker,' which is designed to be a robust ballasted single-axis tracker with automated cleaning robots, making it an ideal solution for rocky, hard, dusty and other challenging environments. The primary components of the Storm Tracker are a continuous, jointed concrete track supporting an A-frame structure with an arc drive, purlins, drive shaft and flexible coupling joining tables. Major parts are factory pre-assembled to reduce field labour and allow for all parts to be installed by two people.

PV systems with lowest LCOE using bifacial modules: State-of-the-art systems and components

System integration | Bifacial technology is proving to be an effective means of reducing the levelised energy costs of PV systems, offering substantially improved energy yield for only a minor additional cost. Hartmut Nussbaumer, Markus Klenk, Joris Libal and Radovan Kopecek report on the state-of-the-art in bifacial PV systems, giving an overview of components such as modules, sub-constructions, tracking systems and inverters, and presenting comparative simulation and measurement results from bifacial and monofacial systems

The major motivation to build photovoltaic systems is the economic generation of electric energy. Obviously, the cost of the produced energy is dependent on the specific system layout, its yield and several other factors, such as the system durability. The levelised cost of energy (LCOE) concept is a standard measure to compare different types of energy sources economically [1]. Since the early stages of PV production the LCOE of photovoltaics has been continuously reduced, mainly by lowering the specific US$/Wp cost of the PV modules. This could be obtained by increasing the efficiency, but even more important by reduced material and manufacturing costs. However, over time, the respective possibilities for decreasing costs were increasingly exhausted. Today, with a cost share of solar modules in a PV system below 50%, and with limited options concerning the "balance of system" (BOS) components, there is little room for further improvements in this regard. Other aspects, such as lifetime durability, are increasingly important.

Due to the additional yield from the rear, bifacial PV turned out to be a very effective setscrew to improve the LCOE. Bifacial PV technology has been known about for a long time, but there was no real breakthrough in the early stages, with still quite expensive cells and modules. This changed however due to technical progress, such as improved bifacial cell concepts or the availability of thin solar glass. Some of the advanced solar cell technologies, which are currently implemented in industrial production, enable a comparatively simple adaption to a bifacial layout. This allows a harvesting of the additional yield with little or no additional cost. The general trend towards glass/glass-modules with superior reliability, as well as the interest in "peak shaving" and customised solutions for specific applications, further supports the development towards bifacial technology. Based on that, since about 2014, bifacial PV systems have grown from being a niche application to a larger market, showing an improved energy yield in various types of applications and orientations [2-6]. In parallel with the increasing market share, remaining issues, such as the definition of a meaningful power rating procedure or the development of simulation tools, which consider the more complicated irradiation conditions [7], are currently being addressed by numerous companies and institutions.

Modules

The LCOE of a bifacial PV system is obviously dependent on the price and the output of the used solar modules. All module manufacturers have to deal with the continuing price decay and try to optimise the specific cost (per Wp or kWh) of their products. For an optimization, the technologies of cells and other components are as well important as the module layout and the used materials.

For bifacial as for monofacial modules, a common attribute is the used cell technology, which is often not directly referring to the underlying technology, such as n-PERT, IBC, HJT or p-PERC, but to the name chosen by the manufacturer for their specific process. There is a wide field of

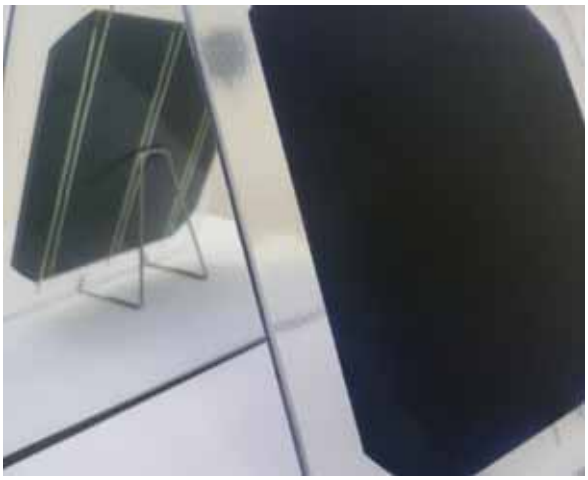

Figure 1. Bifacial IBC (interdigitated back contact) cell with bifacial character (ISC Konstanz, "ZEBRA" cell; bifacial factor in module >0.75)

technologies, which allow a differentiation. A detailed discussion of the respective cell concepts, their advantages and drawbacks, would be beyond the scope of this article, but comprehensive information can be found elsewhere [8-11].

HJT and IBC, both with more complex processes and more expensive n-type wafers, promise the highest efficiencies and HJT is superior with regard to the bifaciality. Bifacial IBC is the most complex but least investigated technology. N-PERT and also PERC+ are the most common bifacial cell types today, with n-PERT showing a higher bifaciality and higher efficiency potential, but at higher cost. There is a large number of n-type manufacturers, but there is also a steadily growing amount of p-type PERC+ competitors. Bifacial PERC+ has the advantage that the cell process can be comparatively

easily upgraded from monofacial PERC and PERC is currently replacing Al-BSF as mainstream cell technology. Considering the historical development and the repeatedly shown focus on the mainstream technology in the PV industry, it may be reasonable to guess that in the short to mid term PERC+ will increasingly dominate, while the improvements in n-type processing will in the mid to long term make this technology superior.

Apart from the cell technology, the layout of bifacial modules is still quite homogeneous. Aside from some products which use bifacial cells in a monofacial module with white reflective backsheet, as offered e.g. by Panasonic [12], the rear side of a bifacial module has to be transparent. Also modules which partly utilise internal reflection, by covering the cell spacing with white reflective material [13], have a transparent rear side, as implemented in some commercial modules, e.g. from Solarworld [14], Trina or Linyang.

To obtain a transparent rear side there are two options available on the market: laminates with transparent backsheet or glass/glass layout. By far most of the suppliers choose a double glass design, which promises better reliability and is also increasingly used for monofacial modules, while some very large bifacial manufacturers as LG and Jolywood (Jolywood is also a leading producer of backsheets) offer transparent backsheet modules. (Jolywood offers bifacial modules with glass/glass and glass/transparent backsheet structure [15]). DuPont recently announced that it had released a transparent Tedlar backsheet [16]; manufacturers such as Krempel [17], Dunmore [18], Coveme [19], Isovoltaic and others offer a transparent backsheet or are working on its development. Solarworld changed the module layout and replaced the variant with transparent backsheet [20] against a glass/glass version [21].

The advantages and disadvantages of both layouts are widely discussed in the community. Glass/glass has obvious advantages concerning the mechanical stability and shielding capability of the inner components. In a symmetrical structure, the cell matrix is also located along the neutral fibre, which means that a bending of the laminate does not result in tensile or compressive stress in the cells. On the other hand, a backsheet allows undesired chemicals, such as acetic acid, which is a result of degrading EVA, to diffuse out of the laminate [22]. It also promises a lower operating temperature of the cells, may result in a more lightweight module and allows a faster lamination process.

For double glass modules, glass thickness could be reduced to 2mm or below, from a technical point of view. There is however no real cost reduction potential since a thickness reduction of hardened solar glass below 2mm is complicated and at present only feasible with expensive techniques such as chemical strengthening. In addition, the module layout would need a redesign with supporting structures at the rear side, since the mechanical stiffness of such thin laminates would not be sufficient.

Glass/backsheet modules usually have a circumferential frame, while for glass/glass modules, dependent on the glass thickness, size and the aimed mechanical load resistance, frameless modules are possible. As for monofacial modules, presently most modules are with 60 cells, 156mm x 156mm side length, but the share of 72-cell modules is increasing. The number of cells also defines the module size and is therefore often dependent on the application.

In addition, other trends, such as half-cells and shingle cells, are relevant for bifacial as well as for monofacial modules. With regard to half-cells the lower current is particularly interesting for bifacial modules, which, due to the additional rear side contribution, have higher currents and consequently increased ohmic losses, compared to monofacial ones. Innovative module layouts for half-cell modules [23-25] with non-standard interconnection scheme may be advantageous for bifacial modules also in other regard, because it could improve the performance at partly shaded conditions.

Measures to reduce the series resistance, particularly the multi-busbar approach, affect, due to the higher currents, bifacial modules even more than monofacial ones. Currently, also bifacial modules with shingled cells are being tested at R&D level [26, 27] and the first bifacial products have even been launched [28] already. Another trend, which is also implemented in monofacial devices, but which may, due to the more inhomogeneous irradiation conditions, be even more relevant for bifacial modules, is the use of optimisers [29] for bifacial installations or even at module level as implemented by Sunpreme [30].

A factor that heavily affects the competitiveness of bifacial modules is not directly related to the LCOE from the technical point of view, but to the power rating. It is still common to regard bifaciality as an add-on and to base the power rating/pricing on the front side STC-measurement. In addition, not all companies state the bifacial factor of their products; it is also not yet common practice to give a quantitative statement on the bifacial energy gain at specific irradiation conditions. While it is comparatively simple to define standardised indoor measurement conditions for a monofacial module, the measurement of a bifacial module also has to include the power, which is generated by the rear side. Standardised measurement conditions for bifacial modules are still being discussed, but close to finalisation [31, 32]. In the future, different efficiencies for standardised rear side illumination levels and measurement will allow a better comparability.

Systems

Bifacial systems have been constructed continuously at larger volumes starting with a ~1MWp installation with PVGS modules in Japan in 2013 [33], ~10MWp by

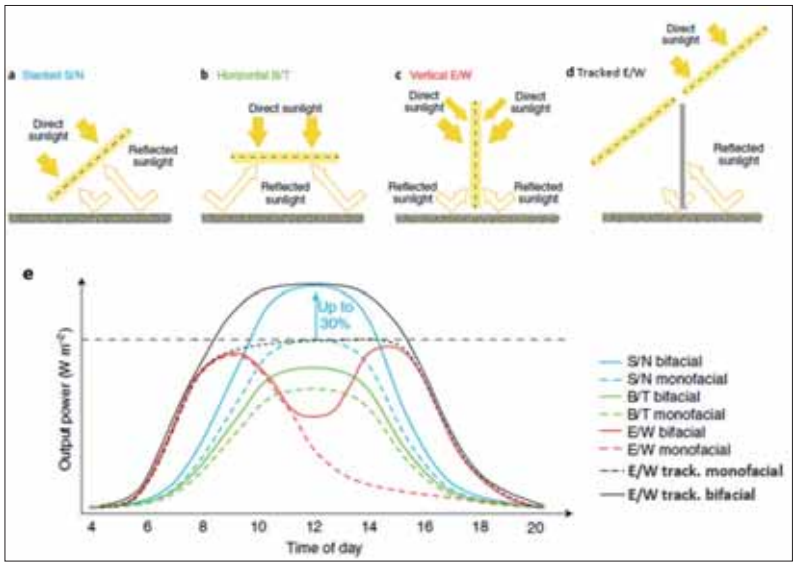

Figure 2. (a-d) Possibilities of installations for bifacial modules and (e) power generation curves for monofacial in comparison with bifacial modules [38]

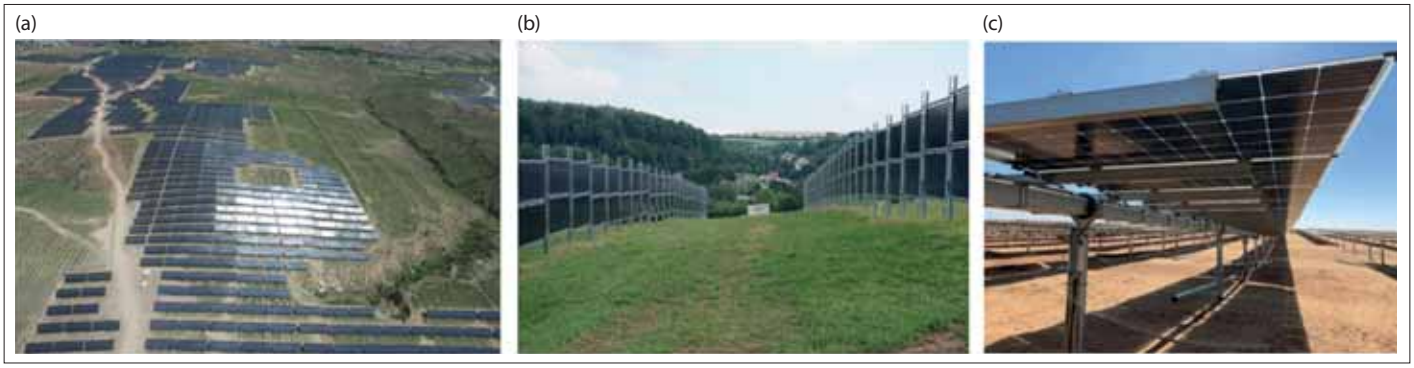

Figure 3. (a) Bifacial 50MWp fixed tilt PV system by Yingli (China), (b) bifacial vertical 2MWp installation by Next2sun (Germany) and (c) bifacial HSAT 400MW by Scatec Solar (Egypt)

Sunpreme in 2016 in the US [34], ~100MWp by Yingli and NSP in Asia [35, 36] in 2018 and the currently largest one in construction by Scatec with 400MWp in Egypt [37]. Now, at the end of 2018, the total installed capacity of bifacial systems amounts to about 3GWp, which corresponds to a market share of about 0.7% (bifaciality is becoming "visible") but is expected to grow to a total share of close to 20% in the coming five years in the 1TW-scale market.

When using bifacial modules the possible geometries for installations are getting more complex, depending on the application, as the rear-side irradiance of the modules also have to be considered. Figure 2 depicts the variety of possibilities (a-d) and corresponding schematical power generations curves in (e).

The systems can be installed classically with (a) a slanted tilt facing towards the sun receiving additional albedo from the ground reflection. When the bifacial modules are used in a carport and installed (b) horizontally then the power generation is decreasing – however still showing a bifacial gain. Vertical E/W installations (c) need bifacial modules with a high bifacial coefficient (n-PERT, HJT) to achieve a symmetrical power generation curve as depicted as a solid red curve in (e). The most common applications these days with the highest yield potential are bifacial horizontal single-axis tracking (HSAT)systems (d) which were discussed in detail at the 5th bifacial workshop, bifiPV2018, in Denver. Such systems can reach up to 50% more power (black solid curve) in comparison with classical fixed-tilt monofacial equivalent systems (dashed blue), which, depending on location, albedo, installation height etc, can lead to the lowest LCOEs possible as already proposed by EDF/Masdar in the lowest bid of all times of 1.78 US cents per kWh [39].

Utility scale

Figure 3 shows the largest bifacial utility-scale PV systems for (a) bifacial fixed tilt, (b) bifacial vertical E/W oriented application and (c) bifacial HSAT.

The annual yield gains due to bifaciality, compared to a standard fixed-tilt monofacial PV system, are reaching from about 10% (Yingli) [40], above 10% (Next2Sun) [40] to 13% (enel) [41]. For Scatec´s installation in Egypt, no numbers are available yet, as the system is still under construction.

The largest system so far, set up by Scatec Solar in Egypt, uses the natural albedo of the desert in combination with bifacial PERC modules with an expected bifacial gain of about 10% (compared to monofacial HSAT) - slightly lower to the La Silla installation by enel in Chile [41] where nPERT (BiSoN) modules with a higher bifaciality were used.

As bifaciality is becoming increasingly bankable and the yield simulations more and more precise, bifaciality will presumably dominate the utility -scale market in desert regions in combination with HSAT very quickly. At the bifacial workshop in Denver last September, several presenters from the US were convinced that, similar to trackers three years ago, bifacial HSAT systems will become standard in the US in the next two years.

Rooftop and building integration

HSAT is not a technology that can be simply used on flat roofs because of several reasons. On the one hand the trackers will add too much weight and on the other the wind loads of such high installations could not be anchored easily to the roof. However, there are companies working on lightweight trackers for roofs as well.

Figure 4. (a) 10 MWp bifacial fixed tilt installation by sunpreme (USA) [42] and (b) bifacial vertical installation by Solarspar (Switzerland) [43]

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Installation	Monofacial comparison	Bifacial gain [%]	Comment
Fixed tilt bifi	Fixed tilt mono	15+-3 [40]	MegaCell in La Hormiga (without white quartz)
Vertical bifi	Fixed tilt mono	10+-3 [40]	Next2sun in Germany
HSAT bifi	HSAT mono	10+-3 [40]	Enel in La Silla in Chile

Table 1. Typical bifacial gains (albedo 30%, module bifacial factor of 0.9 and module edge distance from the ground of 60cm) in comparison with standard monofacial systems

The main installation mode for bifacial modules on flat roofs is fixed-tilt mounting, as e.g. realised by Sunpreme (Fig. 4 (a)). However, there are also more unconventional approaches, such as vertically installed mini modules (Fig. 4 (b)) as installed by Solarspar.

As the distance of the modules from the roof is quite low, in the most common installation mode bifacial gains are limited. However, the albedo of many roofs can be considerably enhanced by using reflecting paint or roofing foil and bifacial gains can exceed 10% as well.

Floating PV is, similar to bifacial PV, a growing market. A combination of floating PV and bifacial PV is a logical consequence even if water is not the best reflector. Depending on the type of installation, bifacial double-glass modules above water may result in higher yearly energy yields, because of better cooling compared to installations above ground [40].

Table 1 reports bifacial gains for typical utility scale installations. In order to achieve the highest possible bifacial gains, appropriate mounting structures are necessary; a topic that is discussed in the next paragraph.

Sub-constructions

The first large >1MWp bifacial PV power plant used PVGS n-PERT modules [33]. Fig. 5 depicts the historical PV plant with a non-optimal sub-construction for the bifacial modules, as shown in Fig. 5 (b).

You can clearly see the shadowed rear side of the modules by the stabilisation bars that are nearly touching the rear side of each module. Even with this very un-optimised feature, PVGS was reporting very high yearly bifacial gains of close to 20%. The reason for this was partly that the system was built in a snowy region where seasonal high albedo values of snow enhance the bifacial gain.

From this system we also learned that such a severe shadowing on the rear side does not cause any hot spot and consequent shunting problematics of the modules which was not observed by PVGS and is explained in the next section.

Shadowing of the rear

During the bifacial workshop bifiPV2018 in Denver, Hanwha Q CELLS showed various systematic experiments and measurements of how a shadow on a rear side affects the module performance and reduces the bifacial gain [44]. Similar studies were done e.g. by ISC Konstanz and ECN [45] before. Figure 6 (a) shows very demonstratively how the current distribution looks and that only a little fraction of that comes from the rear side. Therefore, hotspot problematics, which are often discussed by the bifacial community, simply do not exist for shadows from sub-constructions.

The experimental graph in Fig. 6 (b) then also shows how such a loss depends on the distance of a certain object (here 6cm wide and 10cm deep) as shown in Fig. 6 (a) that is shadowing the rear side. For a minimum distance of 30cm the losses are almost zero.

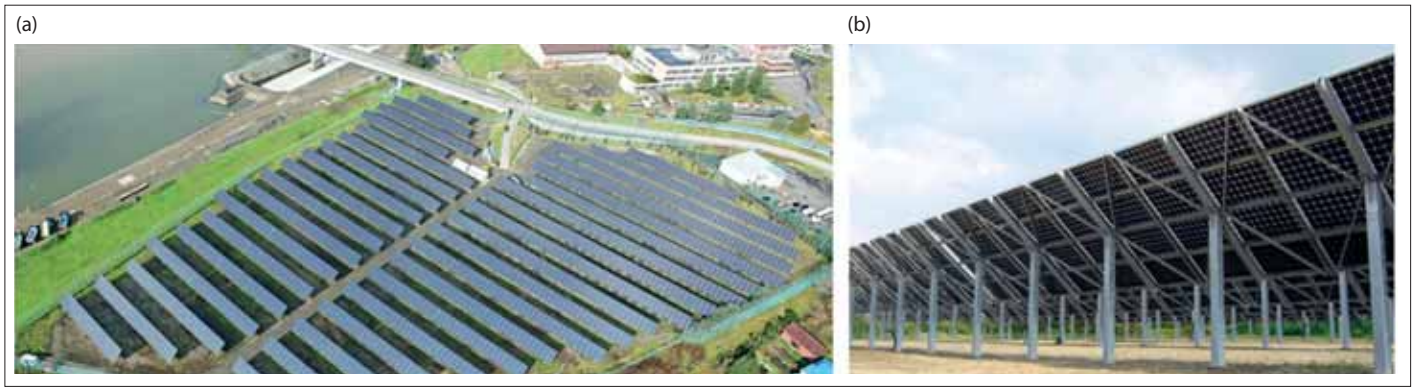


Figure 5. (a) Top view and (b) detailed view on the first large bifacial installation by PVGS in Japan [33]

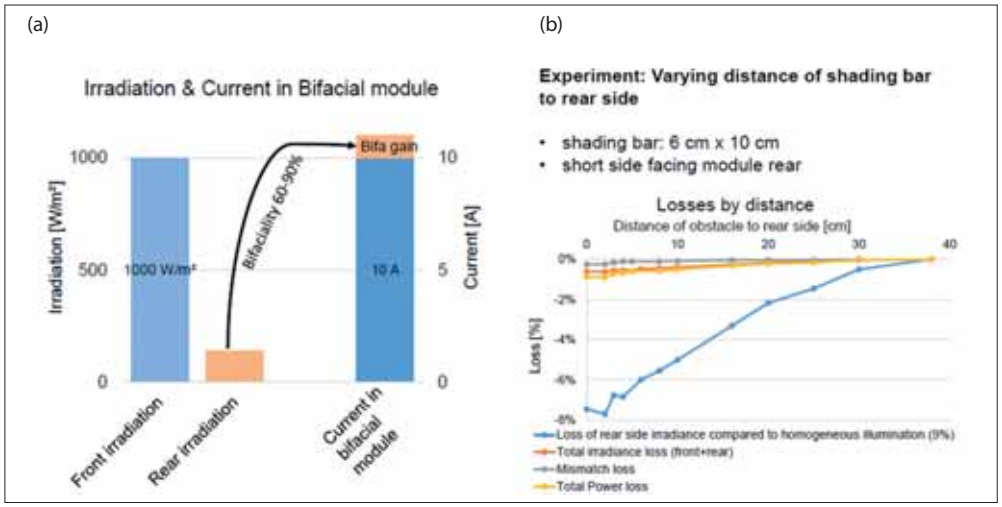


Figure 6. Hanwha Q CELLS' explanations at bifiPV2018: (a) why shading on the rear side does not cause hot spot problems; and (b) when the shading object is a certain distance from the cell then the shading effect is negligible [44].

With such a non-optimal sub-construction Hanwha Q CELLS reached still very good yearly bifacial gains as summarised in Figure 7 (b).

Fixed-tilt systems

We have seen in the previous paragraphs that even in the non-optimal cases high bifacial gains can still be obtained. However, in order to reach the highest possible energy yield the sub-constructions need to be optimised for bifacial use. Figure 8 shows two very nice examples where specially designed sub-constructions were used for bifacial applications. There are already a couple of large companies that are offering adapted products standardly – such as Arctech Solar [46].

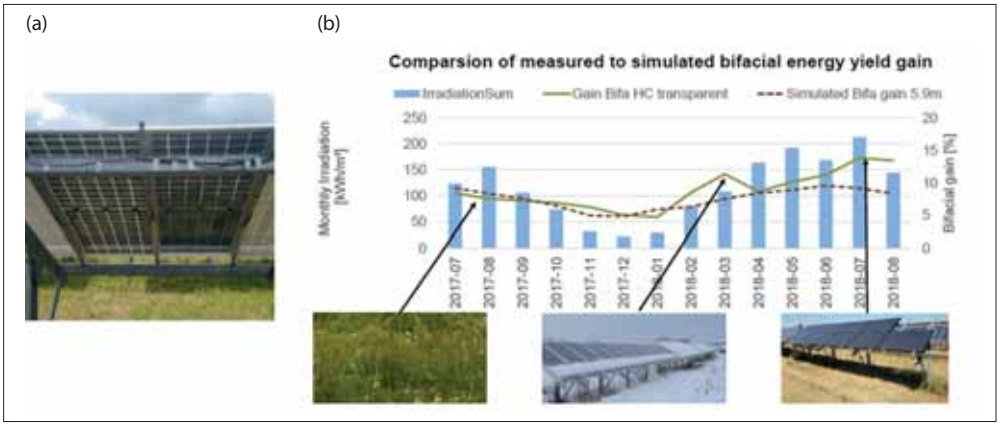


Fig. 7: Hanwha Q-cell's (a) sub-construction and (b) a graph of monthly bifacial gains in that bifacial PV system [44]. Note: this non-optimal standard sub construction was used on purpose to demonstrate that even in this case bifacial gains of 9% in average were obtained.

Tracking systems

In the meantime there are many bifacial tracking systems out there that are optimised for bifacial use. The reason is that many large electrical companies such as EDF, TOTAL, Engie, SPIC and many others realised that in order to reach lowest LCOEs in desert regions bifacial HSAT is the best solution. On the other hand it is very simple to design an optimal solution in the case of trackers.

Standard single module trackers [47] are not particularly optimal for bifacial applications when the bar is covering the rear side close to the module (but acceptable for lower bifacial gain). But many tracker manufacturers such as Soltec [48], Arctech Solar [46] and NEXTracker [49] are putting two modules right and left in a distance from the rotating axis - in landscape or in portrait. In January 2019 NEXTracker revealed that it is currently setting up more than 750MWp bifacial 1V HSAT systems in the US. In some of these systems, advanced half-cut-cell modules are used where the junction boxes are in the middle of the module. This clever configuration helps to reduce the bifacial losses and maximises the power output of the system.

Landscape or portrait have both their advantages and disadvantages but it seems that the portrait technology is going to win due to an easier clamping technology as well as a higher mounting density for the modules. The distances and dimensions as shown in Figure 8 and 9 are important to be optimised in order to achieve maximum energy yield by also considering the material consumption. As said, the most popular installation for bifacial HSAT is the portrait geometry, which is also seen in the picture of Figure 9 (a). However, these systems have to be more robust, as for example 1V systems, due to possible wind loads. Typical numbers in that case are d_{1min} =60cm, d_2=200cm, d_3=10-30cm and d_4=0-30cm. In order to minimise all the losses and to get a deeper understanding of all effects including soiling of bifacial systems many test sites have been launched lately. For example Soltec has established an evaluation centre in the US. In addition Chile is granting a bifacial module and system institute for desert PV

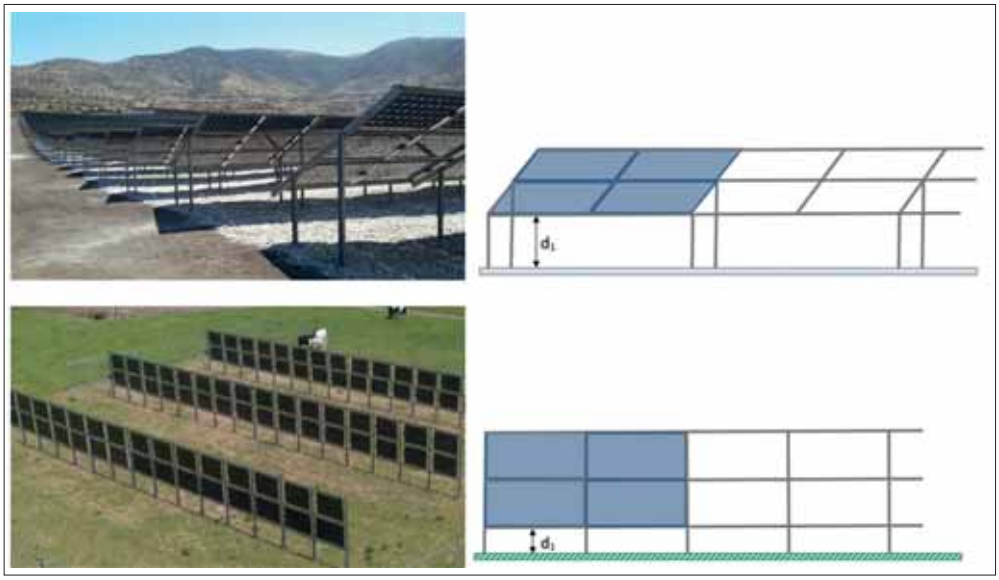


Figure 8. (top) La Hormiga close to San Felipe in Chile and (bottom) vertical bifacial PV system testing site in Losheim am See in Germany

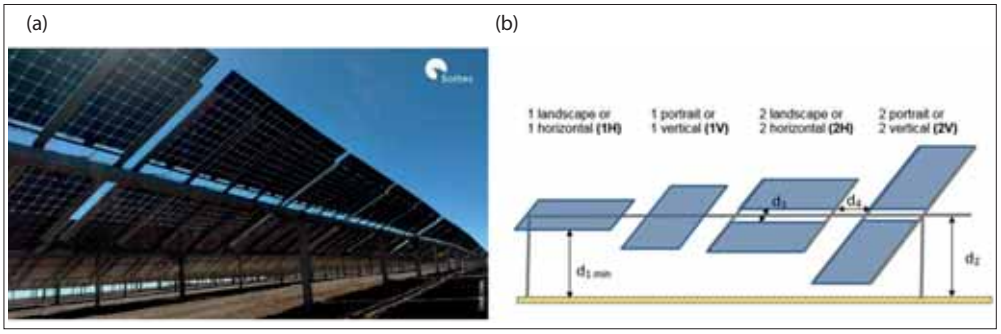


Figure 9. (a) Tracking system from Soltec in La Silla in Chile and (b) and possible configuration of modules on horizontal single-axis trackers

applications – AtaMoS-TeC [50].

In order to reach bifacial gains between 20% and 30% the reflectance of the ground has in most cases to be conditioned as described in the following section.

Energy yield enhancement by improving the ground surface properties

The ground reflectance is described by a factor called albedo, which is defined as the ratio between the power of the reflected and the total incoming light. The albedo of the ground underneath the modules of a PV system is of upmost importance with regard to the ground reflected rear irradiance, which can be calculated by:

$$E_{ref,rear} = \rho \times GHI \times F_{ns} + \rho \times DHI \times F_s \quad (1)$$

with ρ being the albedo of the ground surface, GHI, the global horizontal irradiance, DHI, the diffuse horizontal irradiance and F_{ns} the view factor from non-shaded, F_s from shaded areas respectively [51]. The rear irradiance of a bifacial module over time is, in turn, decisive for the energy yield of the bifacial PV system and the bifacial gain defined by

$$BG(\%) = \frac{eb - em}{em} \cdot 100 \quad (2)$$

With e_b and e_m being the normalized energy yield in kWh/kWp (nominal operating hours) of a bifacial and monofacial PV system respectively.

The higher the albedo and the rear side efficiency of the bifacial module, the higher is the potential bifacial gain of a PV system. However, it has to be noticed, that the energy yield of bifacial systems is also dependent on a variety of additional factors, such as ground cover ratio, installation height of the modules and tilt angle. The factors also show interdependencies, so there may be different optimum tilt angles for different installation heights. Nevertheless, it is clear, that the albedo has a decisive role for the bifacial gain of a PV system.

The albedo is strongly dependent on the ground surface properties. Green grass for example exhibits an albedo of about 0.2, whereas the albedo of snow ranges between 0.6 and 0.9. In order to enhance the ground reflectivity, material with high albedo, for instance white stones, sand or special reflecting plants can be chosen.

Summarising reflectance properties in a single, constant factor is of course a simplification. The reflectance of the ground depends on the angle of vision [52], except for a perfectly diffuse reflector. In addition, the reflection is dependent on the wavelength [53, 54, 55]. Both effects have an influence on the rear side irradiance of bifacial modules in PV systems. There may also be varying albedo factors due to seasonal changes, for instance from soil to snow, or ageing effects.

Numerous approaches to improve the rear side irradiance artificially have been realised. At the PV power plant "La Hormiga", for instance, white quartz sand was used in order to improve the albedo of the ground (see Figure 8 top). Tempress in the Netherlands (Figure 10) chose the same approach [56].

Another way of improving the rear side irradiance of bifacial modules is to mount them on flat roofs covered with highly reflecting foil or paint. Special reflecting roof sealing foils are available for instance from the companies Sika and Kemperol. An example of an installation with roofing foil is shown in Figure 4 (a).

The installation of bifacial systems on roof tops is a trade-off between maximum installed peak power and nominal operation hours of the system. In most of the cases, rooftops were covered with modules at a low tilt angle in the range of 5 to 15 degrees, resulting in a ground cover ratio (GCR) of 80-95% depending on the specific design of the PV system. Low tilt angles and high GCR values, however, are not favourable for achieving high bifacial gains because in that case the ground is self-shaded by the modules.

Combining green roofs using highly reflecting plants in combination with vertically installed PV modules is an option to combine an energy-generating roof and water retention in urban areas [43]. The vertical installation enables a considerably improved accessibility, reduced maintenance effort and the realization of real green roofs instead of largely covered areas, as shown in figures 4b and 11. Choosing plants with reflective, silvery leaves may enhance the ground reflectivity (Figure 11); these types of plants are also more resilient to extreme sun exposure as typically found on flat roofs.

In future bifacial PV systems also specifically formed cheap reflectors could be realised, leading to a further enhancement of the light concentration on the collector [52, 57].

Inverters

The most obvious factor concerning the inverter of bifacial systems compared to standard, monofacial ones, is the increased current and power of bifacial modules. This affects the availability of suitable inverters and causes an uncertainty in the system design. While there will soon be a new IEC-norm for measurement of bifacial modules [58], the actual increase of the current is still dependent on the albedo and the installation conditions (height, row distance and row width, tilt, shading by structure, latitude).

According to an estimation of the expected bifacial gain, the electrical components of the system (inverters, cables, protection devices, etc.) have to be dimensioned and selected. It is important to note that not only the maximum DC input tolerances need to be considered, but also less obvious factors such as the fuses which are implemented in the string inverters or DC combiner boxes. A too large fuse will leave the module unprotected while a prolonged small overload may result in heat generation and potential damage.

When the DC power produced by the PV array exceeds the maximum input level of the inverter, the inverter adjusts the direct current to reduce the DC power. This process is also referred to as clipping. Designers of bifacial systems will tend to select an inverter with a larger DC input current, based on the expected gain. Concerning the LCOE this can be detrimental if a more expensive inverter is chosen. Also manufacturers of inverters state in their system design guides [59, 60] that the typical annual clipping loss is in the range of a few percent, even if an inverter is chosen according to the STC-rated power, which means without considering the bifacial gain. The reason for this is the comparatively rare occurrence of conditions that actually lead to clipping. In contrary, the inverter can be operated at higher efficiencies most of the time [60].

Another characteristic of bifacial modules and systems is the impact of the more inhomogeneous rear side illumination. This is unavoidable and enhanced for low installation heights, steeper tilt angles and all factors which increase the rear side shading. Due to the inhomogeneity there is a mismatch and reduced efficiency at both module and system levels. As a result of the increased mismatch it is considerably more difficult to define an optimum common MPP for a system. Measures which consider these effects are inverters or optimisers at module level or central distributed inverter systems with multi MPP inputs.

In the meantime there are several products which are adapted for use in bifacial systems. Sineng Electric launched a central distributed PV inverter for bifacial solar modules [61]. The inverter is equipped with a MPPT combination box designed especially for bifacial modules, capable of supporting an increase in the maximum operating current up to 12.5 A. Huawei promotes its "FusionSolar Smart Solution" and upcoming string inverter multiple MPPT units [62]. The system also adopted a fuseless security protection solution. Another manufacturer of different inverter types for bifacial applications is the company Senergy [63]. Options at module level (optimisers, module inverters) are now also implemented in modules from Sunpreme (Tigo) [64], Panasonic (Enphase) [65] or offered by Solaredge [66].

Bifacial yield simulations and LCOE

In the same way as for standard (monofacial) modules, predicting with a good level of accuracy the expected yearly energy yield for a planned bifacial PV system is of paramount importance in order to determine the LCOE and therewith its profitability.

The prediction of the yearly energy yield of a bifacial PV system requires the calculation of the power output of each module of the PV array at each moment of the year. In order to perform this task it is necessary to model –

for each time stamp – based on meteorological data (global horizontal irradiance, diffuse irradiance data and ambient temperature) the front and rear side irradiance in the plane of array (POA) as well as the module temperature. In addition, it is necessary to establish an electrical model that allows the calculation of the electrical output of the module using the calculated POA irradiance and the module temperature as input values.

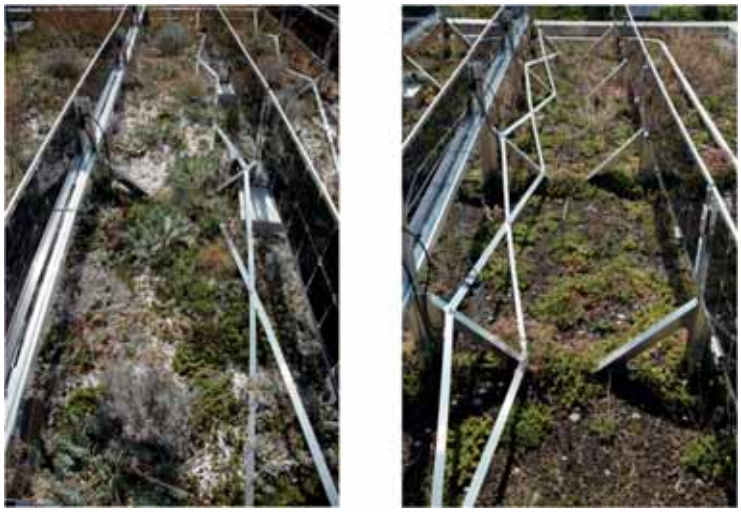
Compared to monofacial modules, the modelling of bifacial modules is more complex, mainly due to the fact that also the irradiance on the module rear side has to be calculated. The rear side irradiance is strongly influenced by the module installation height, the ground reflection coefficient (albedo), as well as by the distance between module rows. In addition, the diffuse irradiance fraction plays an important role, as most of the light incident on the module rear side is diffused light that is either reflected from the ground or scattered by the sky.

Early work showing the potential of bifacial PV [67] and dealing with the modelling of bifacial modules [68] has been performed in the late 20th century. In recent years, an increasing number of studies about the energy yield modelling of bifacial modules have been published [69–74]. The main challenge when modelling bifacial PV systems is the calculation of the rear POA irradiance. The main concepts used for this scope are view factors [75, 76] and ray tracing [77]. Regarding the modelling of module temperature, several approaches exist such as the so-called NOCT (normal operating conditions temperature) model [78, 79] used by ISC Konstanz bifacial simulation tool, MoBiDiG (modelling of distributed bifacial gain) [80], and the steady state mode as used e.g. by the commercial software PVSyst [81] and ECN's bifacial simulation tool [82] in its energy yield models.

In the following, an electrical model is needed in order to calculate for each time stamp of the considered time period (usually one year) the electrical output (Impp, Umpp) of a given bifacial module based on its I/V parameters measured at STC (under front as well as under rear side illumination) and based on the simulated module temperature and the modelled POA irradiance (front and rear) for the respective time stamp. Thereby one-diode models as well as two-diode models [72] are used by various authors (e.g. [72] and [83]). From this, the expected total energy yield can be easily calculated.

Source: Tempress, Amtech Group

Figure 10. Bifacial 400kWp system from Tempress with East/West orientation [26x]. The white gravel results in an albedo of 40%. Left picture: View from above; Right picture: View onto the back of the bifacial modules.



Source: T. Baumann

Figure 11: Silvery leaves (left) may enhance the ground reflectivity compared to standard plantings (right); this type of plants is also more resilient to extreme sun exposition as typically found on flat roofs [43]. Details from the Solarspar system shown in Figure 4 (b).

As for suitable applications and locations, this configuration has the potential to result in the lowest LCOE amongst all types of PV systems, in recent years, particular efforts have been made in modelling bifacial tracking systems – in particular horizontal single-axis tracking (see e.g. [84], [85], [86], [87])

Analysis of LCOE for bifacial systems

LCOE is a widely used metric that is obtained by dividing the complete cost for setting up and operating a PV system by the total electricity generated during the useful lifetime of the system:

$$LCOE = \frac{total\ life\ cycle\ cost\ [EURO]}{total\ lifetime\ electricity\ generation\ [kWh]}$$

Taking into account the fact that the present value of future payments (and revenues) has to be discounted (net present value) by a rate that is linked to the interest rates to be paid for bank loans and equity financing, and including the yearly expenses for operation and maintenance of the system, the LCOE can be expressed as (see details about the derivation e.g. in [88]):

$$LCOE = \sum_{t=1}^{N} \frac{(I_t + O_t)/(1+d)^t}{E_t/(1+d)^t}$$

With N being the system lifetime, It being the repayment for debt and equity in the year t, O_t the cost for operation and maintenance in the year t, E_t the energy produced by the system in year t and d being the discount rate.

Accordingly, as most of the input parameters, such as e.g. the solar irradiance as well as the financing conditions (discount rate), are subject to different levels of uncertainties, the result will be rather a range of possible LCOE values than one single value (a comprehensive study on this topic has been presented e.g.in [89]).

Figure 12 shows the summary of a set of LCOE calculations for a typical installation site in Southern Europe. These results show for example that assuming a price premium (based on total system cost) for the bifacial system of 10%, a bifacial gain of at least 10% is required in order to achieve the same LCOE as for the equivalent monofacial systems, while higher bifacial gains will lead to a lower LCOE for the bifacial system.

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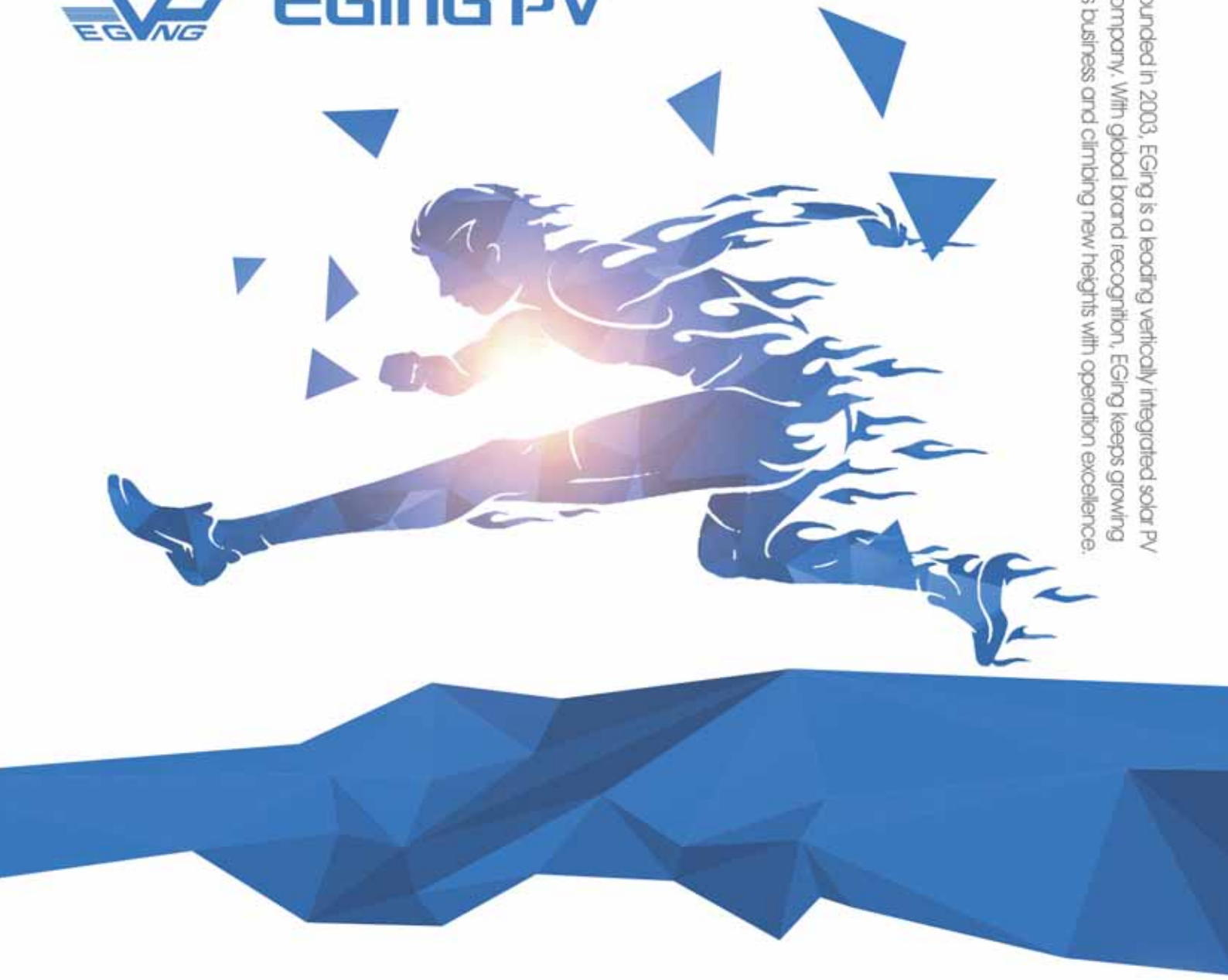

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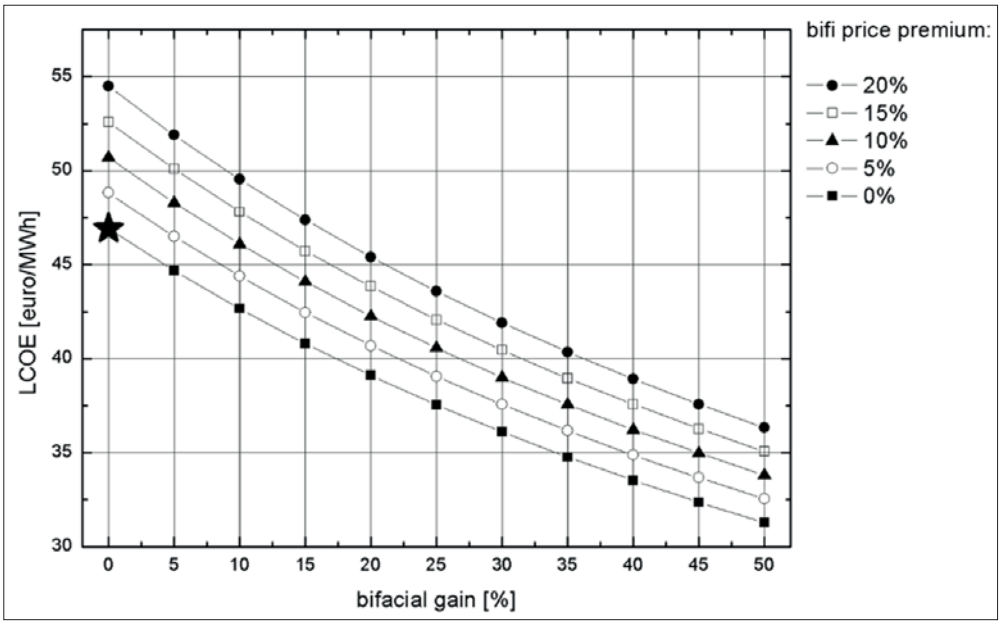

Figure 12. Results of LCOE calculations for a location where a monofacial fixed-tilt, utility-scale ground-mounted PV systems shows a yearly energy yield of 1,750kWh/kWp and the total system cost (including modules) of the monofacial system is €0.79/Wp. The resulting LCOE of the monofacial system is marked with a star. The percentage of the price premium for bifacial systems refers to the system cost and can be – at least partially – due to a higher module price. For all cases (monofacial and bifacial gain), a discount rate of 6% has been assumed. Figure from [82]

tool for LCOE calculations is included in the System Advisor Model (SAM), developed by National Renewable Energy Laboratory, Sandia National Laboratory and the US Department of Energy [90]. It allows for the implementation of the most important financial parameters

A detailed overview about modelling of bifacial PV modules can be found e.g. in [91] and in the related chapter of [40]. Many useful codes can be found in the library (PVlib) provided by the PV Performance Modelling Collaborative [92].

Summary

The LCOE of photovoltaics has been continuously reduced, mainly by lowering the specific cost of the PV modules. However, over time, these possibilities have been increasingly exhausted. Bifacial PV modules and systems are a means to overcome this limitation. Lowest LCOE values are obtained due to the additional energy yield from the module rear side.

Even though bifacial technology is not new, it has become increasingly attractive in the last couple of years. The early bifacial cell types were considerably more complex and expensive, compared to the monofacial industrial standard cell with Al-BSF. Currently however, more advanced cell types have transferred into industrial production; most of them enable a cost-effective realisation of a bifacial layout.

Other trends, such as the increasing share of glass/glass modules to improve durability are favourable for the implementation of bifacial systems as well.

While earlier bifacial modules and systems were quite similar to monofacial standard products, their design is increasingly adapted to bifacial technology. Corresponding module and system components, such as slender junction boxes, sub-constructions or inverters are available today. In addition, adapted installation concepts such as vertically mounted modules or horizontal single-axis tracking have turned out to be very effective, or enable innovative applications.

Even though the additional energy yield of bifacial compared to monofacial systems has been repeatedly demonstrated in numerous studies and projects, the still limited predictability of the energy yield is an obstacle for the bankability of bifacial PV systems. The more complex irradiation conditions at the rear side of the module do presently still not allow as reliable simulations and yield predictions as for monofacial modules. However, several groups are currently working on simulation tools for bifacial systems and studies that prove the prediction accuracy are increasingly published. Also another drawback – the lack of a clearly defined power rating procedure – has been successfully addressed; a corresponding norm was recently presented.

These measures will further promote the installed bifacial capacity and its market share that is constantly increasing. It can be expected that the yearly share of bifacial systems may reach 50% or 75GW in 2022. Lowest LCOE are possible with utility-scale, ground mounted bifacial systems, particularly when realised with horizontal single-axis tracking. Such systems can reach up to 50% more power compared to classical, fixed-tilt monofacial equivalents. This enables the lowest LCOEs that are possible today with PV, as proposed by EDF/Masdar in the lowest bid of all times with 1.78 US cents per kWh. Also, the size of realised systems is increasing, with a recently announced bifacial HSAT system, 400MW by Scatec Solar in Egypt, being the largest one in construction today. ■

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Halting desertification in the Sahel with solar power

Africa | Solar power is at the heart of an ambitious plan to tackle environmental degradation and poverty in the Sahel region. Tom Kenning reports on a programme that, if successful, could bring a multitude of environmental and economic benefits to a fragile part of the world

Life in the Sahel, a semi-arid region of Africa stretching from the Atlantic Ocean to the Red Sea, is at threat from persistent degradation of land as the increasing population inflicts ever-greater pressure on resources. According to Sweden-based think tank, Eden Foundation, which has been active in the Sahel for 30 years:

"Desertification is a man-induced process that leads to soil nutrient depletion and reduction of biological productivity. In the Sahel slashing and burning of natural forest and bushland in order to clear land for annual agriculture is the main cause of this destruction. Farmers continue to degrade their environment in the agricultural zone even after the decimation of perennials [trees, shrubs and plants which flower reliably every year]."

The idea that the Sahara Desert has been descending south across the Sahel over time caught the imagination of certain leaders more than a decade ago and led to a plan to build a giant blockade of trees – the 'Great Green Wall' – running across the southern edge of the desert from Senegal in the west, to Djibouti in the east.

Dismissed by some as simplistic, the Great Green Wall idea and its emphasis on planting and preserving trees and vegetation rather than cutting them down is nonetheless a key aspect of plans to safeguard the future of the Sahel region. Offshoots of the project that also focus on planting trees are seen as a chance to mitigate the worst impacts of climate change, to counter potential drought and reduce the chance of conflict over dwindling natural resources. They are even touted as a chance to create employment opportunities that could reduce the cavities left by swathes of youth emigration.

However, a widespread lack of access to electricity has meant that trees are also a primary source of fuel for many local people. This paradox means that tree preservation efforts are fighting an uphill struggle against the human consumption of wood for essential day-to-day living. While rural areas demand firewood, the cities of West Africa are hungry for charcoal.

Credit: United Nations Climate Change

Off-grid solar is a key element of the African Development Bank's 10GW solar plan for the Sahel region

"That's huge," says Tappan. "It is really hitting the remaining woodlands and tree savannahs of West Africa; it's really hitting them hard."

The 'Great Charcoal Wall'

Thus, if the people of the Sahel are not given access to renewable energy sources, then the figurative great wall of trees could be transformed into a literal 'Great Charcoal Wall', as the president of one bank is reported to have quipped.

Michael Keating, executive director of the European Institute of Peace, and former UN Special Representative of the Secretary-General for Somalia, a country at the far eastern end of the Sahel, says that the main sources of energy for most of the population are biomass, wood and charcoal, all of which are problematic for different reasons.

"Biomass, a combination of environmental degradation and climate change in a country which is still primarily nomadic and agricultural is a disaster, and it means that there is more competition for natural resources and that is contributing to conflict," adds Keating. "Charcoal has also become a source of income in illicit economic activity. Al-Shabaab, the jihadist group, is using revenues from charcoal to finance itself so that is a problem."

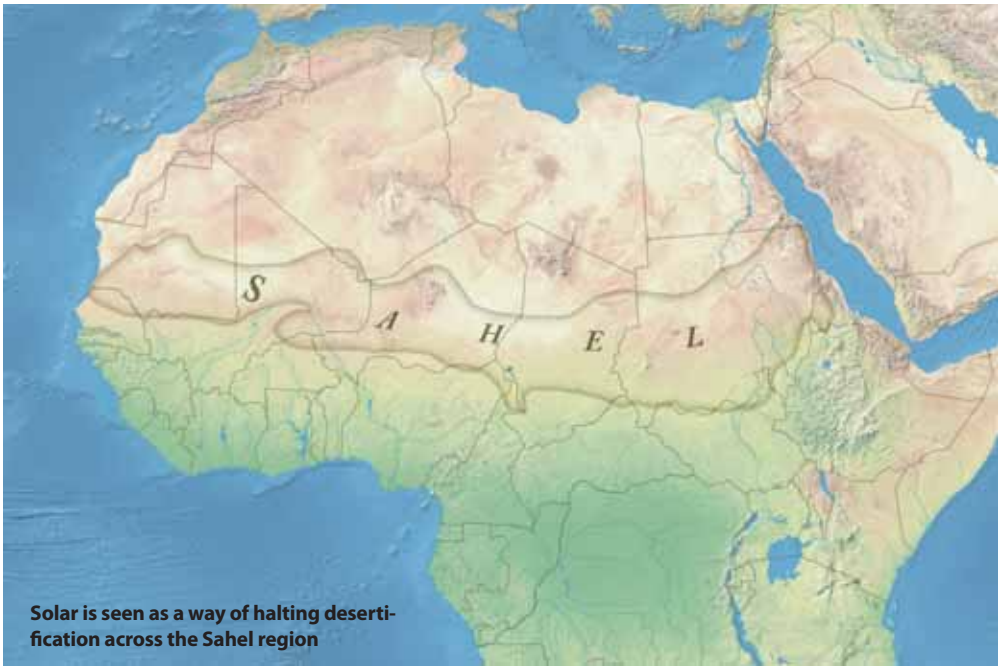
Keating says that although clean energy has not yet been proven to contribute to peace and reconciliation, his instinct suggests that it does. Meanwhile, local attitudes have also been favourable to the adoption of solar.

"Everybody is up for it," says Keating. "There is nothing negative about it. The sky is the limit."

'Desert to Power'

The threat of a 'Charcoal Wall' is partly why in January this year, the African Development Bank (AfDB) conceived of a huge electrification plan across the Sahel region, targeting a mammoth 10GW of solar capacity by 2020 that it claims could provide power to 250 million people and reduce deforestation driven by fuel poverty. The so-called 'Desert to Power' programme, which uses a combination of grid-connected and off-grid solar photovoltaic (PV) technology, would see AfDB support renewable energy proliferation in Sahel countries that until now have either lacked regulation and policy drivers or suffered from a chronic lack of willing financiers. The bank is still coordinating how to procure and deliver this technology deployment but is eyeing a mix of public and private routes, delivered either through state-run utilities or international developers.

William Fiebig, an independent consultant in climate-smart agriculture, who has



Credit: Munion, Natural Earth Data – Commons Wikimedia

Solar is seen as a way of halting desertification across the Sahel region

worked with 186 communities across seven African countries, also says that solar has the power to "transform the rural economy" and offer improvements in education, agriculture and access to journalism that otherwise wouldn't be possible. Meanwhile, the increasing desertification of the region has become an unnerving driver for such action.

Fiebig and other organisations with lengthy experience in agricultural practices of the region warn that it is critical to define the precise applications of any solar power systems before touting any supposed benefits for the local communities.

Not everyone is convinced that solar energy can significantly improve living standards in the Sahel in the way it has been imagined. For example, Staffan Göranson, chairman of the board at Eden Foundation, says that to date he has not seen the translation of deployment of various solar products into added well-being for the poorest sections of society, particularly where sourcing food is the absolute priority. When it comes to solar-power irrigation pumps, he acknowledges that solar is probably the most suitable energy technology, but he has serious concerns about the effects of irrigation on groundwater levels in a region of such delicate water supply as the Sahel. For Göranson, more effective action can be taken with various seed programmes, that take some time to literally bear fruit, but which can also see trees providing food to people even in a year with minimal rainfall, he claims.

Some have also warned of the potential for the wealthier locals to take most of the benefits of solar with less urgent frills such as improved air conditioning, perhaps to the disregard of the poorest farmers whose absolute priority is often food not power, particularly in the Sahel. However, rapid advancement in solar technology and reduced costs have to be considered and as Keating has mentioned, replacing fossil fuels with clean energy could be a key factor in reducing conflict and even extremism in the region.

World's 'largest' solar power system zone

AfDB's vision for 10GW of solar would, in any case, impact most echelons of society. The off-grid solar targets, which tend to focus on remote rural areas, are only a part of its grander strategy, which also includes large, utility-scale solar plants to power towns and cities. The bank aims to tackle traditional African development problems through public funding and dialogues with central governments, says Ousseynou Nakoulima, who as director of Renewable Energy and Energy Efficiency at AfDB, is in the process of sending teams out to select countries to assess their readiness and potential for solar deployment.

Credit:

The Green Climate Fund and the Africa50 investment fund are collaborating with the AfDB on the programme

"Everything that I'm saying in this conversation is about achieving speed and scale," adds Nakoulima. "Because so far if you look in the past into this sector, things have been done in a very isolated and a very protracted way."

The countries being considered at present are: (from west to east) Mauritania, Senegal, Mali, Burkina Faso, Niger, Nigeria, Chad, Ethiopia, Eritrea, Sudan and Djibouti. All the countries are well-endowed with high levels of solar irradiation and the worldwide price reductions in solar PV equipment mean the time is ripe for kick-starting PV across Africa, not just in the Sahel. A 20MW utility-scale project was completed by a Chinese firm named BXC in Ghana two years ago at a time when most sub-Saharan Africa solar plans were nothing more than ideas held up in early stages of development, without finance, without PPA signings and without any flagship projects to learn from. That's all changed in the last year with significant-sized projects announced for many sub-Saharan African countries including a 50MW project in Burkina Faso that was backed by AfDB.

A major boost to the bank's Sahel plan also came in late May when the Green Climate Fund (GCF) and the Africa50 investment fund announced they would be collaborating with AfDB to share ideas and resources on this 'Desert to Power' programme.

The AfDB has said that it expects its Sahel projects to become the 'largest solar power system zone in the world' once completed. Individual projects are unlikely to match up to the 2-5GW solar parks rising up locations like India, Egypt and the UAE, but the breadth of geography AfDB wants to cover makes fulfilling the Desert to Power vision a grand task in itself.

The method

The 10GW goal is designed to create an order of magnitude or sense of potential in the region that would trigger a number of benefits such as creating a sizeable market for solar manufacturers, project developers and investors. However, while contemplating the task at hand and

hoping to build momentum, Nakoulima is keen to maintain a sense of realism:

"How do you eat an elephant? It's just one bite at a time."

Understanding political dynamics in Africa is also pivotal, adds Nakoulima. Even though there is some level of integration at the sub-regional level, countries are still very attached to their sovereignty, which means regional programmes cannot be carried out without addressing individual national priorities and circumstances.

Burkina Faso's political will

When AfDB first tested the water by entering Burkina Faso in partnership with French development bank Agence Francaise de Développement (AFD), under its 'Yeleen Programme', the bank was pleasantly surprised to find strong and organic political will to harness solar for the development of the country.

The financier's actions in Burkina Faso then formed the blueprint for how it would assess each country henceforth. This included evaluating the current political and economic environment, accounting for both long- and short-term ambitions and then immediately attempting to drive solar investment.

Having assessed the state of Burkina Faso's electricity grid, the bank decided to plan 1GW of solar PV capacity even though the present grid could not absorb that level of additional power. This approach came with good reason. Waiting for grid improvements before deploying solar could delay projects by three to four years, so AfDB aims to deploy solar in small increments straight away, starting with 50MW in the first phase and an additional 50MW to follow quickly, while simultaneously backing transmission upgrade activities.

The first phase 50MW project will be developed in partnership with a local utility but at the same time the country is engaged with some private players to encourage private power projects, says Nakoulima. As part of the project financing, the bank is also supporting the North Dorsal electrification project, a plan to connect Burkina Faso with Nigeria, Niger and Benin. This is a clear example of promoting solar with simultaneous work on grid capacity and power distribution.

Adiaratou Bah, principal investment officer at AfDB and coordinator of the 'Desert to Power' scheme, says the Yeleen Programme aims to increase supply and energy independence, lower the cost of energy and reduce greenhouse gas emissions through three components, namely:

1. Development of grid-connected PV plants (one large 40MW plant and six small 1-2MW plants);
2. Strengthening the electricity transmission network, by introducing electricity storage, energy control centres and developing the distribution network. The bank is also mobilising funds from the European Union to address these grid constraint barriers;
3. Rural electrification using mini-grids and individual pay-as-you-go (PAYG) solar systems.

In total the fast-track phase of the Yeleen programme aims at developing 70MW of electricity through solar PV plants on-grid and off-grid.

The AfDB also has primary responsibility for Yeleen's rural electrification component that aims to electrify 50,000 households and adjacent community infrastructure in schools, health centres and community water pumps, among other locations.

Megawatt by megawatt

Roadshows in other Sahel countries will facilitate dialogues between the bank and developers to help identify bottlenecks and to ascertain what developers perceive as a risk and vice versa. Elite teams have already been sent on identification missions to Mauritania, Mali, Senegal, Chad and Niger, as a first step before launching programmes in these countries.

"What I don't want to do is have a theoretical programme and no megawatts on the count," says Nakoulima. "So the approach we adopted: we build it from the ground up, we have a vision, but it's not about having a top-down approach where you build a very complex architecture and try to apply it to countries. No, it's conveying the vision, giving the signals to all players, but starting from the outset in each country megawatt by megawatt."

As a financier rather than developer, AfDB will be providing funding but, as process at a country level is a concern, it will also help governments to form procurement plans, such as tendering out capacity for public sector projects. The bank can then use its 'Africa legal support facility' to help review standard power purchase agreement (PPA) documents.

Credit: Flickr, Lance Cheung

The AfDB's intention is to avoid a 'top-down' approach and implement the programme megawatt by megawatt

Nakoulima says that once studies are approved and financing secured in Burkina Faso, then the country will launch a tender to have an EPC contractor come and develop the project, but AfDB and the government are still discussing the model they want to adopt.

Challenges

To date, adding capacity in any of these countries has been a tall order and Nakoulima repeats that projects currently being financed in Africa have often taken five years to develop. Nigeria, for example, which had multiple large-scale projects of greater than 40MW in size held up for several years, took until July 2016 to sign nearly 1GW worth of PPAs all in one go with 10 project developers.

"Understanding political dynamics in Africa is pivotal. Even though there is some level of integration at the sub-regional level, countries are still very attached to their sovereignty"

"Even if you put financing on the table, countries cannot absorb this financing because for instance the grid capacity is a challenge," says Nakoulima. "Secondly, the time tenders take to be finalised, even for an IPP it is quite daunting. So there are a number of hurdles and when we thought about this programme, we thought about really addressing first and foremost this challenge."

Another problem is risk perception and the difficulty of managing administration. Developers don't know which depart-

ments to approach in the various energy ministries and they often believe they need to see the country's president for action to be taken. For this reason, AfDB is trying to facilitate the necessary dialogue between public sector and private sector.

Hardest but counts the most

The big grid-connected projects always grab headlines, but in the context of tree-cutting and the supposed threat of the 'Green Wall' being turned to charcoal, AfDB's off-grid plan out in the remote rural areas will need a similar level of focus. Nakoulima readily admits that these off-grid projects are "the most difficult part of the equation".

It's too early to say just how much budgeting will go towards this segment, but initial estimates suggest that at least 90 million people could be reached by off-grid PV systems. Low incomes in these countries mean that special payment methods must be devised to make solar accessible to the poorest sections of society. Uptake of solar has traditionally been barred by the high upfront costs of a PV installation, but pay-as-you-go (PAYG) and third-party ownership models have helped to alleviate this problem.

"It's a question of access and what kind of credit plan can you provide," says Fiebig. "I've seen it work in seeds. That's why I say if the technology is there and when improved varieties and seeds of those varieties become available, farmers and smallholders will find a way to purchase them and believe me if they can get a solar panel to put on their grass hut so they can have a light bulb in the evenings for their kids to be able to do some homework... they'll figure out how to use it."

AfDB is itself testing a few of these payment models before it puts its full weight into the off-grid programmes. A specific model will be defined for each country and project, usually through mobile phone operators. It has experience helping countries develop green mini-grid policies combined with helpdesks and assessments of market potential. It has also backed solar home systems in Togo, a West African country that lies outside the Sahel belt, through its 'Cizo' scheme.

Social impact

When describing the key goals of the 10GW target, Nakoulima is confident that several social issues stemming from a lack of in-country development can be mitigated by solar power, particularly in rural areas where economic activity is stunted by poor access to electricity and compounded by a widening sinkhole of emigration.

A key goal on the off-grid solar side is mitigating the impacts of climate change, because these countries have witnessed a steady change in rainfall patterns over recent years and to remain self-sustained in terms of food and agriculture, farmers will have to adapt.

"If they cannot rely entirely on rainfall, you need to develop irrigation, which needs power. And if you think about power, the easiest way is solar PV," says Nakoulima. "So all these combined give a strong rationale for us to devote enough effort and resources to this key enabler, which is deploying solar generation in these countries."

Combined with solar deployment, education is also required to spread good practice in farming. For example, Fiebig has travelled Africa encouraging farmers to grow crops that are more resilient to the increasingly unpredictable and extreme weather phenomena that are set to come hand-in-hand with climate change. Reliance on individual cash crops such as maize in Western Africa, for example, leaves farmers more exposed to higher temperatures and flooding, while higher carbon dioxide levels can also impact nutrient levels in many staple foods. The focus has to shift from cash crop to climate-smart agriculture.

> "A key goal on the off-grid solar side is mitigating the impacts of climate change, because these countries have witnessed a steady change in rainfall patterns over recent years and to remain self-sustained in food and agriculture will have to adapt"

Göranson is concerned specifically about irrigation, which he says can increase salinity at the surface of the farmland making it increasingly hard to grow food as time goes on, while in extreme cases irrigation could even empty the waterboard.

"Power for irrigation is totally wrong in my eyes," he says. "I think it's a bluff. It doesn't work. You can drill the wells but you will take away the groundwater if you do that in a large-scale. There's a huge risk on that. We believe that if they can grow trees that give food, it will motivate them - we have proven it for 30 years. I am not against [solar] in itself, but for the poor farmers it's no help."

Göranson cites Niger as an example where the unemployment rate is 70% and he does not see how solar can benefit this section of society. He also looks back on 20 years of what he describes as undelivered promises in the region from a range of technologies and vendors, but not just solar PV.

In response to concerns that solar power for irrigation in the Sahel region may cause long-term salination of the topsoil and seriously affect groundwater levels, AfDB's Adiaratou Bah claims that the Bank has a strong due diligence process whereby each project to be supported and financed by the Bank must be duly analysed by the project teams including technical, legal, financial and any other required expertise – adding: "Thus any project undertaking solar power for irrigation, supported or financed by the Bank, will have to be cleared by the relevant expert for that sector.

Meanwhile, in contrast to Göranson, Nakoulima claims that many people are suffering from malnutrition in the Sahel partly as a result of energy insecurity, so he says every dollar spent on off-grid solar can improve people's lives, and certainly in an even more impactful way than many utility-scale solar projects.

"Even though urban areas are growing in terms of population, rural areas are still very populated and you have very few successful business models that work," adds Nakoulima. "So one part of our mini-grid programme is to see how we can combine investment in energy and investment in agriculture so that we can induce a positive feedback loop."

Fiebig also believes that Africa is ready for solar, with its potential to transform rural economies and especially when it addresses community access to solar pumps for potable drinking water. Ultimately, it depends largely on whether the policymakers are on board and this is where the ambitious Desert to Power programme, with the AfDB's financial clout, could make a difference. ■

Africa large-scale solar update

The African Development Bank's plans for the Sahel reflect the extent to which solar is emerging across the continent more broadly as a key future energy source. After many years reporting in the pages of this journal on proposed sub-Saharan Africa projects that in time have failed to amount to more than the initial PR they generated, headlines these days are more frequently related to projects achieving financial close, entering construction and even reaching completion.

As with the AfDB's Desert to Power programme, the principal driver behind solar's deepening significance across Africa is its steadily improving economics. In the past two to three years, solar tenders around the globe have hit some stunningly low prices as equipment and capital costs have fallen. With some help from players such as the World Bank subsidiary the International Finance Corporation (IFC), sub-Saharan Africa has benefited from this wider trend, to the extent that solar has become a viable competitor in many parts of the continent.

Aside from South Africa, which has recently revived its renewable energy procurement programme that gave it an early lead but which later stalled, other notable players include Zambia. The southern African country is one of the early beneficiaries of the IFC's Scaling Solar initiative, which aims to support countries looking to develop solar by helping create the right conditions for private investors to come in and develop projects. Zambia's first two projects – respectively a 54MW project developed by France's Neoen and a 34MW project by Italy's Enel Green Power – are under construction and slated for completion this year, while a second, 500MW round of Scaling Solar projects has been agreed between Zambian authorities and the IFC.

Elsewhere, Madagascar, Ethiopia and Senegal are also benefiting from the Scaling Solar programme. The latter took some significant steps forward in 2018 when, towards the end of the year, two Scaling Solar projects totalling 60MW attained commercial close. Separately, Senegalese authorities have also invited bids for up to 100MW more grid-connected PV. Outside of Scaling Solar, other sub-Saharan African countries with projects now under construction or in the ground include Ghana, Mali, Burkina Faso, Uganda and Rwanda, to name just a few.

When posing the question of whether the steady trickle of utility solar projects now appearing in Africa will develop into a torrent, one big factor to consider is that as things stand, the capacity of national grids to absorb large volumes of any new generation capacity, not just solar, is still extremely limited in many countries. But with programmes such as the West African interconnection project outlined in the main article, national-level transmission upgrade activities and the steadily improving economics of combining solar with storage as a means of enhancing grid stability, this situation should not been seen as an insurmountable barrier to the future roll-out of large-scale PV in Africa.

Ben Willis

Credit: Access Power

Sub-Saharan Africa has begun to realise its huge solar potential through large-scale projects

Land of the rising shadows

Japan | At the end of 2018 the Japanese government caught solar developers by surprise with a raft of punitive regulatory changes. Tom Kenning reports on the short- and long-term impacts these could have on the country's PV industry

Credit: Sonnedix Japan

Renowned as a stalwart in stable policy making, Japan gave its solar industry the shock of its life towards the end of 2018. Having divvied out projects with some of the most generous feed-in tariff (FiT) subsidies seen across the globe starting in 2012, many winning developers had been happily biding their time as they navigated the traditional Japanese PV struggles of land acquisition and transmission. Alas, last November the government decided it had done enough waiting and took decisive and shocking action with its threat of cutting those existing subsidies, much to the anger of developers.

Nobody can predict how much contracted capacity will be junked by the regulatory change, but the expectations are that it will number in the gigawatts. A sense of panic around the FiT changes, combined with a disappointing round of auctions, caused by a gap between government and industry expectations, particularly over ceiling prices, has cast a grey mood over the sector. Not helping brighten things is the fact that bankruptcies among solar companies reached an all-time high in 2018, according to one research firm. Yet, as ever, not everyone is set to miss out, with plenty of vulture-like opportunities to grab hold of flagging projects at cutthroat prices.

Granted, there has already been an industry-wide shift from utility-scale to residential rooftop and self-consumption models in Japan over several years and the ensuing focus on energy storage particularly as well as electric vehicles (EVs) is in progress. Nonetheless, opportunities for large-scale solar are far from over despite the sector's current predicament, as the country continues its push for alternative energy sources in the wake of 2011 Fukushima disaster.

FiT shock

Last November's FiT announcement by the Ministry of Economy, Trade and Industry (METI) angered power producers and investors, who said the cuts would undermine their projects' profitability and violate earlier agreements. Previously, project rights holders with FiTs were allowed to keep those projects for as long as they desired, but METI mandated PV projects that had been granted permits between 2012 and 2014, under the FiT scheme, to submit applications to connect to the grid by March 2019. Players that fail to meet the deadline would have their tariffs cut by up to half from JPY32-40/kWh (US$0.29-0.36) to just JPY21/kWh (US$0.19).

The threat of reduced feed-in tariffs has added to a sense of gloom within Japan's solar industry

METI revealed that 23% of the capacity approved in 2012 was not yet operational, as well as 49% of the capacity awarded in 2013 and 59% from 2014. It also claimed that its move would be protecting consumers from higher costs of electricity, but the plan will no doubt result in legal disputes over what many have described as retroactive changes; reminiscent of, but not as destructive as those of the Spanish government in 2012.

In the aftermath of the announcement

and taking into account the pleas of the industry, METI decided to delay the deadline for projects of 2MW capacity or more to the end of September 2019, whilst also delaying the deadline for start of operations by six months to the end of September 2020. It also relaxed the rules so that projects that are already under construction would not be subject to the new regulation, significantly reducing the potential number of legal challenges.

"It's a very interesting moment, but it has really shocked and lots of people are panicking around the market here, especially the project rights holders with the higher tariffs," says Shinichi Kato, representative director and CEO, juwi Nippon Energy KK. METI jumped into the new rule, "retroactively damaging the rights holders" by threatening to cancel their rights without clarity on whether a project's construction had already started or was near completion, he adds.

For Kato, the government is so strong in its motivation to lower tariffs quickly that, given the cost being passed on to consumers, it is willing to press on despite the clear threat of legal challenges. Nonetheless, from the developers' point of view, the move is far too sudden and is extremely harmful, particularly to those who have already spent large amounts money on preparing permits or grid payments. Despite the relaxed rules, a number of in-development-stage projects, including some very large-scale projects of 50-200MW, will still find it difficult to proceed due to land or environmental issues, says Kato.

The rule that projects must be commissioned within one year of the grid connection permit or face a reduction of the FiT period is the real threat for Kato. It means that after the deadline, the longer the construction period takes, the shorter the FiT period is to be applied. Even rescued projects, that were expecting a three-year window, after another shock announcement from METI in April 2017, now face a one-year commissioning period; this while all in the face of classic Japanese headwinds such as requiring huge civil works to flatten land, building on mountains, or securing grid connection, all with high costs. Delayed projects may simply become economically unviable as a result says, Kato. Grid connections can be particularly time consuming and costly as the PV developers share the grid expansion with the utility, which all makes

Banks have become more cautious about providing loans for greenfield solar projects in Japan

Credit: Sonnedix Japan

projects not receiving the full 20-year FiT more likely.

"So 21 yen plus less than 20-year FiT price... almost all projects may not be economically viable anymore," Kato adds. "That's the reality."

However, Kato explains that rather than letting projects falter to zero value, an alternative option now is for affected developers to cash out by selling their in-development projects to new entrants who can come in and turn around a project's fortune, but price negotiations are likely to be very harsh.

"It's a new rule and it's really damaging, but on developers like ourselves who are newcomers here, we don't have any backlog or any projects already on our balance sheet," says Kato. "We try to capture any panicking sales guys with a deep discount negotiation and we try to pay as low an amount as possible to get the project rights cheaper because at the end of the day, the worst case, the 21 yen FiT, plus shorter FiT is really killing the project. That's why in order to be viable to revitalise the project, only a deep discount almost at dumping price is really making sense for us."

Given the new deadlines to receive the full FiT, time is of the essence and this means 100% cash equity purchases are more suitable than borrowing from banks right now, so as to speed up the financing process, adds Kato, who also claims that the market appeared as of early January to be already moving very fast in terms of projects rights holders trying sell.

"We have witnessed a reduction in players in the Japanese PV market as the FiT drops," says Kageyama Tomomichi, representative director of developer and asset manager Sonnedix Japan. "This has translated into short-term players assessing the Japanese market as less attractive, and therefore shifting to other sectors or technologies. Likewise, it has deterred other players for whom solar development is not their core business."

Sonnedix Japan currently has 14 projects in the country with a total capacity of nearly 500MW, of which nearly 200MW are under construction.

"The recently announced regulatory changes have added complexity especially to the development and financing of valid and well-managed projects. Even though we continue to meet our expected timescales to deliver these assets to completion, we believe that the change has increased uncertainty in the industry," adds Tomomichi.

Although it is understandable that the government wants to clear the slate in terms of project backlogs, Franck Constant, president of PV developer and investor, Constant Energy, notes that the rule changes were "quite harsh".

Debt dried up

The debt market in Japan for greenfield projects has all but ceased since the end of October, says Constant, so any projects that were about to get debt for start of construction were put on hold. The banks have been watching the rule changes closely before deciding what actions to take.

Japan has more than 60GW of solar deployed, with 20GW having rights to PPAs that are not yet built. Of this 20GW, Constant estimates that between 5-10GW

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(25-50%) of the projects could be killed, with many yet to secure land or forestry permits.

Kato says the debt has not dried up completely, but the banks are ceasing to process loan transactions, and there is a fairly aggressive attitude prevailing of turning down every request. As a result it may take some time for banks to start lending to the market again.

"The project finance base or non-recourse base is difficult, so 100% equity is definitely a winning game," he says, expecting what he describes as low quality and low credit players to be eliminated from the market.

Litigation chances

Data from private research firm Teikoku Databank has shown that bankruptcies among solar-power firms reached an all-time high in 2018. A total of 95 firms went bankrupt last year, up from 88 in 2017, 67 in 2016, 38 in 2015, 20 in 2014 and 16 in 2013. Teikoku said the upwards trend was likely to continue, driven by the woes of the FiT cut.

Offering a legal perspective on the fallout, Hajime Kanagawa, founder, Kanagawa International Law Office, says that after METI announced its plan and was targeted by many lobbying efforts from developers and financiers, who thoroughly opposed it, the ministry's response was very stubborn as it was under big pressure from the government and politicians. Kanagawa says that even though the industry felt the move was too harsh, METI itself had actually pushed back against the original plans suggested by politicians, so their new rule was more of a middle way.

METI's reasoning was clear: that project developers were sitting on high FiTs while enjoying the swift reduction in solar module prices. Meanwhile, non-operational projects that had secured grid connection were causing a suspension in the development of grid capacities in Japan. Nonetheless the larger projects require a much longer time to start construction and financiers could see few positives in the changes, leading to a high potential of legal challenges.

Despite METI's relaxation of the rules after a few weeks of intense pressure from industry and mass media, many market players still feel this provision is not sufficient, but to some extent the litigation order has been mitigated and several projects will be saved under the new grace period, says Kanagawa.

Discussing the prospects of under-development project acquisitions, he adds that this is a good chance to obtain a new project at a cheaper price.

"Of course they have to be very careful whether those projects can be feasible or not," Kanagawa says. "Timing is very, very tight. My view is that as a result of the introduction of this new rule, many market players will focus on the secondary market."

Auction angst

Three solar auctions have been conducted to date, with an original plan to secure between of 1-1.5GW in capacity. However, the auctions faced drawbacks.

The first auction in November 2017 saw just 140MW awarded out of the 500MW on offer, with an average tariff of JPY19.6/kWh (US$0.18).

The second auction, in September 2018 saw 197MW of awarded capacity out of 250MW available with a lowest bid of JPY16.47, but this was higher than the JPY15.50/kWh ceiling price put down by METI.

> "We have witnessed a reduction in players in the Japanese PV market as the FiT drops. This has translated into short-term players assessing the Japanese market as less attractive. Likewise, it has deterred other players for whom solar development is not their core business"

In the third, most recent auction in December 2018, another 196.6MW were awarded with an average price of JPY15.01/kWh (US$0.14) and a lowest of JPY14.25/kWh.

"Currently there is a gap between the government and the sector in terms of where the market actually resides and future expectations," says Tomomichi. "This is in terms of the bidding price and the process implemented (in terms of bonds and terms of withdrawal). All three rounds had a ceiling price (this figure was not disclosed for the last two), which is not necessarily in line with what the market sees today as a figure that economically makes sense for the Japanese market. This disparity resulted not only in the [lesser] amount of megawatts that were finally awarded but also in the number of bidders who withdrew from the process."

Sonnedix Japan has yet to participate for these reasons, but Tomomichi is confident that the government and the sector will find a common path ahead.

Despite the early disappointments in terms of trying to drive the price of solar down – the auction rates were higher than recent prices in parts of northern Europe – Kato thinks this model will eventually deliver the sought-after cost reductions.

Tomomichi is also optimistic that the Japanese government's priorities can be fulfilled while also reinforcing Japan's reputation for stability.

Some cause for hope

It was an unusual move from Japan because a lot of people were basing their investment on the steadiness of the regulation, compared to some southern European countries for example, says Constant. So regulatory risk perception has now increased in Japan. However, Spain's retroactive FiT changes back in 2012 were far more damaging and now developers are pouring back into Spain to invest in both wind and solar, with different corporate PPAs and going into the pool market, with different off-taker risk profiles.

"So it's unfortunate as there are still a lot of projects to be done, but it doesn't jeopardise the future of goals for renewable energy in Japan," adds Constant. "Japan will recover and there are a number of opportunities in decentralised solar development and storage in the future. Penetration of renewable energy will continue to increase and this creates all kinds of need for balancing tools, especially storage batteries, so I think there is still some bright future in Japan for deployment of solar, wind and battery storage."

Kato agrees that market expansion will slow down in the short term, but he has a less optimistic view in that he believes the METI move was about shifting the focus from solar onto other alternative energy sources such as wind and biomass, since the progress of overall solar deployment has actually been too fast rather than slow. Thus, the number of players in the market is likely to continue to decrease and competitive elements such as having EPC and O&M capabilities, as well as access to lower priced module makers, will become increasingly important. ■

Plugging the hole: How can solar fill UK nuclear's void?

UK | When Hitachi suspended development of its planned new nuclear power plant at Wylfa in early 2019, many thought the news would blow a hole in the country's decarbonisation plans. But as costs continue to fall, even the UK government, not usually considered to be renewables' closest ally, has pointed to the technologies' role in plugging that gap. Liam Stoker looks at what might be required

Credit: Horizon Nuclear Power

The UK has had something of a rocky relationship with new nuclear in the past few years, but developments in January 2019 pushed it firmly into 'it's complicated' territory, and sent the country scrambling for alternatives.

Horizon Nuclear Power, the Hitachi division response for the development of a new nuclear power station at Wylfa in Wales, ended months of speculation in January by confirming that it had indeed suspended the project's development. Falling just short of scrapping the programme altogether, Duncan Hawthorne, chief executive at Horizon, squared the decision solely at its difficulty in identifying financial partners.

"As a result we will be suspending the development of the Wylfa Newydd project, as well as work related to Oldbury [the company's other site in Gloucestershire], until a solution can be found. In the meantime we will take steps to reduce our presence but keep the option to resume development in future," Hawthorne said.

It was a decision which, according to Emma Pinchbeck, chief executive at Renwable UK, risked "blowing a hole" in the government's carbon reduction targets.

Of course, it's not the only time there's been a sense of fallout from new nuclear plans in the UK. The oft-derided Hinckley Point C saga has proven so controversial that the project can barely be mentioned in passing without attracting significant ire. Even the UK government's own spending watchdog, the National Audit Office, slammed its approach to pushing the plant over the line.

And, at £92.50 per megawatt hour (plus inflation, which sends the 2019 strike price to £99.87) you can perhaps understand why. That's the strike price the government agreed to when negotiating with EDF Energy over the 3.2GW plant which commenced construction last year. Hinkley Point C is indeed a landmark project, as it's one of the most expensive baseload energy generation projects on the planet.

The suspension of one of a new fleet of nuclear power stations in the UK has created a big opportunity for solar and wind

As the cost of intermittent renewables and battery storage technologies continue to fall, it's entirely within reason that questions are starting to be asked. And, now, it's the UK government asking them as well.

The new energy landscape

The UK's energy secretary Greg Clark was surprisingly candid when discussing the suspension of Wylfa, revealing how discussions with Hitachi had sought to progress in the months leading up to the decision. He stated how the government was prepared to take a one-third equity stake in the project, that it was willing to consider providing all of the required debt financing to complete construction and that it was to line up a contract for difference (CfD) to guarantee the project a price for its output in much the same vein as it did Hinkley Point C.

In short, the government was willing to bend over backwards to get Wylfa signed, sealed and delivered. And with good reason, ex-NextEnergy Capital MD and UK energy sector stalwart Abid Kazim, says: "There is a political will to build nuclear… because it buys votes. Hinkley Point C created 3,500 jobs in an area that swung from Labour liberal to Conservative. It's gerrymandering."

But, Clark revealed, any strike price for Wylfa was to be "no more [than] £75/MWh", indicating how the British government was, finally, expecting to see some kind of return on its support for the technology. Clark's insistence that he could not justify going above it "given the declining costs of alternative technologies" would suggest that the establishment's patience is wearing thin.

Renewables subsidies have been a

contentious topic in British politics since the Conservative Party swept to an election majority in 2015 and proceeded to swing a great green axe at renewables support mechanisms in the name of protecting consumer bills. The last of the country's solar subsidies are to close at the end of March 2019, heralding the dawn of the post-subsidy era. And, as contentious as they may have been, the cost reductions seen in solar and wind in the UK have been nothing short of remarkable.

That the UK government expected similar to happen in nuclear is open for debate, but Clark was steadfast in his opinion that the evolution of renewables had changed the energy landscape for good.

"We have also seen a strengthening in the pipeline of projects coming forward, meaning that renewable energy may now not just be cheap, but also readily available… Across the world, a combination of factors including tighter safety regulations has seen the cost of most new nuclear projects increase, as the cost of alternatives has fallen and the cost of construction has risen.

"This has made the challenge of attracting private finance into projects more difficult than ever, with investors favouring other technologies that are less capital-intensive upfront, quicker to build and less exposed to cost overruns," Clark said.

So with the UK government seemingly closing the door on expensive new nuclear plants and firmly opening it for much cheaper renewables, where does solar stand?

Reigniting deployment

The government shouldn't have to look far for advice. The Committee on Climate Change, the UK's climate watchdog, published a progress update last year that, amongst a raft of other issues, advised on the level of low-carbon generation required to meet the targets laid out in the government's carbon budgets, key pieces of legally binding legislation that map out the country's progress towards a low carbon economy.

Last year's progress update stated that should Hinkley Point C begin generating power on schedule – which in itself is open for debate – and no further new nuclear plants come on stream, then an additional 50-60TWh of low-carbon generation will be needed throughout the 2020s. With Wylfa's suspension, this looks like a job for wind and solar.

The UK's Energy and Climate Intelligence Unit (ECIU), a non-profit organisation that compiles research and analysis on energy matters, published a briefing to coincide with Wylfa's suspension that sought to demonstrate the role renewables could play in replacing it.

Key numbers

60TWh – The amount of new low-carbon generation required by 2030 in the UK

20% - The share of this that could be provided by solar PV, according to the ECIU

£50-65/MWh – The average LCOE of wind and solar PV in that bracket

15-33% - The expected discount on the cost of new nuclear

The ECIU assessment argues that a suite of renewables technologies – 80% provided by onshore and offshore wind, 20% by solar PV – would provide the same equivalent firm capacity as the prospective Moorside, Wylfa and Sizewell C nuclear stations at an average price of £50-65/MWh, including the cost of system balancing such intermittent generation would require.

> "Hinkley Point C created 3,500 jobs in an area that swung from Labour liberal to Conservative. It's gerrymandering"

System balancing and security of supply are often a stick to beat renewables with but, as BayWa r.e.'s Benedikt Ortmann suggests, experience from Germany would attest that it's a bit of a fallacy. "There's empirical evidence on this already. In Germany, always there's a discussion from the utilities that says, 'Oh, what happens if it's dark and the wind is not blowing, then the country will go bust'. But empirical data shows the opposite, that more renewable energy we add to the system, the more stable the system is," he says.

Should solar PV indeed look to fill 20% of that shortfall, it would equate to some 12TWh of power being required from new-build solar. Again, using CCC estimates, that would require an additional 13GW of solar capacity in the UK, essentially doubling what has already been energised on the country's rooftops and fields.

And, what's more, such an average price is representative of a 13-33% discount on the cost of new nuclear. So not only could new renewables replace Wylfa, but it could do so as much as one-third more cheaply while reigniting the UK's solar and onshore wind industries. If that's the case, then subsidies may begin to look like an increasingly good deal for the UK consumer.

Review the policy

Pinchbeck insists that renewables can step into the void, but those technologies cannot simply go it alone. "As the cheapest source of new power, onshore wind can make a major contribution to the UK's clean growth ambitions. We have a pipeline of shovel-ready onshore wind projects that can provide cheap power to consumers and help close the gap on our carbon targets and it's time government allowed onshore wind to compete on a level playing field, including letting projects compete for contracts for difference."

Pinchbeck is referring to the Conservative government's principled blocking of onshore wind developments, a manifesto promise that remains one of the very few consistencies in British politics of the last four years. As other articles in this magazine will attest (see p.50 for more information on how subsidy-free CfDs could stimulate UK solar deployment), the policy landscape in the UK is far from conducive to an extra 13GW of solar PV being connected in the next 11 years.

Lawrence Slade, the chief executive of utility trade association Energy UK, was however more measured, insisting it was disappointing to see work at Wylfa suspended. "It is important that low carbon, secure sources of generation, such as nuclear, can get the necessary investment to enable them to help meet the energy needs of consumers and our country over the coming decades. Therefore we urge the government to continue to work with the energy industry and investors to ensure projects like this can go ahead," he said.

As is so often the case, the UK market has come to serve as a microcosm for the global energy sector. A transition is occurring at great pace and, in early February, yet another coal plant was revealed to be closing early. With new nuclear projects falling by the wayside, new renewables will have to come to the fore.

And with just a little nudge from government, all the empirical evidence, analysis and statistics suggest that by 2030, the UK could have a generation sector fit for the future. ■

Turkey take the winding road to solar success

Market update | Turkey has around 5GW of installed solar capacity, but potential for much more. Ekin İnal and Chris Down explore the latest developments in Turkey's solar market and the regulatory reforms that could help PV take a much larger share of the country's energy mix

While it could be one of the world's leaders in solar power, Turkey has still not fully tapped its potential. It enjoys an average of 7.2 sunshine hours a day, almost two times that of Germany. However while Germany's installed capacity is over 40 gigawatts, Turkey only has 5GW of installed capacity. On the bright side, this untapped potential awaits domestic and foreign investors.

The Turkish solar market is traditionally divided into two segments. Licensed generation, which is done under a licence granted by the Energy Market Regulatory Authority (EMRA), applies to generation above 1MW of capacity. Generation below this capacity does not require a licence from EMRA and is also exempt from some other formalities such as establishing a legal entity in order to operate. Currently, almost the entire installed capacity comes from unlicensed generation.

For the last two years, the government has been taking action to promote solar power beyond the usual licensed-unlicensed dichotomy. The 1MW capacity threshold is still in place; however the two types of generation are being transformed. On the licensed front the government is attracting big players (developers, manufacturers) to large-scale solar power projects of 1GW (YEKA projects). On the other hand, unlicensed projects are getting smaller. A rooftop regulation was recently promulgated for installations of 10 kilowatt hours or less.

A brief look into the history of solar power

While solar power has been used for a long time for water heating purposes in Turkey, its use in power generation is relatively new. When the current feed-in rates were introduced to the Renewable Energy Law back in 2011, there came a huge interest for hydro and wind power investments.

Turkey has twice the solar potential of Germany, but only a fifth of the installed generation capacity

It was only in 2014 when Turkey started tapping its solar potential (with unlicensed generation installations).

In 2013, EMRA announced for the first time that it would start accepting applications for licensed solar generation. The applications were for a nation-wide capacity of 600MW as set out under the renewables legislation. EMRA received an enormous interest from investors: 9GW of applications for 600MW of installed capacity. This oversubscription meant that multiple investors applied for the same substation and, as a result, required the opening of a tender process to determine the winning investor. The first tender was held in May 2014. In these tenders launched by the state-owned electricity transmission company, TEİAŞ, investors who offered to give the highest "contribution fee" (an amount per megawatt of capacity) were granted the right to apply for the licence. In some cases, the fees were as high as approximately 3 million Turkish Liras (per megawatt) (approximately US$563,000). The price offered by the successful bidder needs to be paid within three years (at the latest) after the plant goes operational. Currently there are 12 licensed solar power plants with a total 82MW of installed capacity (out of 600MW) and 40MW more currently under construction. There are also 21 pre-licensed plants, including the YEKA project mentioned above. Each power generator (not only solar) is issued a preliminary licence during the pre-construction stage that will be replaced by a permanent licence at the beginning of construction.

Licensed renewable generators can benefit from the "renewable energy support mechanism" or "YEKDEM", introduced in 2011. This support mechanism encompasses feed-in tariffs and other incentives, including those granted for the use of domestically manufactured components. Power generators that wish to opt into the support mechanism for a particular year must apply to EMRA by October 31 of the preceding year. The support mechanism and the incentives thereunder will be applicable to those projects, which come online by 31 December 2020. Solar power plants are granted a feed-in tariff of US$133 per megawatt hour. In addition to feed-in rates, renewable energy legislation provides for incremental price incentives for generators that use certain domestically manufactured mechanical and electromechanical components in their facilities. Incentives for using domestic components are available for five years after a project commences operations. If a photovoltaic plant were to obtain the maximum amount of domestic component incentive (by employing all domestic components listed in the legislation) the total feed-in rate could be as high as US$200 per megawatt hour.

Unlicensed generation has moved at a much faster pace than the licensed generation. This is due to a creative interpretation of the unlicensed legislation. The legislation itself states that, as a general rule, power generated in an unlicensed facility must be used by the consumers to meet their own power needs and not primarily for trading. It allows them to sell only the excess power to the grid. Based on this general principle, investors moved

to set up multiple facilities (for instance 10 facilities each having an installed capacity of up to 1MW) within the same region with a view to selling the excess power to the grid. Normally a generator planning an installed capacity larger than 1MW would need to secure a licence from EMRA. The unlicensed legislation neither allowed nor prohibited this structure, and it could be implemented until legislative amendments in March 2016. These unlicensed facilities make up 99% of the total installed capacity.

Although exempt from a number of formalities, unlicensed facilities must still obtain approval from the distribution company in the relevant region for grid connection and system usage, and secure land use rights and environmental clearance. They can sell the excess power to the local distribution company at the applicable feed-in rate of US$133 per megawatt hour. The local component incentive no longer applies to unlicensed generation after a legislative amendment in 2016. They are also not allowed to enter into bilateral power purchase agreements (PPAs) to sell excess power.

Current state

As briefly explained above, Turkish solar power is exploring new ways of generation beyond the typical licensed-unlicensed categories. The licensed generation has been taken to a new level with the YEKA (renewable energy resource areas) investments. Legislation passed in October 2016 sets out the legal framework to streamline the process of allocation of publicly or privately-owned land for large-scale renewable energy projects. The first tender under this legislation was launched in March 2017 for a 1GW solar power plant in Karapınar Resource Area. The winning bidder undertook, in addition to the generation facility, to set up a solar cell and module manufacturing facility, and to conduct R&D activities. The tender started with a ceiling feed-in rate of US$80 per megawatt hour. The winning bid was US$69.9 per megawatt hour. The facility will sell electricity over this feed-in rate for a period of 15 years.

The government expressed its eagerness to continue with more YEKA projects and announced a second YEKA, this time covering three regions with a total capacity of 1GW. The ceiling feed-in rate was US$65 per megawatt hour and the power purchase agreement would have a term of 15 years. However this tender was cancelled in January 2019 two weeks before the deadline for bid submission, reportedly due to lack of interest. We expect this would give the authorities the opportunity to revisit the project conditions and re-launch a new tender, or tenders.

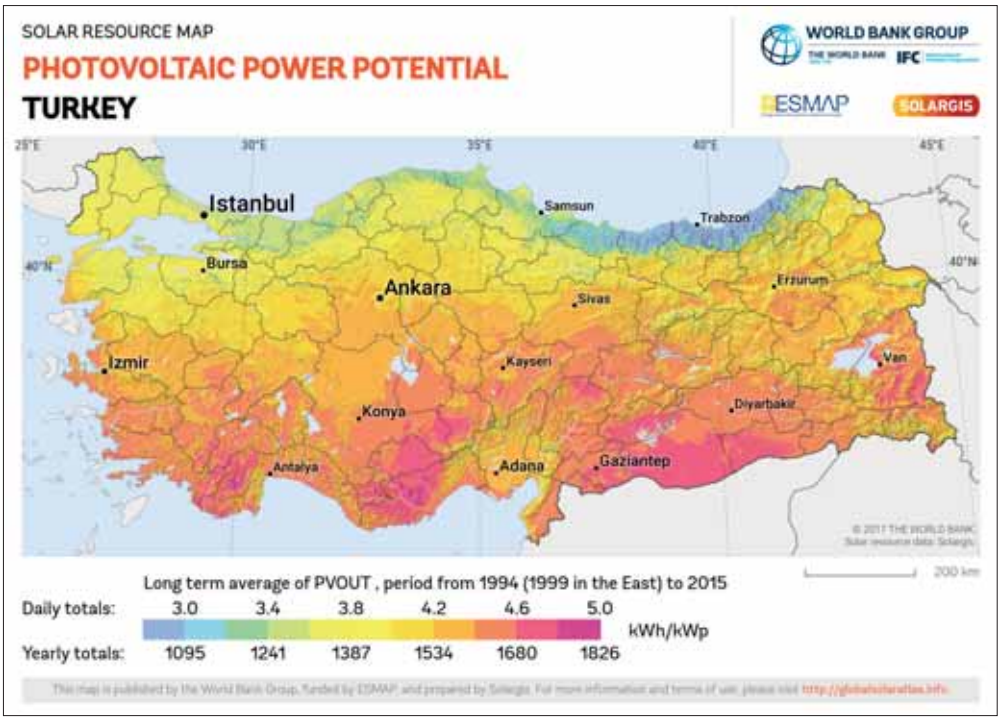
> "It is high time to benefit from what solar power has to offer. While solar power will help Turkey cut its hefty energy bill, protect environment and ensure supply security, it will also contribute to the advancement of a value-added manufacturing industry and job creation"

On the unlicensed front, efforts have focused on returning the unlicensed legislation back to its original purpose: production for self-consumption. Indeed, in March 2016, the legislation was amended to explicitly state that no legal entity or individual (including entities under their direct or indirect control) may have more than 1MW of unlicensed installed power capacity within a transformation station. Therefore, investors will no longer be able to establish separate special purpose vehicles, each holding a separate unlicensed project to be operational in a substation. Unlicensed generation facilities, which secured a call letter (letter issued by the local distribution company allowing the facility to connect to the grid) prior to 23 March 2016 (the date when the amendments became effective), are exempt from this restriction. There may still be room for investment in unlicensed projects if they hold call letters issued before March 2016.

A positive development has been the promulgation of new rules applicable to rooftop (and façade) installations of up to 10 kilowatt hours in January 2018. These rules aim to facilitate solar power installations for households. The application process is less burdensome and less costly compared to larger unlicensed generation facilities. The rules provide for an even simpler process for installations of up to 3 kilowatt hours. Excess energy generated from rooftop and façade installations may be also sold to the grid for a period of 10 years, however at the reduced tariffs announced by the government in June 2018 (and not at the applicable feed-in rate of US$133 per megawatt hour).

What does the future hold for Turkish solar?

Turkey is very much dependent on imported fossil fuels. From environmental concerns to issues around supply security, this constitutes a major point of concern for the government. As part of its strategic plans, the government promotes the use of more "domestic and renewable" energy resources. In that respect, it is high time to benefit from what solar power has to offer.



Credit: SolarGIS

Turkey's huge solar potential offers the country a chance to wean itself off imported fossil fuels

While solar power will help Turkey cut its hefty energy bill, protect environment and ensure supply security, it will also contribute to the advancement of a value-added manufacturing industry and job creation. Last but not least, the rooftop installations will pave the way for cheaper, decentralised power generation by households and businesses.

Investment costs of solar power have dropped significantly over the last years. While many sector representatives might have questioned the low solar prices a few years ago, the decreasing trend shows that these prices are in fact sustainable. The Turkish market also benefits from the lower investment costs.

There are two issues worth noting on financial matters: one is the uncertainty around the YEKDEM mechanism. The government announced that YEKDEM would be discontinued after 2020. The feed-in rates have been a good driver for the lenders to finance renewable projects. Although the development costs have dropped significantly, they are still mostly denominated in foreign currency and it remains to be seen how the lenders will evaluate their credit processes after 2020. That said, certain sector representatives believe that the market could sustain itself even without the feed-in rates, provided that the applicable rules are amended to cut bureaucracy and facilitate the power sales by, including, net metering mechanisms and PPAs.

The other potential issue is the amended foreign exchange legislation (not solar/renewable specific), which restricts the foreign exchange borrowing by Turkish investors. In an effort to curb the foreign exchange exposure of Turkish residents, the government introduced certain restrictions on foreign currency loans borrowed by Turkish residents both from local and foreign banks. Under the amended rules, save for certain exceptions, foreign currency income is a prerequisite to obtain foreign currency loans. A specific exception is made for renewable investments, which allows investors to borrow foreign currency loans up to 80% of the total feed-in rate payments for the remaining feed-in period. The calculation methodology is not very clear and there is also no guidance as to what will happen after 2020 when there will be no feed-in rate support. That said, such investors may still benefit from other (non-renewable specific) exemptions under the amended rules, such as having an existing foreign currency exposure of US$15 million or more. In addition, no restrictions apply to Turkish lira financings.

Credit: Hive Energy

The recent rooftop regulation is a positive development for the 'prosumers'. Since the practice is still new, it would be advisable for the government to provide some incentives for rooftop installations, including tax exemptions/cuts for the electricity sold, grants, less or no application fees, domestic component incentives and reduced bureaucracy. We expect that households and small businesses will benefit from this regulation. If they gain sufficient popularity and the legislation is permitting we can expect to see investors investing in portfolios of residential and commercial rooftop installations.

YEKA projects should continue. However, rather than launching very large projects of 1GW, sector representatives propose smaller capacities between 10 and 20MW, which are easier to finance and complete.

The government is currently working on draft legislation on unlicensed generation. This draft has provisions on monthly net metering, a mechanism called for by the sector representatives for a long time. Once the sector and the authorities become familiar with the mechanism, an annual net metering could be easier to implement. The draft legislation, however, still has the prohibition on bilateral agreements, which should be removed.

Future investments into solar power would be incomplete without energy storage facilities. Storage facilities will intensify the competitive edge of solar, by making it a fully reliable resource, and help stabilise the electricity prices by feeding the stored power back to grid when the prices are high.

Turkey's solar sector has called for a focus on projects of between 10 and 20MW rather than much larger projects of <1GW

Finally, Turkish solar power offers great potential for the manufacturing industry. Although there are local module manufacturers, there is much room for cell, feedstock, ingot and wafer manufacturers. Indeed, the government announced in April 2018 a project-based US$34 billion incentive package for high-technology projects. Out of the 23 projects that were granted incentives, one project will manufacture solar cells and ingots and another project will manufacture electricity storage facilities. ■

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By Tom Kenning

Emerging market briefing

Tom Kenning looks at the latest developments in some of the most promising emerging PV markets worldwide. This issue features Saudi Arabia, Colombia, Mexico and the UAE

Saudi enters second phase of solar revolution

Saudi Arabia has launched the second round of its solar power tender programme with a request for proposals for 1.5GW of solar, following a year of big announcements attracting both scorn and excitement. The Middle Eastern country and Japanese firm Softbank made headlines last year with their talk of a 200GW solar plan, but Saudi Arabia's sovereign wealth fund later rejected media reports that the multi-billion dollar solar programme had been halted.

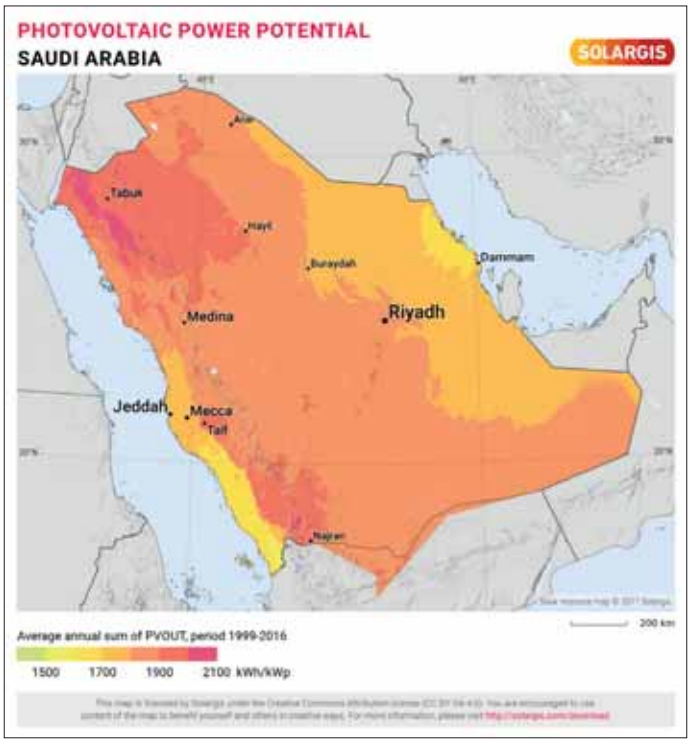
The latest move, following the 300MW Sakaka project awarded to local firm ACWA Power last year, is part of the landmark National Renewable Energy Program (NREP) by the Renewable Energy Project Development Office (REPDO), with an overall target of 40GW of PV installs and 20GW of wind energy by 2030. The new 1.5GW of solar capacity will be split up between seven projects ranging from 20MW to 600MW, with another 700MW or more to be made available later this year.

The move comes as part of a Saudi attempt to integrate more alternative energy sources under the framework of the KSA Vision 2030 and the National Transformation 2020 Programme.

News also emerged recently that China-based firm Huawei had been chosen by a consortium of ACWA Power and contractor AlGihaz as the sole inverter supplier for the 300MW Sakaka plant, the first large-scale solar project Saudi Arabia, won with a world record-low tariff in early 2018. The developers have also closed financing of SAR1.2 billion (US$319 million) for the project in Al Jouf. The transaction for the PV system, which has a tariff of just 8.781 halalas/kWh (US¢2.3417/kWh), is financed through limited recourse ring-fenced project financing with the entire debt fully underwritten by Natixis. In addition, the Arab National Bank provided an equity bridge loan for the transaction.

In related news, Saudi Arabia's National Industrial Clusters Development Programme (NICDP) and petrochemicals conglomerate SABIC have signed memorandums of understanding with China-based PV manufacturing giant LONGi Group and OCI to bring fully integrated solar manufacturing to the country.

Tariq Bakhsh, vice president of the chemicals and renewables program at NICDP, said that the signed MOUs included a feasibility study that was expected to take around six months to complete.



Credit: SolarGIS

Saudi Arabia has invited proposals for 1.5GW of PV

South Korea's OCI is a major polysilicon producer, while LONGi Green Energy Technology is a largest dedicated monocrystalline wafer producer. Plans for establishing a major PV manufacturing hub in Saudi Arabia are not new but previous plans have never materialised.

Saudi Arabia has a young, growing population, soaring electricity demand and a desire under the relatively new leadership to aggressively diversify its economy. Its package of reforms are collectively referred to as Vision 2030.

Colombia poised for first renewable auction

After some delay due to developers and investors requiring more time, Colombia has announced that it will now hold its first renewable energy auction on 26 February, with the aim of awarding 1,183GWh of electricity per year under 12-year power purchase agreements (PPAs).

The country is hoping to raise its installed renewable energy capacity from roughly 50MW to more than 1.5GW and in this case will be selecting solar, wind and biomass projects with a capacity of over 10MW.

The Ministry of Energy and Mines had originally scheduled the auction for 2 January, but most stakeholders had asked for extra time. Any new projects allocated must be connected to the grid by 30 November 2021, but projects that have been online since 31 December will also be eligible to compete in the auction.

In January, Spanish renewable energy company Diverxia Infrastructure gained approval from the Mining and Energy Planning Unit (UPME) of Colombia to develop its first large PV project within the country. Diverxia's project will have an installed generation capacity of 240MW.

More and more large-scale PV projects are starting to sprout up in Colombia. Back in May 2018, Enel announced that it was developing the 86.2MW El Paso solar power plant in the Cesar department in the north of Colombia, which was the largest solar project approved in the country at that point. The plant will be connected to the National Power Transmission System through the El Paso Substation.

Vikas Bansal, head of business development, solar international at major EPC

Mexico stutters with auction cancellation

Having muscled into the solar PV world stage through its energy reform and a series of successful tenders, Mexico has hit a major roadblock through the cancellation of its latest clean energy auction and a shift in power back to state-run power firms.

The fourth long-term energy auction had been due to take place last December, but was placed under review after the new government, led by Andrés Manuel López Obrador, took office. The Mexican National Centre for Energy Control (CENACE) then cancelled the auction following the orders of Mexico's Department of Energy (SENER), which noted that the move would be compliant with Mexico's legal framework and technical, economic and energy planning considerations.

The cancellation has surprised investors, developers and even members of the government.

López Obrador wants to give market control back to the Comisión Federal de Electricidad (CFE), a state-owned utility, which has been facing competition from independent power producers under moves to liberalise energy markets through a major energy reform. It was this reform that had paved the way for Mexico stake a claim as one of the most promising PV markets across the Americas. There are now worries that besides cancelling the auctions, there could be further moves to reverse the progress made under the energy reform.

Credit: Enel Green Power

Solar's progress in Mexico has suffered a setback following the cancellation of its latest clean energy auction

Under its three previous auctions, Mexico had awarded more than 4.8GW of solar PV capacity.

Emirates go large

Two emirates of the UAE revealed major plans for solar progress in the last quarter. Ras Al Khaimah (RAK) has revealed a 1.2GW solar ambition, while Abu Dhabi announced a whopping 2GW tender.

At the launch of new sustainable building programme dubbed Barjeel, Ras Al Khaimah's municipality said it would look to build out 600MW of rooftop solar and 600MW of utility-scale projects.

The RAK Municipality has a 2040 objective of 30% energy efficiency improvements, 20% water savings and 20% renewable energy generation. A retrofit programme was announced last year followed up by this week's new-build guidelines, which will be applied throughout the emirate, including in Free Zones. The programme, coordinated by the Energy Efficiency and Renewables Office (REEM) within RAK Municipality, aims to retrofit about 3,000 buildings by 2040. RAK Municipality had also issued a set of guidelines to support all government entities in achieving their energy efficiency goals, and will provide direct support through its Energy Efficiency and Renewables Office (REEM).

Meanwhile, the Barjeel guidelines for new buildings will require a 30% cut in energy and water usage. A 'solar ready' requirement has also been added. The rules are voluntary for the first year with incentive offered via discounted permitting fees, before becoming mandatory.

Elsewhere, Abu Dhabi has invited expressions of interest (EOI) to develop a 2GW solar PV Independent Power Project (IPP) in Al Dhafra in the emirate's Western Region. Emirates Water and Electricity Company (EWEC) said in a public notice that the project would involve the development, financing, construction, operation, maintenance and ownership of a greenfield solar PV power generation plant together with associated infrastructure. The deadline for submissions for the EOI is 5 March 2019.

China's JinkoSolar and Japan's Marubeni had bagged the 1.2GW Sweihan project in Abu Dhabi in March 2017 with then record-breaking low bid of 2.42 cents per kWh, which was subsequently eclipsed that same year by the 1.786 cents per kWh low bid received for Saudi Arabia's 300MW Sakaka solar PV project, though that project was eventually awarded in 2018 to the second lowest bidder who bid 2.34 cents per kWh.

Adding to the fray, Dubai Electricity and Water Authority (DEWA), Expo 2020 Dubai and Siemens have also broken ground on a joint project that will become the Middle East and North Africa's first solar-based hydrogen electrolysis facility, showing the UAE is also ready to diversify its energy mix in unconventional ways.

firm Sterling & Wilson, has previously said that although Colombia's government policy has a lot of regulatory challenges, in the next one to two years the country will become an important market from a scale perspective. Colombia depends largely on hydropower, and solar is expected to help generation during the dry season.

Last April, Colombian utility EPM installed what it claimed to be the country's first floating solar plant, standing at 100kW at the El Peñol reservoir. The pilot project tests the technology and its fundamentals in comparison to ground-mount and rooftop systems. For this purpose, traditional solar panels were installed on a roof at the Guatapé Central camp, under the same irradiation conditions. Innova Capital Partners and French floating PV specialist Ciel & Terre (C&T) have also agreed to jointly develop floating solar plants in Colombia.

Colombia renewable energy company Celsia has also started construction on its second solar farm in Colombia, which will be located in the municipality of Santa Rosa de Lima, in the department of Bolívar, and will have an installed generation capacity of 8.8MW. The installation will be developed by Celsia's subsidiary, Epsa, and will feature 32,000 PV modules. It will be built on a 12-hectare site. During construction, an estimated 120 jobs will be created.

Colombia is currently supporting solar and renewables through its new auction mechanism and the 2018 Resolution CREG 030, which regulates distributed solar generation (up to 100kW) and distributed generation from renewable sources (between 100kW and 1MW).

Subsidy-free solar: Europe's search for new allies

Solar economics | Led by a bullish Spain, the industry's free-market revival has dispelled memories of the FiT fallout but also ushered in an era of uncertainty. José Rojo charts players' efforts to master the rules of a new game of tough PPA interactions and merchant risks

Credit: BayWa r.e.

"Contra fortuna no hay arte alguna." The Spanish saying – a warning to those trying to fight an impossible fight against fate – epitomises the tough, recent journey of European solar developers; a forced transition from feed-in tariff (FiT) stability to unpredictable post-subsidy waters.

Spain's rollercoaster flight from boom to bust, and towards a boom again, has been especially dramatic. The country's subsidy clampdown of the early 2010s was hardly unique in Europe but its approach of choice – retroactive FIT scrapping and punishing self-consumption rules – made it typical of solar's harsh fate at the hands of policymakers. The comeback that is now underway is no less noteworthy, particularly given that it is being accomplished without the need for government incentives.

In late January, the mood music at the Solar Finance and Investment conference in London was one of cautious optimism. Attending developers and investors hailed the grid parity progress to date in Spain and elsewhere, but were not blinded to the challenges in a post-subsidy era, not least securing financing and taming merchant risks.

The PPA acronym loomed large over the discussions on- and off-stage. Live polling showed that the lack of quality agreements and willing offtakers is seen as the chief barrier for subsidy-free projects; negotiating these documents was described in panel talks as the must-have skill in the post-incentive world. How to ensure the success of the PPA hunt, do new sources exist for solar to tap into?

The corporates are coming

Alliances, as it turns out, are increasingly being sought not only with utilities but also the corporate camp. Pledges under the RE100 initiative and others helped corporate renewable PPAs more than double worldwide from 6.1GW in 2017 to 13.4GW in 2018, according to the latest BNEF update. Corporate solar PPAs in particular ballooned from 1.21GW to 5.66GW over the same period, greatly narrowing – but not fully closing – the gap with wind PPAs' 6.87GW in 2018.

On the ground, however, scepticism persists on the current spread of European corporate solar PPAs, particularly in Spain. At the conference, Quintas Energy managing director Declan O'Halloran argued they remain so rare they "make unicorns look like cattle". The BNEF data confirms the phenomenon is overwhelmingly a US story, with 4.34GW (77%) of the worldwide 5.66GW signed in the country in 2018. At a more modest 182MW, the UK placed third last year, falling behind Australia's 686MW. Remaining European entries Spain (43MW) and Italy (26MW) were overtaken by Mexico, Chile, Singapore and India, in that order.

The London conference linked Europe's slower embrace of corporate PPAs to a "large gulf" in understanding; the premise is echoed by those approached by *PV Tech Power* in recent weeks. Daniel Pérez, PPA lead and chief legal officer at clean energy firm Holaluz, notes that PPA uptake has naturally thrived in traditionally subsidy-free markets. Spanish players, by contrast, lack familiarity and experience, he says: "Financial backers can be an obstacle. Spanish banks tend to be conservative with PPAs, sometimes demanding risk-mitigation clauses that drive potential offtakers away," Pérez adds.

BayWa r.e.'s Benedikt Ortmann.

Benedikt Ortmann, managing director at developer BayWa r.e. Solar Projects, conveys a similar sentiment. Speaking to *PV Tech Power*, he cites corporates' lack of experience – as well their refusal to take long-term contracts on balance – as the "biggest obstacle" to PPA success. According to him, companies' purchasing departments are sometimes "simply overwhelmed" by the decision-

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	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Solar volumes (GW)	0	0.17	0.02	0.03	0.05	0.19	0.07	1.18	0.91	1.21	5.66
Wind volumes (GW)	0.16	0.1	0.11	0.17	0.05	0.65	1.82	3.18	2.72	4.32	6.87

Source: BNEF

Chart 1: Corporate PPA volumes for solar PV and wind, 2008 to 2018

making involved in these contracts. Establishing the credit rating of even seemingly solid corporates can also create problems, Ortmann adds: "When a bank comes asking 'is this company good for 20 years', who has the answer?"

PPA interactions: a how-to

Despite audience fears over low-quality PPAs, developers working in Spain told the London event "lots of options" exist on the ground.

Later conversations help sketch out the average corporate solar PPA in Europe. Partner Sophie Dingenen and associate Levent Gürdenli of law firm Bird & Bird say sleeved deals set against a 10- to 15-year time horizon are the rule in the continent. However, the lawyers add, Spain's remuneration rules mean shorter, synthetic PPAs are better suited to everyone's needs.

Multiple or not, the options on offer are not easy, nor cheap, to negotiate; the stories of those who have faced talks for a corporate PPA confirm as much. Speaking at the London event, BayWa r.e.'s Ortmann noted that discussions take on average a minimum of six months to conclude, earning lawyers billable hours at the expense of developers and others.

Contacted later by *PV Tech Power*, he shed some light on how these negotiations play out. According to him, developers sitting across a corporate will find a less-knowledgeable counterparty that may harbour "unrealistic expectations" of what a PPA can accomplish.

"Developers should check the credit rating of companies early on as that can be a quick showstopper," he says. "If the corporate in question doesn't have any experience I'd strongly recommend to get them to hire external commercial and legal advisers."

By contrast, Ortmann adds, utilities understand a developer's language but are, in turn, more price-sensitive. The energy trading nature of their business will see them push for short-term agreements in ways a corporate, which typically wants the energy for its own use, may not.

The financing conundrum

Listen to solar insiders and it soon becomes clear that the subsidy-free story cannot be written without banks and investors. As the London event noted, financing remains solar's last obstacle to market-economics after years of plummeting technology costs.

Financiers' hesitations are two-fold, as speakers pointed out. On the one hand, risks from merchant-heavy projects will make many – particularly debt providers – hold back. On the other, those eyeing safer ventures may find the investment returns on offer fall short of expectations.

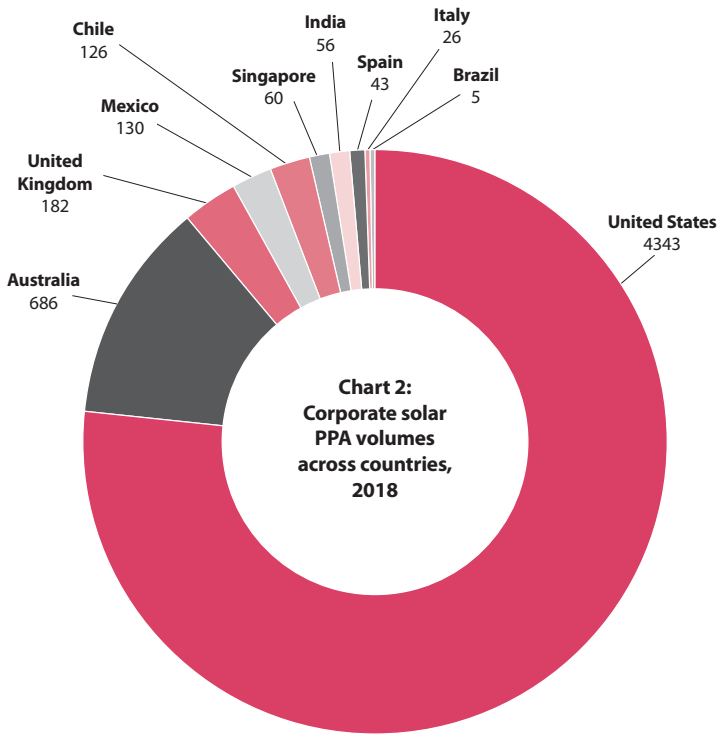
> "Everything is up in the air and that's why nobody is building plants, because nobody knows what tomorrow holds – if you do know, you'll get finance"

Could corporate PPAs help win over risk-averse sceptics? Bird & Bird's Dingenen believes so, noting that banks feel "very comfortable" with the steady revenues a strong corporate will bring to a PPA. "In the case of the Netherlands, mandatory unbundling rules for utilities mean banks can actually prefer PPAs involving a corporate with good credit rating."

Foresight's Carlos Rey

Carlos Rey, director at Foresight Group, agrees PPAs are today preferable for those keen to derisk from regulatory support. His own firm, investing in solar through retail, listed and unlisted funds, completely steers clear of auctions in Spain. "What's beautiful about projects today is the regulator risks have left the picture," he tells *PV Tech Power*.

Positive or otherwise, corporate PPAs can prove elusive in a country where credit-worthy Google-type offtakers are scarce. Even those keen on a PPA deal may seek conditions that are hard to stomach, according to Rey: "In Spain, it is not corporate responsibility that drives companies to PPAs but a price that, often, can be at odds with what developers and investors need."



Biggest corporate solar buyers in Europe were, in descending order: Anheuser Busch InBev, Anglian Water, Uvesco, Amazon, Kutxabank, Euskaltel.

Source: BNEF

There are things Spanish policymakers could do to energise the corporate PPA scene, Rey believes. "Rather than only prioritising auctions, they could help provide long-term certainty in the revenues of us equity players through, for instance, tax advantages for corporates signing renewable PPAs," he says.

Bubble fears bite back

Only time will tell whether Google (see table below) and others are but among the first of a new breed of large-scale corporate solar PPAs. Their ultimate success will not be dictated by their first few steps under the PPA today, but a mixture of complex factors – value of the installation, the corporate's own financial health – measured in 10, 15 years' time; the shorter, lower-price PPAs brought about by the current buyer's market mean the value created after contracts expire matters more than ever.

Whether Spain in particular is sleepwalking into another bubble is a question panellists had to field. Some conceded the competition was overheating but many felt that bubble fears were, for the time being, unwarranted. Solarcentury BD director Peer Piske said the banks, offtakers and equity shops he speaks to are all looking for projects. "There might be a lot of press releases but that doesn't mean we've got all the supply," he argued. Everwood Capital partner Alfredo Fernández spoke of the "Spanish hole", commenting: "In order to get to a bubble, we first have to get to normal."

Not everyone was equally upbeat, however. "There is a bubble," said Abid Kazim, managing director of NextEnergy Capital. "Most Spanish assets are uninvestible, they're not being built because if 36GW came into the system, it would collapse." The unease over grid availability in Spain – its limited capacity and high interconnection costs – was echoed elsewhere in the panel discussions, with a speaker wondering how developers will sell if interconnections don't improve.

Question marks were also raised over stability in Spain; a country which, in the words of Quintas' O'Halloran, cannot disassociate its regulatory past from its post-subsidy future. The current administration, O'Halloran told attendees, appears supportive but this may not hold in the longer term. According to him, factors including an unclear tax framework and expected grid legislation changes could all impact a PPA's fortunes. "We haven't seen the commitment to stability from politicians that we wanted," O'Halloran remarked.

> "Corporate solar PPAs…remain so rare they 'make unicorns look like cattle'"

Uncertainty is here to stay

How much further can the current corporate PPA boom go? At the conference, Solarcentury's Piske reported witnessing a "growing demand" from both corporate buyers and in this, he appears to be supported by BNEF analysts.

According to their estimates, companies will need to snap up 190TWh in clean power by 2030 to meet RE100 targets. If the gap is plugged with offsite PPAs alone, BNEF believes, 102GW of wind and solar capacity would have to be built worldwide, 48GW of it solar.

Developers treating the forecast as an opportunity know it comes with an equally significant challenge. Turning soaring PPA demand into a subsidy-free success will require investor backing, as well as long-term planning to ensure projects remain money-making despite aggressive PPA terms.

From sound O&M practices to data analytics and co-location with storage or wind, all potential allies in solar's value-creation journey were explored at the London conference. Many felt, however, that nothing will ultimately save firms from the tough PPA negotiations ahead; an interaction where, until standardisation becomes a reality, rules and references will be few and far between.

As argued by Ricardo Folgado, structured finance director at Lightsource BP, the difficulties partly stem from the fact that value is no longer what it was when subsidies ruled. "Developers' returns have been squeezed a lot," he told attendees. "The previous supply chain had elements to make sure there was some value for everyone, but the aggregated model we're moving to now means value is condensed around a single point."

Unsurprisingly, these efforts by PPA counterparties to attract most of that condensed value are only mirrored by their will to push risks onto others: Solarcentury's Piske described "tough" negotiations with an offtaker for a Spanish project, with neither party keen to take on full-profile risk. Elsewhere in the panel discussions, speakers stressed that banks and investors won't be happy either to take on excessive merchant risks.

However, perhaps the conference's key takeaway is that uncertainty, the vulnerability to future fortune twists, is a reality subsidy-free players will need to live with.

"Demand, opportunity, grid parity; they're all in place. Why are we not building, then?", came the question from NextEnergy's Kazim. "We're no longer living in an era of energy certainty. The world is different from last year…and in the transition, the way we understand the grid will go away – consumer demand will change, technology will change.

"Everything is up in the air and that's why nobody is building plants, because nobody knows what tomorrow holds – if you do know, you'll get finance," Kazim continued. "So how to create certainty in this world for investors to invest? That's going to be the interesting conversation." ■

Solar PPAs in action – case studies

Our selection of European solar PPAs of recent years shows that, however much Spain may hoard the subsidy-free spotlight, consequential corporate deals have also been signed in less-sunny reaches.

Don Rodrigo – 175MW built and run by BayWa r.e. near Seville (Spain)
The solar park features a 15-year physical PPA with Norwegian energy group Statkraft as the utility offtaker. The deal spans a five-year fixed-price period and a subsequent 10-year discount-to-market phase. German bank NORD/LB supplied a €100m construction bridge financing facility.

AB InBev UK – 100MW built and run by Lightsource BP in South Wales and Lancashire (UK)
The Lightsource-Budweiser deal, billed last December as the UK's largest unsubsidised project to date, comes with a 15-year corporate PPA.

SunPort Delfzijl – 30MW built by Wirsol, run by Eneco at Delfzijl (the Netherlands)
Similarly pitched as its country's largest solar farm – unsubsidised or otherwise – the project first announced in mid-2017 will see Google's data centre powered through a 10-year PPA.

Weesow-Willmersdorf – 175MW built by EnBW near Werneuchen (Germany)
Germany's contribution to the subsidy-free scene is also, at the time of writing, reportedly the country's biggest planned park to date. EnBW, which bought the project from Procon Solar GmbH last year, declined to comment on PV Tech's questions on PPA arrangements.

Solara4, Ourika and others – 708MW built and run by WElink in Spain and Portugal
The most recent addition to the list will see Spanish utility Audax Renovables purchase, through a 20-year PPA, the power generated by a solar portfolio WElink is currently building. According to media reports, the solar farms will be acquired by Allianz Capital Partners once WElink wraps up construction.

Ensuring the bankability of the UK's low-carbon fleet

Policy | Strong policy support to safeguard the bankability of low-carbon energy technologies and underpin the UK's ongoing decarbonisation efforts. Gareth Miller of Cornwall Insight outlines proposals for a new route to market that would guarantee future investment in much-needed renewables such as solar and onshore wind

Credit: Mr Renewables/Wikimedia Commons

Officials at the UK's Department of Business, Energy and Industrial Strategy (BEIS) will inevitably be turning to how they manage the production of an energy white paper alongside the taxing demands of Brexit, and against a context of the new nuclear pipeline collapsing in on itself (see p.37). Whilst recent ministerial statements suggest very little appetite for reigniting contracts for difference (CfDs) for onshore wind and solar PV, with a nuclear and offshore wind-led strategy likely to be to the fore, the opportunity remains for onshore renewables to re-state its case for rehabilitation. And it is a powerful case when weighed up against the infrastructure and investment challenge that presents itself to the power sector as we pursue perhaps steepening 2050 decarbonisation objectives.

Projections show that even with big growth in offshore wind, significant capacity still needs to be delivered from onshore renewable technologies if we are to achieve the decarbonisation pathway to 2050. National Grid produced analysis as part of its 2018 Future Energy Scenarios (FES) which showed that for its "Two Degree" case, which is most compatible with 2050 targets, there is a 107GW gap between the 53GW of low-carbon capacity that we have today and the 160GW that may be required in 2050, which includes a further 30GW of new solar PV and 10GW of new onshore wind.

The scale of the challenge is even greater given the age of the existing low-carbon fleet. Existing nuclear plants will encounter difficult decisions in the early-mid 2020s and are due to go off-line during the next decade. In addition, by 2050 every renewable power plant currently operational or committed to today will have exceeded its useful 25-year asset life. Without a meaningful signal to repower or rebuild these sites they may close.

It is conceivable that all the 160GW will need to raise new investment by 2050: 53GW in terms of repowering or replacement and 107GW of new-build generation. This is four times the level of capacity that has been delivered in the last two decades.

Strong policy support is necessary to underpin future investment in solar and wind in the UK

Currently, the government assumes that onshore renewables can continue to deploy without policy support. In our view, this is a mistake. Whilst there have been significant reductions in costs in onshore renewable technologies, this does not make investments credible without revenue stabilisation. Project funding from banks and other risk-averse investors will still require insulation against short-term, substantial swings in wholesale power prices.

Price cannibalisation

Renewable power output from wind and solar is highly correlated to weather. For example, when it is windy, and particularly at times outside of peak demand, the level of output from the UK wind fleet creates substantial downward pressure on wholesale market power prices. The same is true of solar PV, although there is a marginal

softening of the impact by virtue of solar generation tending to peak with demand.

This means that wind and solar PV generators will "capture" a price that is below the average price in the market for baseload generation, a phenomenon known as "price cannibalisation".

Even with the advent of battery storage, price cannibalisation will intensify if deployment increases. Whilst gas and carbon will remain price-setting commodities in the near term, in the medium to long term, the changing generation mix means the influence on power prices from these commodities diminishes. We foresee significant cannibalisation during the 25-30 year asset life of new onshore renewable projects.

From our experience banks and other risk-averse investors are unlikely to invest large amounts of capital in projects which face these kinds of risks. In assessing whether to make a loan, banks examine whether in downside scenarios there will be enough cash to repay the entire loan and meet each six-monthly instalment, and debt service cover ratios.

Investment models which reflect greater cannibalisation and volatility will encourage lenders to be prudent. This will mean either banks will lend less, and at a higher cost, or they won't lend at all. Lower debt levels mean more equity committed to fund construction, and a consequential negative impact on equity investor returns. Fewer banks willing to lend at all means lower capital flowing into the sector.

At a sectoral level this matters because project finance lenders have provided hundreds of billions of dollars of capital to the sector globally in the last decade, and – at an individual project level in markets like Britain – between 70-80% of the capital funding requirements of individual onshore wind and solar projects.

At the same time, equity investors' return expectations will rise to reflect higher risk. A report by the financial accounting, advisory and auditing firm Mazars in August 2018 supports this view, highlighting an upward trend in discount rates related to increasing levels of wholesale power price risk.

It is unlikely that suitable "de-risking" support will be forthcoming from the commercial power purchase agreement (PPA) market. Many PPA providers will now offer long-term (10-15 year) contracts but these contracts have floor prices between £10-20/MWh, which are insufficient to allow projects to raise the level of debt required to reach a reasonable rate of equity return.

The corporate PPA market has been identified as a stimulus for wind and solar PV to flourish outside the CfD. Corporate PPAs tend to see business buyers fix a long-term price for an offtake with a renewable generator, with a licensed supplier providing trading and balancing services in the background. Some corporate PPA transactions have already been closed in the UK, mostly for extensions to existing subsidised renewable power stations.

It is highly likely that corporate PPAs will deliver some new-build projects, particularly in prime development locations. However, prices agreed in corporate PPAs are currently not at levels that will deliver a large volume of projects. In addition, whilst there is significant demand from generators and developers for corporate PPAs, there are not yet matching levels of supply.

Finally, hopes that the capacity market will provide a transformative bankable support for new or repowering renewables projects are likely to be misplaced if the recently published parameters and methodology for de-rating renewables are eventually adopted.

The lack of revenue stabilisation will significantly reduce the bankability of grid-scale onshore wind and solar PV and make it inconceivable that our power sector decarbonisation objectives can be achieved.

CfD floor

To bridge the gap, we have recently written to BEIS recommending that the government explores the implementation of a 'CfD floor'. This structure is based on a simple premise that the generator will receive protection against wholesale reference prices below a guaranteed floor price (in £/MWh), and would only be able to realise upside in power prices above the floor price to the extent that any sums received under the floor had been fully repaid first. To avoid the unnecessary administrative burden of reconciling and settling individually for every half-hourly period, settlement against the floor would be based around 30 six-month reconciliation periods over the 15-year payment term of the CfD.

This model would deliver several advantages. There will be lower CfD strike prices. This is because bidders would be aiming to secure a floor that covers their fixed costs and debt repayments rather than a price which delivers their total return. Anecdotal discussions with developers suggest onshore wind floor prices could be in the region of £30-35/MWh in 2011-12 values for highly efficient projects. This is compared to administered strike prices for offshore wind of £53-56/MWh in 2011-12 values announced for the third allocation round.

As a result, subsidy costs and consumer costs of decarbonisation will reduce, potentially to zero. Not only will lower strike prices result in a greatly reduced risk of subsidy, notably the CfD floor is designed to ensure that any subsidy costs incurred would be recouped. Subsidy, if arising at all, acts like a working capital facility, and would not be expected to result in long-term, sunk subsidy cost to consumers.

From a practical perspective, the CfD floor would not necessitate any material changes to how CfDs are auctioned, contracts are administered, levy payments collected and payments settled to generators. The contract payment mechanism would need to be adapted to accommodate payment against a floor price rather than a fixed price. An amended CfD contract could be auctioned and settled in a fashion compatible with the regulatory and institutional design of the current CfD.

Critically, the CfD floor would turbo charge the attraction of low-cost-of-capital investors back to the onshore renewables sector. The floor CfD is entirely compatible with the risk appetite of the traditional and substantial providers of capital to this sector.

To conclude, it seems to us that if the government is serious about meeting climate goals at the lowest possible cost, onshore renewables must play a substantial role. As it becomes clear that this role cannot be facilitated by market-based solutions, then the imperative for good policy support becomes irresistible. The CfD floor idea isn't the only solution, but – given its focus on leveraging substantial private capital at low public cost – it is a compelling model around which to frame a wider debate on other options. As the white paper is prepared, we hope government open its mind to the full suite of levers available to it, onshore renewables included. ■

Author

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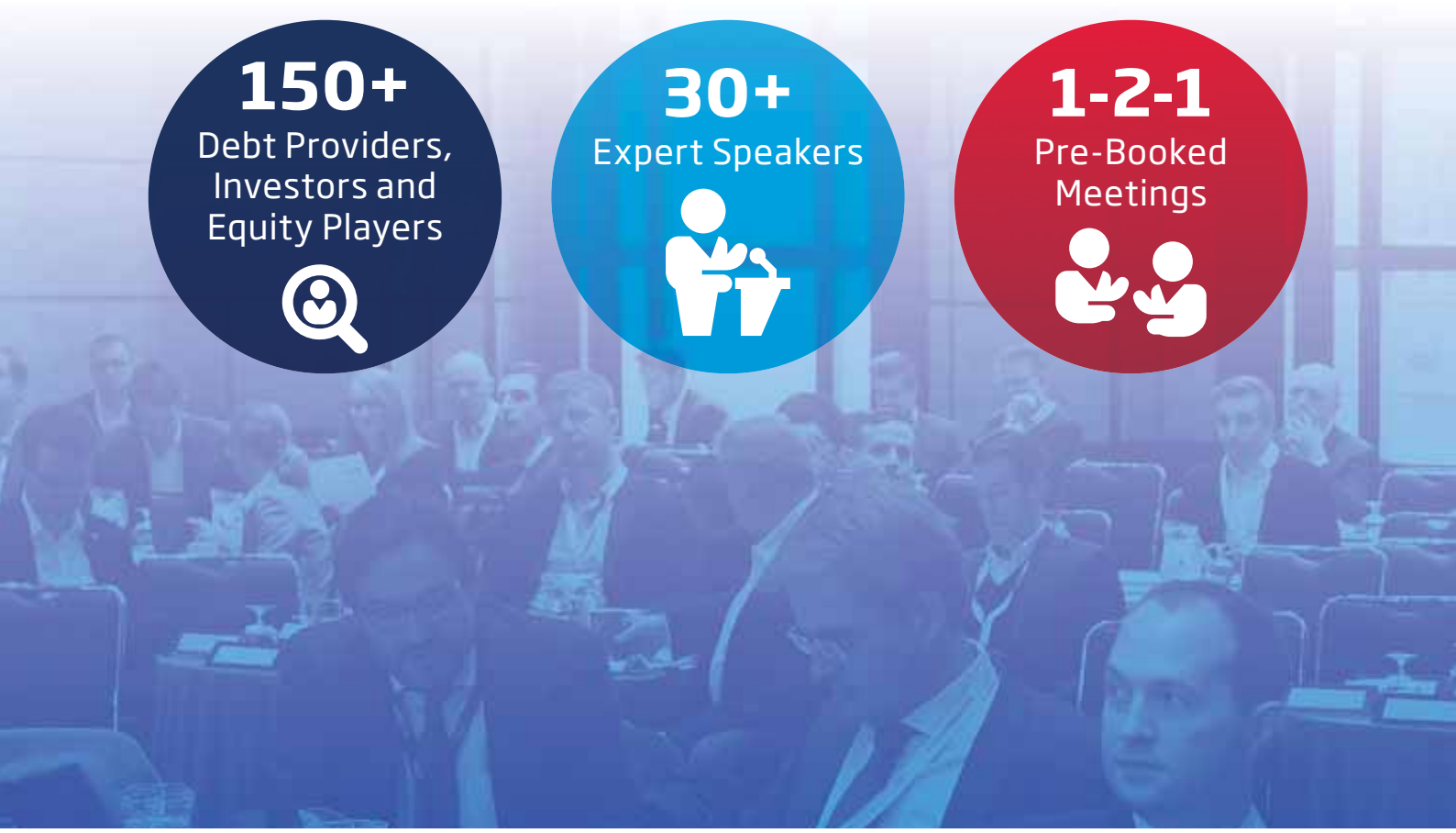

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Floating PV systems – an overview of design considerations

System design | Floating solar has huge potential in areas where difficult terrain or land constraints make ground-mounted systems impractical. Gijo George and Pranav Patel of DNV GL explore some of the technical challenges in designing and building floating PV projects

Credit: Lightsource BP

Floating solar design and installation pose considerable technical challenges

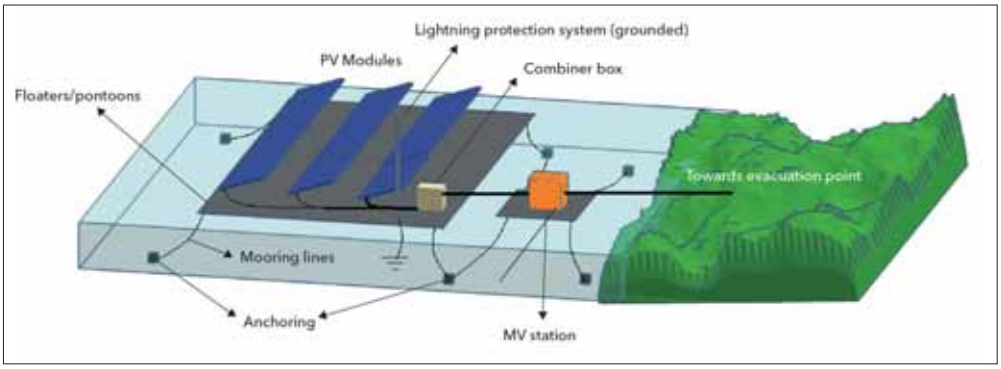
DNV GL's 2018 Energy Transition Outlook forecasts that by 2050 solar photovoltaic (PV) will provide 40% of global electricity generation, corresponding to 19.1TW of global solar PV capacity [1]. We estimate that 70% of this PV capacity will be realised as ground-mount systems, which would require approximately 400,000 square km of land. Non-availability of land in some locations and multipurpose use of land could make land acquisition difficult for energy projects. Considering this, it is important to explore any potential technology application that:

- Optimises existing man-made infrastructure and suitable natural resources;
- Improves water conservation;
- Increases renewable energy generation given the background of climate change and water shortage.

Floating solar PV projects (FSPs) can satisfy the above conditions by providing an alternative deployment option for PV modules, namely on bodies of water such as lakes, lagoons, reservoirs, ponds, canals, etc. As a relatively new concept that combines the intricacies of both solar and floating technologies, the specific deployment drivers of FSPs can find application when factors influencing a project might include:

- Densely populated countries
- Limited area for large-scale, ground-mounted PV
- Mountainous terrain compared to largely available water bodies
- Innovation-driven necessity
- Requirement for higher specific yields (kWh/kWp)
- A need to reduce water evaporation, especially in dry areas

Floating solar installations consist of floats/pontoons, module mounting structures, mooring system, PV modules, inverters, and balance of system (BOS) components. PV modules, which are the main components of FSPs, are mounted on top of floats, which are fundamentally buoyancy units used to keep the panels floating on the water surface. PV modules, which convert the incident solar irradiation into electricity, can be mounted either directly or in combination with frames on the floaters. A mooring system is used to keep the floats in place. The system is similar to a spring, where displacement of the floater from a neutral equilibrium position causes a restoring force to react to the applied loading. The choice of mooring system depends primarily on the location,



Representation of a floating solar plant

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Floaters with module mounting structure

depth of water, geotechnical parameters and reservoir bed profile. Such mooring systems mainly consist of two components, namely the mooring lines and the anchoring mechanism. The direct current (DC) power generated by PV modules is converted to alternating current (AC) power by inverters. For small-scale floating plants close to shore, it is possible to place the inverters and BOS components on land. Otherwise, both central or string inverters can be installed on specially designed floats along with other BOS components.

Even though there are several advantages of using FSP installations, there are also several challenges in using this technology, which should be assessed on a case-by case-basis. These installations are vulnerable to storms, waves, currents, etc. that could adversely affect the life of the plant. Such dynamic loads can result in floats getting overturned during adverse weather events, or the increase in motion can induce stresses on the mounting structure.

Unlike ground-mounted systems, the environmental dynamic loads in FSPs result in higher fatigue loads that need to be addressed in the design of physical connections. Floats that are connected to the mooring lines experience higher forces, and floats on the periphery need to be designed for possible impact loads as well. Mooring systems should be configured such that the lateral movement and rotation of the plant is minimal, while allowing for variation in water level. This means that the mooring lines should neither be too tight nor too slack. Finding the right balance between the two can be very challenging, especially if the water level variation expected at the site is significant.

FSP installations have additional challenges due to their local environment. For example, there is an increased risk of corrosion and hence a possible reduction in the design life. Inverters and BOS components are exposed to high humidity environments and movements due to the waves. Preventive measures ensuring that the chosen equipment has an adequate ingress protection (IP) rating and has undergone environmental tests for the saline marine conditions should be taken into consideration during the design and installation stages. Additional safety measures that address risks related to the use of electrical equipment in such environments should be put in place as well. Depending on the design and site constraints, installation and maintenance costs may be higher relative to onshore PV plants. Furthermore, environmental impacts should be taken into consideration. For example, by preventing the penetration of sunlight into the water, these installations have the potential to affect the aquatic life and biodiversity of the site.

The design of FSPs can be a long and complex process. Each of the components in a floating solar system faces a plethora of challenges, some of which are discussed above. In addition to these challenges, understanding the interactions between components is essential for a stable system design. The external design parameters including environmental conditions that influence the system design will vary between different sites. As a result, preparing a universal solution might not be feasible and each project will need to be dealt with on a case-by-case basis. Although challenges in FSPs are different from conventional ground-mounted or rooftop solar projects, similar challenges have been encountered in other fields such as maritime, oil & gas, and offshore wind projects, where floating systems are used based on proven technical grounds. Hence, parallels can be drawn from these fields and adapted for the FSP application. The FSP design process broadly includes following activities:

Site surveys

Site surveys should include bathymetry, geotechnical investigation, hydrology study, metocean study and collection of historical data. These surveys should be conducted as a preliminary step to arrive at the baseline for the environmental and climatic conditions that the FSP will need to be designed for. *Bathymetry* is the study of underwater depth of lake or ocean floors and helps to map the reservoir bed. *Geotechnical investigations* need to be undertaken to understand the stratigraphy, engineering properties, behaviour and composition of the soil. *Hydrology* is the study of flow and storage of water in the environment, which provides valuable insights on expected variation of water level as well as water flow. The combined wind, wave, current and other climatic conditions that are prevalent in the site are called the 'metocean' characteristics of the site. A *metocean study* where these characteristics are monitored can help arrive at appropriate design values for wind, temperature, humidity, water level variations, storm surges, seiches, wave parameters and water currents. Historical data, whenever available, should be used to supplement and validate the data obtained from site.

Environmental conditions

FSPs need to be designed for different environmental conditions such as wind, wave, currents and water level variations. The design environmental conditions can be established from site surveys and historical data.

Similar to ground-mounted solar systems, the site-specific wind condition is one of the prominent environmental

conditions that govern the design of FSPs. The wind acting on the system generates suction, pressure and drag forces on the system's components. The varying nature of wind also generates dynamic loads on FSPs.

Waves generated in waterbodies can interact with FSPs, and the motion induced by waves will generate inertial forces on the system. In addition, the varying nature of waves results in dynamic loads on the structure, similar to wind loads in FSPs and in traditional ground-mount systems. Wave heights can vary from a few centimetres to a few metres depending on various site conditions. The properties and behaviour of the waves are typically influenced by the size, shape and depth of the waterbodies, the wind velocities and the fetch distance. Thus, the effect of waves can be negligible for small waterbodies of shallow depth compared to large deep reservoirs with long fetch distances. The different wind wave models available can be used to predict the waves, which can be validated from a combination of the metocean study and historical data. The output of the models will be a spectrum of waves with a significant wave height and characteristic time period.

Water level variation and water currents are also of significance in the design of FSPs. The hydrology study in combination with metocean data, historical data and reservoir design criteria can be used to determine their effects.

Loads and load combinations

The different components in FSPs are exposed to diverse load types, which arise due to the normal operation and local environmental conditions. Components should be designed for probable combinations of these loads.

Similar to any other structure, FSPs should also be designed for dead and live loads acting on it. Dead loads are the permanent loads acting on the system such as the self-weight of the components and weight of the panels etc. Live loads are the variable and dynamic loads that are expected to act on the system, primarily during normal operation of the floating solar plant.

Winds can generate dynamic effects such as vortex shedding on the structure. Studies on utility-scale ground-mounted solar panels systems have shown that the dynamic loads can be several times the normal loads; and a similar phenomenon can be expected for floating solar projects, depending on the type, configuration and material choices for the system. The presence of wind will also have a significant impact on the cyclic loads applied to the floaters.

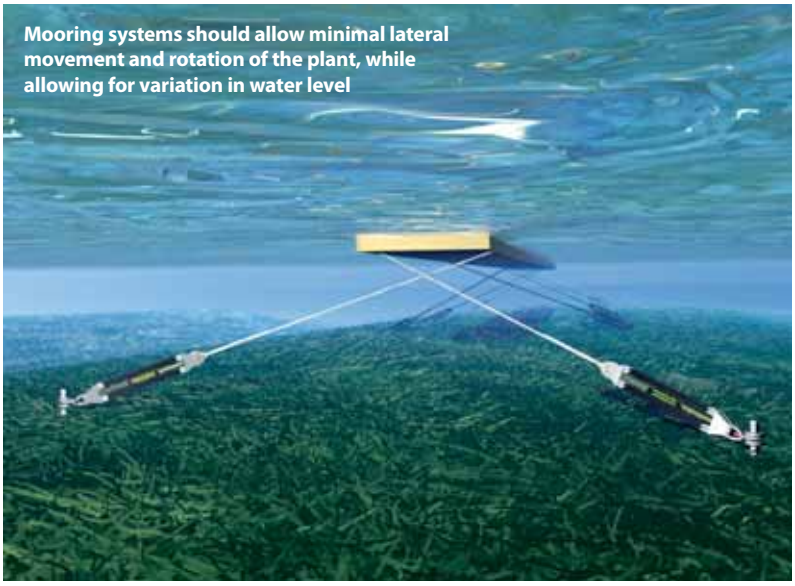
Stresses can be developed in FSP components due to the action of waves. The submerged components will be subjected to lateral forces due to the motion of water whereas the floating components experience vertical and horizontal motion, which will induce internal forces on the floaters. The cyclic nature of waves can result in dynamic loads on the structure, modules, inverters and BOS as well.

Waves generated in inland waterbodies are generally due to the action of wind, and hence maximum wave loads can act simultaneously with maximum wind loads. In addition, the simultaneous actions of wind and waves can lead to complex behaviour of the floating system, which can only be determined if the wind and wave phenomena are simulated simultaneously.

Currents prevalent in reservoirs can apply a lateral load or drag force on the structure. Large submerged components can also develop dynamic loads on the structure due to vortex shedding caused by the flow of water past a non-streamlined body. The variation of current near the surface and bed of water bodies can create additional forces and combinations.

In addition to the loads listed above, construction-related loads such as forces applied on the system when the FSP is tugged to the location of installation, and accidental loads such as the impact of a vessel onto the floating system or impact on the system due to a loss of buoyancy of random modular floats should also be considered in the design.

FSP systems should be designed in a way to perform adequately even under the worst possible situation envisaged during the design life of the project. This is generally achieved by designing for a combination of loads. Load combinations should consider the strength and serviceability conditions of the system – the design should be performed not only for different load combinations, but also for different configurations and boundary conditions that the system can adopt. For example, inclination angles of mooring lines will change as the water level changes, and hence should be designed for extreme water levels (i.e. lowest and highest water levels) as well as for intermediate water levels. Similarly, boundary conditions of the system during operation can be different from the boundary conditions during construction or maintenance phase. Directional variations of loads should also be considered in the design.



Mooring systems should allow minimal lateral movement and rotation of the plant, while allowing for variation in water level

Credit: Seaflex

Materials and durability

Materials used in FSP system components should be selected to satisfy the structural and functional requirements for the entire lifecycle. In addition, selected materials should also satisfy requirements related to degradation, environmental stress cracking, UV stabilisation, exposure to water, salinity, humidity, algae growth, toxicity, impact on ecosystem biodiversity and end-of-life recycling aspects.

Analysis and design

The analysis and design of any system is an iterative process, where the effect of external actions (loads) on the system and the resultant response (reactions) are

studied to provide a solution that satisfies the functional safety and durability requirements. Being a relatively new field of engineering, there are very limited standards that can be directly used for analysis and design of FSPs. However, parallels can be drawn from several mature and established fields such as offshore oil & gas, offshore wind, coastal engineering, onshore solar and so on.

FSPs can be subjected to several different loads which can also be dynamic in nature. The different components within floating systems will also interact with one another. These characteristics of a floating solar project make it a highly complex system that is inherently nonlinear and dynamic. The choice of method for analysis and design will depend on the type of structure, complexity of the system and level of accuracy required.

Simplified methods such as equivalent static analysis can be used to arrive at approximate solutions for these complex problems, but an effect such as vortex shedding cannot be captured in these methods. Advanced computer-aided design techniques such as finite element method (FEM) and computational fluid dynamics (CFD) that use mathematical models of the systems to simulate their behaviour can give much more accurate results. However, these methods are often computation-, time- and cost-intensive.

FEM and CFD can also be used to simulate complex phenomena such as simultaneous interaction of wind and waves with FSPs, which might not be possible to simulate in a (scaled) model testing due to physical constraints. (Scaled) model tests such as atmospheric boundary layer wind tunnel testing and wave pool testing can be used to study the effect of the structure under different wind and wave flow regimes. They can provide very accurate values for force coefficients and dynamic behaviour when performed adequately and coupled with modal analysis and a dynamic sensitivity study. The design of the components can also be performed with the help of testing (design assisted by testing) where the test results are compared with design requirements established using the methods described above. These test results can also be used to validate the results obtained from CFD and FEM.

Installation & maintenance

As FSPs need to remain in operation as per the specified time horizon for each project, proper installation and maintenance is required. The layout of the FSPs needs to be such that it is easy to install components in a safe manner with minimal impact on the environment. Care needs to be taken to avoid permanent damage to the land and environment during construction activities on the shore. Precautions need to be taken to ensure the safety of personnel and to avoid any incidents, particularly considering the specialised requirements for installation (e.g. divers working underwater for a prolonged time). Power plants should be designed and installed taking into account ease of maintenance, accessibility and replaceability of the components. End-of-life disassembly and removal of the plant parts should be possible with minimal impact on the environment.

Energy simulations

It is necessary to assess the yield of FSPs, to check the feasibility and profitability of each project. There is a huge range of energy gains reported up to 25%, compared to ground-mount or rooftop systems. Thus, it is necessary to understand the water body and its thermal behaviour along with the type of floating systems used for realistic energy estimates for FSPs. PV modules are rated at standard test conditions, which is 1,000W/m^2, 25^{0}C and air mass 1.5. The module generation is reduced whenever the module surface temperature is above 25^{0}C and vice versa. Due to cooler air temperature over water surface during the day, this can lead to lower temperature loss compared to a ground-mount system.

In one study, the capacity utilisation factor (CUF) of two floating plants of 100kW and 500kW installed in the same reservoir as well as an overland PV system of 1MW, which was 60km away, were compared [3]. The gains in CUF reported were 13.5% and 10.3% for the 100kW and 500kW systems, respectively. However, a direct CUF comparison is not suitable here as there would be different Global Horizontal Irradiation (GHI), different plane of array gains due to difference in the diffuse component, site specific shading loss and different system losses for the two systems. In another study conducted by the Solar Energy Research Institute of Singapore (SERIS) [3], eight floating systems were compared to one another, and an additional system with a rooftop reference system was installed on a building just next to the water body. It was concluded from the study that the performance ratio varied across different floating systems, and on average the best performing floating systems were similar to the rooftop reference system of the test bed. It was noted, however, that the floating systems studied had roughly 5-10% gain in performance ratio compared to a typical rooftop system installed in Singapore; though again it is not suitable to make generic comparisons, given the detailed aspects that contribute to the performance of any given system.

The quantum of energy gain depends upon the size of water body, type of floaters used, system layout (extent of coverage of the water surface), location of the system on the water body, module tilt angle and pitch distance between module rows. The increase in generation due to improvement in efficiency could be offset by lower than optimal tilt angle of the floaters, changes in orientation due to movement of the floating system, increased mismatch losses, soiling losses depending on the location of the installation and system availability due to issues with components, improper installation, faults, response time, etc.

Mitigation of adverse effects is possible through a properly conducted site survey, design methodology and selection of components suitable for the location and application. ■

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Authors

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Power plant wire management

Wiring | Effective management of cabling in a PV system can greatly impact its lifetime maintenance requirements and thus profitability. Samuel Truthseeker of TECSI Solar looks in detail at the latest developments in wire management and highlights several reliability considerations

Wire management failures can have an unforeseen impact on the continued operation of a solar power plant. If left unmitigated, they can lead to electrical shorts or fires that result in system downtime and unbudgeted O&M. Improper installation and device choice, as well as environmental conditions can drive the premature failure of a wire management system. Ironically, the builder of a power plant, who often chooses the deployed wire management device, isn't the asset manager who has to maintain the system for its 25-year life. However, with proper knowledge, investigation and modelling, an asset manager can advocate for proper O&M funding prior to asset purchase. This could save the organisation hundreds of thousands of dollars in unforeseen costs. This article is intended to help those responsible for building solar power plants to determine the right wire management device for the job. It is also intended to help those responsible for continued O&M to create a more accurate budget based upon the risk factors associated with the deployment of a particular wire management device.

Wire management devices for use in commercial power plants can be categorised by three main classes. Two classes, cable ties and wire clips, are the most widely used. The final class, fully integrated wire management devices, although not yet widely deployed, show the most promise for lowest installed cost and zero maintenance costs over the life of the system. This article explores the advantages and disadvantages to each class as well as the factors that should be considered when choosing a product within a class.

Credit: TECSI Solar

Fully integrated wire management devices show great promise for lowering costs and maintenance requirements

Cable ties

Cable ties continue to be widely used as wire management solutions for solar power plants. Their ease of use, availability, nonconductive nature and low cost have proven to be a winning combination. However, there are several issues that have been identified with this option. Most notable is material quality. Zip ties have been around since the 1960s, but suitable polymeric materials for harsh outdoor environments have not. Most commercially available cable ties labelled "UV resistant" for outdoor use, will not survive long in real-world solar applications. The UV resistant labelling is not a certified or industry defined term [1]. It's just marketing. In fact, at some power plants the entire site had to be rewired because there was a 100% failure rate of their "UV resistant" cable ties after just six months. Cable management is often left to the EPC contractor, who is incentivised to provide the lowest cost solution that meets the contractual obligations. This

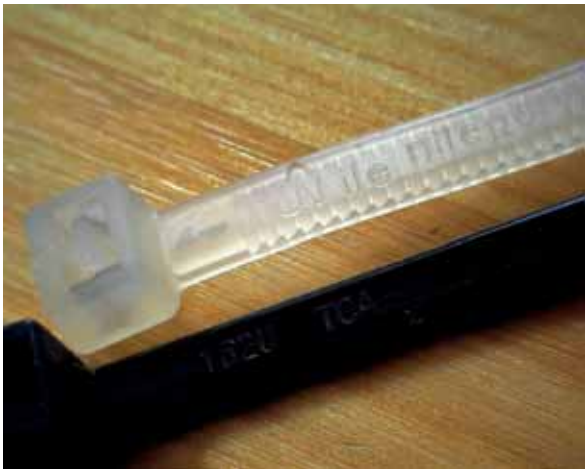

Credit: TECSI Solar

Figure 1. Cable ties markings

is where the ambiguous "UV resistant" specification requirement becomes problematic. Instead, developers should stipulate products by manufacturer and part number or through stringent product specifications. Once the correct specification has been created, a quality assurance programme to evaluate the installed ties needs to be defined. For the most part, cable ties all look the same, making verification difficult if not impossible.

Not all cable ties are the same

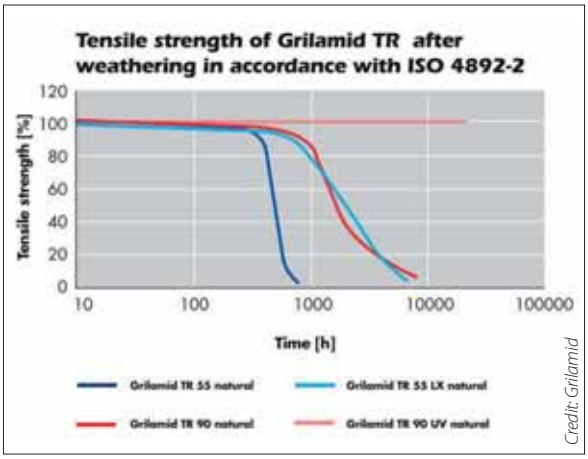
Several cable tie manufacturers, such as HellermannTyton and Nile Polymers, have added their logo to their products as a way to prove the authenticity, and by association the quality, of the installed tie. See Figure 1. However, since the printable area is extremely small and could easily be hidden from view after installation, the auditing process for inspectors or plant commissioning teams can be difficult and expensive even with a reasonable quality assurance (QA) sampling schedule. To make things even more challenging, a single manufacturer may have several solar ties of various UV resistance that look exactly the same, including their markings. Lack of predictable life expectancy and product verification are two of the main reasons why some plant managers have decided to go with metal ties or clips. However, those options, which we will discuss further on, carry their own set of challenges including the need to be grounded.

Expected cable tie life

Specifying the right cable tie depends upon your project costs and O&M schedule. PV modules typically have a 25-year performance warranty while cable ties don't have any. The lack of warranty is driven by the low margins and unknowns associated with the application and environmental conditions. Structural-specific factors, such as the smoothness of the hole where the tie is installed and environmental conditions such as irradiance, moisture and temperature, all contribute to the life expectancy of a cable tie.

Low temperatures in themselves do not generally degrade polymeric wire ties. However, wire ties can become brittle and break under extremely low temperatures. Therefore, it is critical to ensure your wire management specification takes into account the site's temperature extremes. Notched impact tests measure the toughness of a material by measuring the impact energy it can absorb. If the material becomes brittle when it is cold its ability to absorb energy drops precipitously. A product's material data sheet should include notched impact test results Find a result with a temperature equal to or lower than the lowest recorded temperature at your job site (say -30°F for Minnesota) and ensure that the result is within 10% of the baseline test conducted at 73°F/23°C. If it is, then that material should meet the requirements for cold use approval. If the changes are >10% then the material should undergo greater scrutiny. The material shouldn't necessarily be disqualified out of hand since the decreased strength might be acceptable after taking into account the degradations from all possible contributing factors. Calculating the allowable loss is difficult and should only be done by a qualified engineer.

A polymer's strength is typically a function of the length of the polymeric chain. Environmental factors such as UV exposure, elevated temperature, and humidity all contribute to degrading or breaking these chains and reducing the strength and flexibility of the polymer. As exposure times increase, the polymer will become brittle and finally fail under load. And don't forget, just tightening the tie induces a load and stress within the part. Some materials like PVDF (Polyvinylidene Difluoride)-(Kynar) are naturally more resilient to environmental factors than others such as Polyamides (PA)-(Nylon 66). However, using additives such as screeners (carbon black), HALS (Hindered Amine Light Stabilisers), or phenolic antioxidants, the polymeric chains of products such as Nylon 66 can be protected. The impact of using various additives on the weathering performance of a PA material can be significant as shown in Figure 2 for EMS-Grivory's Grilamid TR Polyamides.



Credit: Grilamid

Figure 2. Effects of additives on same PA material

Interpreting and applying test results

Environmental lab testing will not provide direct lifetime estimates due to the inherent complexity of real-world environments. Nonetheless, there is a lot we can learn from it. And, by applying reasonable assumptions, we can make generalised predictions on a cable tie's life expectancy for the purpose of estimating future plant O&M costs. The best approach to predicting life expectancy is to combine indoor and outdoor testing. Indoor testing is used to accelerate exposure, while the outdoor testing is needed to expose the materials to environmental factors more similar to where they are deployed. Typical accelerated UV testing is conducted by xenon arc light exposure in chambers such as the Q-SUN by Q-Labs Corporation. The test procedure is governed by standards such as ASTM D2565 or ISO 4892-2. The xenon arc testing simulates sunlight exposure and can run 24 hours a day at full irradiance. Proper testing includes periods of wetting and humidity to activate potential degradation mechanisms triggered by the availability of additional oxygen from the water. Common xenon arc testing times include 5,000, 10,000, 15,000 and 20,000 hours.

For demonstration purposes, assume an average sunlight exposure of 6kWh a day for a particular site. Then, assume the cable tie is exposed to two-thirds of that solar exposure. The result is 4kWh/day of exposure on the tie. This roughly equates to four hours of light exposure in a 1x concentration xenon arc test apparatus. Taking this into account, the following model could be created:

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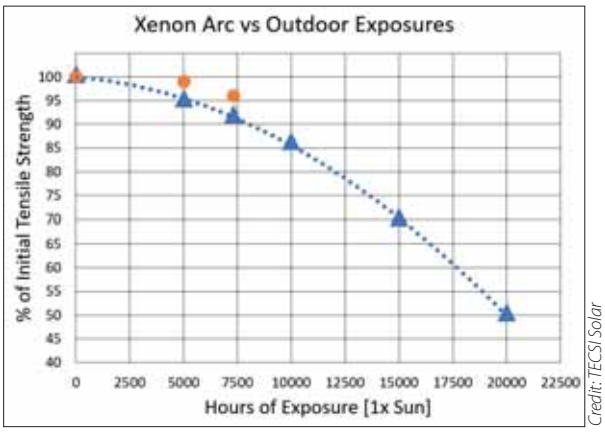
Xenon Arc Target Exposure Time/ Estimated Years of Outdoor Exposure

- 5,000 hours/3.5 years
- 10,000 hours/7 years
- 15,000 hours/10.5 years
- 20,000 hours/14 years
- 25,0000 hours/17.5 years

Once a target exposure time is reached, some of the samples are removed from the chamber and mechanically tested. Strength reductions <10% from baseline should be acceptable. The accuracy of this model could vary significantly due to the limitations of the exposure mechanisms of the xenon arc chamber compared to all the possible factors (and their intensities) that exist at a job site. To increase the accuracy of the model, these results need to be compared to data from outdoor exposures.

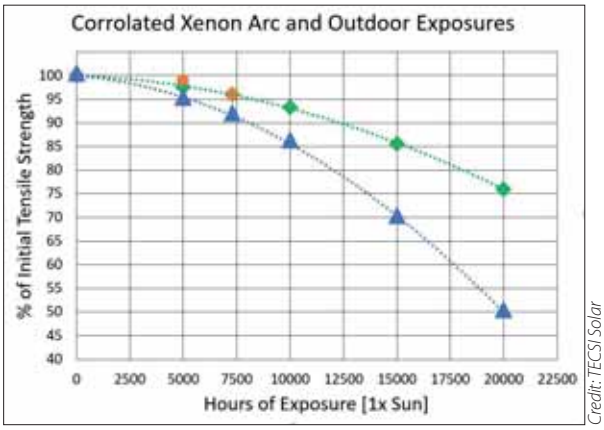
The best methods for predicting a polymer's performance is through real world exposure. So, any real world historical data you can get from a manufacturer on their product is highly valuable and should be sought after. Even more valuable is if their materials have been submitted for unaccelerated outdoor testing to third-party test labs such as Q-Lab Corporation. They have test labs in various environments such as: (1) hot and humid Florida, (2) hot and dry Arizona and (3) cold and moderate Ohio. Samples should be removed and mechanically tested every year (or some other reasonable schedule) to provide strength retention data over time. After 25 years they will have collected all the required data on how the material will behave. However, material manufacturers don't usually have 25 years to wait to sell their product. By coupling the limited outdoor testing with the accelerated indoor exposure from the xenon arc chamber, useful models can be created without having to wait 25 years.

For our example problem of 4kWh of exposure per day, one can compare the outdoor test results at 3.5 years with the xenon arc test results at 5,000 hours. If the results correspond, you can begin to feel confident in the equivalences of the xenon arc exposure times to real world performance. However, if the xenon arc results are different than the degradation found through outdoor exposure, then adjustments need to be made to create a more accurate model. For the fictitious example shown in Figure 3, the xenon arc results represented by the blue triangles overestimate the degradation compared



Credit: TECSI Solar

Figure 3. Xenon arc versus outdoor exposures



Credit: TECSI Solar

Figure 4. Correlated xenon arc and outdoor exposures

to the outdoor exposure data represented by the orange circles. After five years (7,300kWh) of exposure outdoors, the samples lost 4% of their tensile strength. On the other hand, samples exposed to the xenon arc testing lost 8.3% of their tensile strength. By comparing the results, an adjustment factor (4/8.3=.48) can be applied to the xenon arc data to produce the more accurate prediction curve shown in Figure 4 by the green diamonds. The 10% allowable strength reduction limit previously identified can then be applied to the data. The adjusted prediction curve (green diamonds) shows that 90% of the strength is expected to occur around 12,500 hours. This equates to 8.5 years of outdoor exposure which is significantly more than the 5.5 years initially predicted by the blue triangle curve from the original xenon arc test data.

It should be noted that this methodology assumes a constant difference between the xenon arc and outdoor testing when extrapolating the data into the future. However, this might not hold true. There are many factors that bring uncertainty to this approach including the differences between, (1) sample thickness versus tie thickness, (2) actual exposures versus the lab exposures, and (3) tie installation strength requirement versus allowable strength reduction limit. And there are always discrepancies that can arise from improper installation leading to premature failure such as the installation of cable ties across sharp edges of mounting holes. Nonetheless, this methodology can be used to create a budgetary model for comparing the total cost of system ownership for cable ties of varying quality.

Metal wire clips

Metal wire clips were developed as a way to bring predictability to the otherwise unpredictable life expectancy of polymeric cable ties. Most clips are made from stainless steel and come with the expectation that they will last the life of the system. In addition, metal clips are designed to be installed directly to a structural mounting flange (such as a module's frame wall), removing the need for the predetermined attachment hole required by cable ties. Wire clips might seem to be the simple solution. However, these devices have their own issues that need to be addressed through proper design and installation practices. Failure to do so could lead to electrical shorts, attachment failures and plant downtime.

Most clips are punched from stainless sheet steel and then formed by progressive die processes. The punch process can produce sharp edges that can cut or otherwise damage the wire's sheathing, leading to ground faults. Many manufacturers include edge detailing to mitigate this issue. For example, Wiley's ACC-FPV1 clip shown in Figure 5 uses a flare detail to keep the sharp edges away from the wire. Heyco wire clips are produced using a coining punch process which naturally rounds the punched edges.

Credit: Wiley

Figure 5. Wiley wire clip with flared edges to help prevent wire damage

Per code, metal wire clips need to be bonded to the ground path to provide system safety in the event of a short. Meeting this requirement on galvanised steel structures isn't difficult if the clips are made of stainless steel since both metals conduct electricity when they are in contact. However, this is not the case with stainless steel clips against anodised aluminum structures. Anodisation is a surface treatment that protects the base aluminum from corrosion. However, it is also a dielectric, meaning it does not conduct electricity. (Anodisation also occurs naturally, but is more robust and has better aesthetics when driven by industrial processes.) Most clip designs include sharp teeth that penetrate the anodisation layer connecting the clip to the system's ground path. Atmospheric corrosion over time at this critical connection could lead to failure of the ground path resulting in shock hazards and possibly fires. Perhaps even more concerning is galvanic corrosion driven by the dissimilar metals. To prevent this, the clips would need to be made of aluminum to match the aluminum substructure. However, aluminum clips are not practical since they would be highly susceptible to galvanic corrosion on galvanised steel structures and they would not reliably penetrate the anodisation layer of aluminum structures. In addition, due to their greater flexibility they would not have the same clamping force as similar stainless designs.

Corrosion testing

A properly designed clip can make the difference between zero maintenance and a complete plant retrofit. Besides historical data, the best way to evaluate the quality of a clip is through testing. Salt fog testing such as ASTM B117 can be used to evaluate material compatibility and corrosion resistance. Galvanic corrosion occurs when moisture acts as an electrical conductor between two dissimilar metals with different electrode (galvanic) potentials. The greater the potential between the materials the faster they will corrode. For solar wire clip applications, we are typically concerned with the stainless steel of the clip and the aluminum of the substructure (module frame wall). The ASTM B117 salt fog test can be used for accelerating galvanic corrosion between metals and is considered highly aggressive. Since aluminum has a lower electrode potential, it sacrifices itself producing aluminum oxide. Runaway galvanic corrosion can eventually consume enough of the base aluminum that the clip completely falls off. However, before that happens, the aluminum oxide buildup, which is a dielectric, will inhibit the clip's ability to transfer current from the wire to the safety ground path. If the wire insulation becomes compromised and the clip no longer has its current-carrying capacity then it could become energised resulting in shock hazards or arcing. The aluminum oxide produced from the galvanic corrosion has a chalky white appearance that looks very similar to the salt deposits left behind by the salt fog. Therefore, after the salt fog testing in complete, the samples should be thoroughly rinsed to dissolve away the salts. Any white powdery residue left behind at the clip/aluminum interface is a result of galvanic corrosion. By reviewing corrosion residue results from various manufacturers, one can choose the better performing wire clip. Similar to the cable tie manufacturers, many wire clip manufacturers are including identification markings to their clips so auditors can verify the installed product and thus its quality.

> "Asset managers should research the deployed or planned wire management method. Not doing so could easily cost hundreds of thousands of dollars"

The amount of galvanic corrosion that would prevent a wire clip from performing its bonding or conductivity requirement isn't typically tested. This is unfortunate since maintaining conductivity could be critical to the safety and continued operation of a power plant. Bonding performance of a clip to the aluminum structure is dependent upon several factors including the clip's base material, coating, the size and shape of its teeth, the number of teeth, and its clamping force. While straight salt fog testing is useful, a modified version that includes bonding path resistance testing such as the one in Section 13 of UL 2701 would be more applicable. By adding the conductivity testing, a more relevant evaluation is created which can produce results that are both different and more useful than the salt fog testing alone.

ASTM B117 salt fog testing is good for comparing products. However, it is not good at predicting life expectancy. As a rule of thumb, one can say that a moderately aggressive salt spray exposure time is around 500 hours while a more robust timeframe is 1,000 hours or more. Results cannot be used to predict real-world performance. The extreme nature of the test as well as the actual variability of the environmental conditions at the job site makes performance predictions from B117 impractical. A better method for predicting life expectancy of a connection is the standard GMW 14872 – Cyclic Corrosion Laboratory Test. This standard has been defined and refined by the automotive industry to qualify materials for use on automobiles. The standard provides guidance on test protocols and pass/fail criteria for a part's particular location on the vehicle such as under body, under hood, or general exterior locations. The GMW testing includes a more complicated salt solution than B117 and uses a salt spray instead of the fog. Salt exposure is coupled with varying periods of humidity and dryness at controlled ramps to simulate more realistic conditions to which the galvanic corrosion would actually occur in the environment. Over the years, they have tweaked the tests to map with results the auto industry has seen in their fleet of cars. Entire test chambers, like the Q-lab's Q-FOG CRH, have been developed specifically to conduct these tests. The only significant modification that would need to be employed for solar applications is the inclusion of the bonding path resistance testing. One hurdle to overcome with this approach is the expected cost increase of 1.5 to 2 times over the standard B117 testing. However, this approach would allow for predictive modelling, which currently isn't provided by the salt fog testing.

It should be noted that not all stainless steels perform the same. The less corrosion resistant steels such as 410 can begin to rust after just 48 hours of exposure to the 5% salt (NaCl) solution of ASTM B117 [2]. Highly corrosion-resistant steels such as 316 stainless can be exposed for over 1,000 hours before showing signs of rusting. Rust alone does not mean that a clip can't function as intended. However, as rust builds up the likelihood that it will inhibit conductivity between the clip and the base material increases. Also, rust is

generally associated with poor product performance and could trigger warranty claims. Interestingly, theoretical analysis shows that 18-8 stainless steels (304 and 302) which are less corrosion resistant than 316, might be better at reducing galvanic corrosion when in contact with aluminum since they are closer to aluminum on galvanic charts. 410 stainless steel is typically not recommended for use with aluminum due to galvanic issues and should generally be avoided [3]. Passivating stainless can further reduce atmospheric and galvanic corrosion. However, passivation increases cost and often isn't required. This is probably why we don't see passivated stainless wire clips being offered in the marketplace.

18-8 and 316 stainless steel fasteners are typically approved for use in aluminum applications so long as they are not exposed to chloride (i.e. salt). However, the unique requirements of wire clips make them more susceptible to failure by atmospheric and galvanic corrosion. The fact is, at this time, we don't have a good understanding of the life expectancy of the electrical connection of stainless steel wire clips on aluminum. And, until we have more field and chamber test data we will not be able to predict how nor when failures might occur. One needs to account for this added risk of variability when developing an O&M budget.

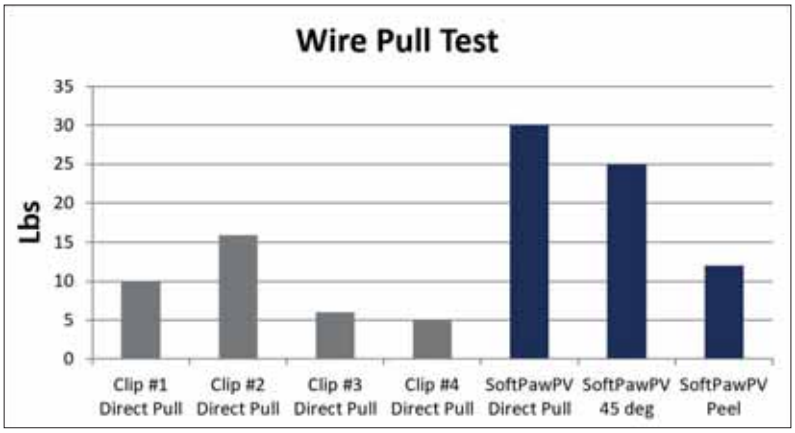
Credit: TECSI Solar

Figure 6. Wire clip mechanical load test

Mechanical load testing

Cycle testing is important to ensure that a clip will not walk off its supporting structure. The most common test procedure for evaluating this is the UL 2703 temperature cycling test. This test protocol cycles samples 200 times from -40°C to +90°C. A minimum of 1lb should be applied to the clip in the most vulnerable orientation at all times during the test to simulate field-applied loads. This target weight is based upon two 72-cell module pigtail wires weighing 4oz each (the target cable and another cable crossing or braided into it) and a safety factor of 2.

Insertion and removal forces should be evaluated for both the clip to the structure and the wire to the clip. A perfect clip would create a strong electrical and physical bond to the structure yet be easy to push on and take off for all types of flange thicknesses. As installers will tell you, pushing on just a few of these clips can leave fingers blistered at best and bleeding at worst. Installers can use gloves, but they lose the dexterity required to pick up, hold and align the clips. Inevitably, a creative and somewhat finger-abused installer will look for alternative ways to install the clips. This can include using the pigtail wires or tools such as hammers or pliers to push the clips onto the structure. These approaches can damage the module's cables or the backsheet. This damage could lead to shorts or module corrosion which might not show up for months or even years after the installation is complete. Some clip manufacturers such as HellermanTyton have tried to address this issue by increasing the push-on zone for the installer's fingers. Nonetheless, the issues persist. Most clips utilise retention teeth that are orientated away from the insertion direction to allow for lower attachment forces. However, this can greatly increase the required removal force during O&M operations, exacerbating the same issues encountered at installation.



Credit: TECSI Solar

Figure 7. Results from mechanical load testing

Mechanical load testing by a universal test machine is typically used to evaluate both the clip and wire securement capacities as shown in Figure 6. Testing by TECSI Solar engineers has shown that the forces required to remove wires from a clip range from 5 to 16lbs, with the average around 9lbs. See Figure 7. Results are from four different styles of clips from three different manufacturers. By pulling on the wire, both the wire capture strength and the clip attachment strength were evaluated. Multiple tests were conducted on each clip. All except one test resulted in the wire evacuating from the clip instead of the clip evacuating from the aluminum mounting plate. Wire removal at a moderate force is preferred since the higher clip attachment loads could lead to wire damage in the event a wire gets pulled unexpectedly. The lower end 5lb force was found acceptable by a cross functional team of engineers and installers. Clips with pull out forces less than this may require greater scrutiny, or possibly be rejected outright.

The right clip for the application

Before you choose a wire clip for your project, look for proper material callouts, testing, and edge treatments as discussed in the previous sections to reduce your risk of corrosion and ground faults. Then address the "Goldilocks" issue naturally associated with clips. Even though the clips are designed for various sizes they don't have the acceptance range of cable ties. First, you need to compare the clip's flange thickness spec to your module's mounting flange thickness. A mounting flange larger than the design range of the clip can make clip securement and removal challenging, leading to hand injuries and product damage. Conversely, mounting flanges smaller than the design range can result in clips falling off from

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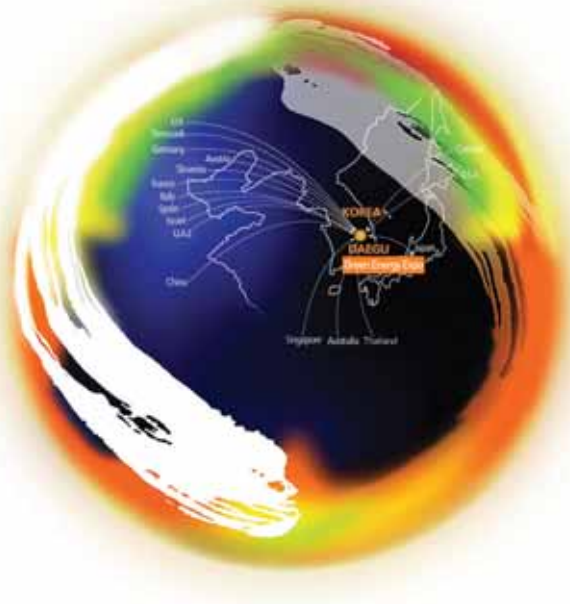

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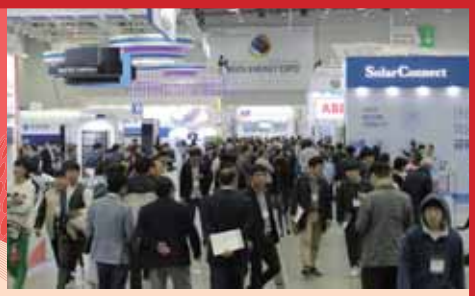

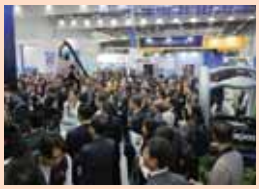

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Credit: TECSI Solar

Figure 8. Esdec racking integrated wire management


Credit: TECSI Solar

Figure 9. SolarCleat perlin integrated wire management

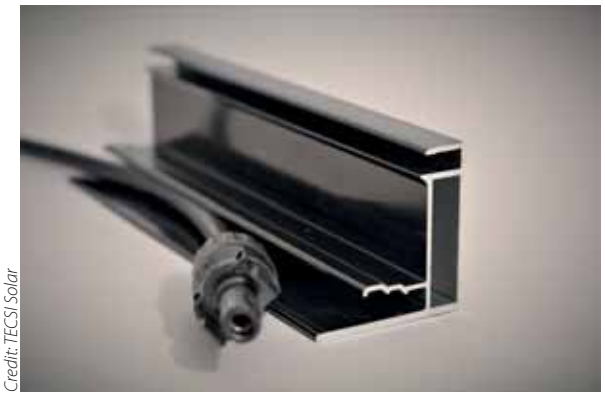
Credit: TECSI Solar

Figure 10. SoftPawPV module-integrated wire management

installed stresses or thermal cycling. Next, test out the clip's compatibility with the project's module pigtail wires and homerun cables. Research by TECSI Solar has shown that PV module j-box wires have diameters varying from 5 to 7mm. Most wire retention devices have a limited acceptance range and even if your cable fits within their stated range the fit should be verified. Too tight a fit along with wire tension can damage the cable resulting in sheathing failure and ground faults. Conversely, a loose fit can allow motion from thermal expansion or


Credit: TECSI Solar

Figure 11. SoftPawPV ready to install factory wiring


Credit: TECSI Solar

Figure 12. Removing standard factory installed wire ties

wind to chafe the wire, which can result in similar failures.

Structure-integrated wire management devices

One of the most promising innovations in wire management is the integrated solution. These solutions fully integrate the wire management into the modules or structure. They don't require additional consumables and come installed on the structure ready to accept wires. Since this approach relies upon the product's existing material, there are no compatibility or corrosion issues as with wire clips or questions about UV and weathering resistance as with cable ties. All of the testing associated with corrosion and weathering is no longer applicable. The wire management features are guaranteed to last the life of the system since they are made of the same material. ESDEC's FlatFix product shown in Figure 8 is representative of such a device. Wire management devices can also be formed right into the structures. The licensable SolarCleat technology shown in Figure 9 is a feature that can be punched out of metal purlins or formed into polymeric products. This single feature can accept several wires at a time and since there are no consumables each one is virtually free, after the initial investment in tooling, of course. As with wire clips, the cut edges of the SolarCleat are treated by coining punch processes or flaring to prevent wire chafing or damage.

Module-integrated wire management devices

Perhaps the most promising integrated wiring management device is the licenceable SoftPawPV flange, shown in Figure 10. This device adds wire management to the frame wall of a PV module. Previous module-integrated wire management devices utilised features on the junction box to hold either the connectors during shipping or the wires at installation. However, the drawback to those designs was their limited use range. The SoftPawPV flange extends all the way around the PV module, providing the full range and flexibility for wire attachment that the industry has grown to expect through the use of wire clips. In addition, since it is integral to the module's frame wall, there are no weathering, UV, or galvanic corrosion issues typically associated with consumable devices, and thus, by definition, the device will last the life of the module.

The SoftPawPV device makes it possible to completely remove the use of clips or zip ties within the array since it can also manage the home run cables. While the j-box pigtails run along the top of the module near the j-box,

Credit: TECSI Solar

Figure 13. SoftPawPV temperature cycling testing

the homerun cables can run along the bottom of the module. In addition, due to the continuous nature of the device, it can handle multiple wires by skipping their attachment along the length of the frame. If circumstances arise where clips are required, they can easily be included as with any other module.

In addition to field wiring, a module with integrated wire management can come from the factory in a prewired "ready-to-connect" position. See Figure 11. Field wiring of the module is essentially removed from the installation process all together. Prewiring also eliminates the need for wire cutters and the installation step of cutting off two or more manufacture applied zip ties that bundle the coiled wires to the j-box. See Figure 12. By removing this step, the installers save prep time and reduce the possibility of damaging the back side of the module. In addition, prewired integrated modules remove the need for managing thousands of scrap plastic pieces across an entire job site. Also, the cable ties that bundle the wires on the module are often cut prior to wiring up the string. This leaves the pigtails dangling from the j-box where they are vulnerable to damage and contamination. As installers have learned, if a connector's contacts get dirty it can lead to dangerous situations including melted connectors and arcing.

O&M is also greatly simplified with module integrated wiring. When a module needs to be replaced there are no clips to remove, cable ties to cut, or replacement parts to bring. The affected module can simply be removed, replaced, and rewired. In addition, module integrated wiring can dramatically reduce the required preplanning normally associated with servicing a failed module.

A module integrated device can be optimised to the junction box's wire size because it is part of the module and can be defined at the bill of materials level. Nonetheless, it needs to be tested for mechanical strength like any other device. Relevant testing includes the mechanical load test and temperature cycle test previously outlined for wire clips. Variants of the SoftPawPV flange with different grip features were tested by temperature cycling as shown in Figure 13. Most of the designs passed the 200 cycle test requirement but some fell out prior to test completion. The designs that passed were further evaluated by standard mechanical pull testing. And to even further define their performance they were tested at three different pull angles. The results from the current design are shown in Figure 7. It should be noted, that at no time during testing were the wires or their sheathing damaged by the SoftPawPV device – hence its name.

Determining lifetime costs

The variabilities that exist in the application of cable ties and wire clips make predetermining lifetime costs difficult. Cost modelling by TECSI Solar engineers has shown a significant volatility in the predictions driven by a number of factors and their potential severity. The TECSI Wire Management Cost Estimation Tool for commercial systems attempts to take these factors into account. This tool is available on the resources page of our website (www.TECSIsolar.com/Resources). Please note, there are limitations to this modelling. For example, if a project deployed a high-quality tie and they were installed such that there were stress concentrations leading to failures at a rate equivalent to lower quality ties, then the cost savings estimated by the tool would not be realised. However, barring any installation issues, the TECSI modelling reveals that the more robust solutions result in lower overall cost of ownership due to lower O&M costs. It all depends upon the reliability of the deployed device to actually meet the target life span. This is where integrated devices have the greatest advantage. Due to their general resilience from weathering and galvanic corrosion, they have the lowest risk of not lasting the design life of the system.

Final thoughts

No wire management manufacturer currently provides a warranty on life expectancy due to installation parameters, site variances and the small profits associated with their devices. So for now, it is up to the asset manager to decide the risk level associated with a given wire management approach. Before one purchases an asset, they should research the deployed or planned wire management method. Not doing so could easily cost hundreds of thousands of dollars over the lifetime of the system. Insist that product manufacturers supply their test data. Specifically, ask them for test to failure information. Often data sheets show only the positive results. However, all products have their limitations. The goal is to understand the failure modes and whether they happen suddenly or predictably over time. Additionally, deploy integrated devices whenever possible. They have the potential to significantly decrease overall costs and take the risks out of wire management. Finally, use a tool like TECSI's Wire Management Cost Estimation Tool to estimate life time system costs and then ensure those costs are included in the plant's operating budget. ■

The TECSI Wire Management Cost Estimation Tool is available at www.TECSIsolar.com/Resources

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Author

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Project briefing

'SOLAR FOR THE COUNTRY': INSIDE SOUTHEAST ASIA'S LARGEST MICRO-GRID

Project name: Paluan Solar-Battery Micro-Grid
Location: Paluan, Mindoro
Project size: 2MW solar, 1,800kW/1,500kWh battery, 2MW diesel backup

While Filipino policymakers pondered a controversial bill that would allow a solar company to set up a micro-grid and transmission franchise aiming to improve power supply across the country, a small town on the island of Mindoro was already enjoying round-the-clock electricity for the first time ever. The town of Paluan, situated in the northwest corner of Mindoro, the seventh largest island in the Philippines, dominated by an agricultural society and dubbed 'the brownout capital of the Philippines', is receiving power from Southeast Asia's largest micro-grid, combining solar PV, energy storage and diesel technology.

The chief of Solar Philippines, the company that developed the project, believes it is also the largest rural micro-grid in the world that is not benefitting from subsidies. Leandro Leviste, the son of Senator Loren Legarda, is making waves in the country's energy sector with his aggressive expansion of solar development activities in both the large-scale and mini-grid segments as well as running the country's first PV module manufacturing facility.

For the mini-grid sector, Leviste is knowingly going into loss-making projects, with full belief in the continued downward trajectory of the prices of both silicon and lithium, combined with increasing demand, in such a manner that will make solar PV module and energy storage battery technology more profitable in future projects.

Operating under its solar-battery mini-grid focused entity named Solar Para Sa Bayan (SPSB) – 'Solar for the country' – Solar Philippines is supplying power to nearly 3,000 customers in Paluan while slashing the cost of power for commercial entities by half.

It's a small dent in the race to improve power for the estimated 20 million Filipinos who lack 24/7 electricity and the 12 million who have none at all, but Leviste believes this kind of project will soon become the norm. His vision is that, once well established, micro-grids will not only power the unserved and underserved populations of remote areas and villages in developing countries, but they will also start to creep into supplying towns and even cities.

"The problem of the global micro-grid industry is that it has limited itself to subsidised projects, which are limited by the imagination of policymakers," says Leviste. "The only way to make micro-grids scale today is to be willing to do unsubsidised, even initially loss-making projects, banking on both growth in demand and decrease in PV-storage costs to turn a profit over time. We're betting our customers in Asia and Africa will one day have standards of living, and thus consumption, [close to] what households in the US and Europe have today, and that our micro-grids can help them reach that point sooner, so we're effectively in the business of ending poverty."

Before the micro-grid was installed, locals in Paluan had just three to eight hours of unreliable electricity a day and brownouts could last for days. State utility the National Power Corporation (NPC) had been running a 5MW diesel plant 30 kilometres away to electrify the area, but difficulty with transmission caused it to stop providing to Paluan around 10 years ago.

The micro-grid, overlooking paddy fields and set against the backdrop of Mount Calavite, a peak above 1,500 metres altitude, is fitted with 2MW of solar power, with inverters supplied by Fronius. It also has a 1.8MW/1.5MWh storage system from US-based firm Tesla and there are three diesel generators with a combined capacity of 1,260kW.

The power of power

Besides giving the community uninterrupted power for the first time ever on Christmas day, the micro-grid has brought direct benefits to the livelihoods of many individuals.

NPC and Occidental Mindoro Electric Cooperative (OMECO) cut their power supply to Paluan around a decade ago because the power plant was too far away, but the micro-grid has allowed the community to enjoy 24/7 power, says Barangay (district) Captain Tinamisan, as he tucks into a fish and vegetable stew, washed down with rum, in a simple hut surrounded by paddy fields, water buffalo and farmers tilling the fields.

"Before we weren't able to store the fish or squid caught from the ocean," he says. "Now we can store for a day and sell it to other municipalities and increase our income."

The district is very thankful for the service and can see plenty of opportunities coming as a result of the power supply, he adds, with plans for an ice plant and cold storage system in the works, to help store not just fish but also produce such as onions and tomatoes – two of the staple crops in Occidental Mindoro.

At this time of year, there's a hive of activity as farmers dry rice in the sun cover-

Credit: Tom Kenning

The micro-grid combines 2MW of PV capacity with storage and diesel generators

Credit: Tom Kenning

Barangay (district) Captain Tinamisan (middle left)

By Tom Kenning

ing long stretches of the road – the most regular sight other than tricycle motorbike taxis and basketball courts.

Senior high school teachers John Robert Villas and Mark Angelo Salvador used to have no choice but to employ traditional teaching methods such as writing on chalkboards and using visual aids, since power only ever came at night time after school ended. But the micro-grid now allows students and teachers to access the internet, TV and other more advanced educational technologies at any time.

The new access to power even led Villas and Salvador's students to win a broadcasting journalism competition. Electricity is also now cheaper for the school to utilise and the community at large is able to enjoy electric appliances more due to this low cost of the kilowatt hour.

Shopkeeper Gina Martinez has seen her business grow since the micro-grid power came to town and she is able to sell soft drinks, bottled water and frozen foods. Just selling ice covers the operating costs of her fridge, she says, and then she can generate income by selling the other products, safe in the knowledge that there will be no more brownouts.

"The solar project is very applicable to business owners and Paluan has grown in economic status ever since," adds Martinez. "We are expecting it to move from a third-class income area to a second- or first-class soon."

It would be fair to say that no matter which locals PV Tech spoke to in Paluan, the project has been received with overwhelming positivity. The unmistakable sound of karaoke in town, well after the sun had set, was perhaps symbolic of that.

Consistent and cheaper

As the project is located near to the centre of demand, there are few transmission losses and the integrated micro-grid ensures power stays at the rated voltage, so this has stopped lights dimming and flickering and kept supply more consistent. Some consumers did receive higher bills initially due to the power coming 24/7, but Solar Philippines has conducted seminars to educate the population on how to manage energy use.

NPC had been supplying electricity at PHP8-10/kWh (US$0.15-0.19) for residences and PHP15-16/kWh for commercial consumers. Now Solar Philippines has slashed that rate to PHP8/kWh for both segments.

The project took just six months to build from October 2017 to March 2018. The pace of developing such projects is one of their key assets, since large-scale PV projects can take around two years, depending on location, and this is already faster than almost all other forms of energy technology.

How it works

The solar PV system powers Paluan during the day, while simultaneously charging the Tesla batteries. As the sun sets, between 5 and 6pm, the batteries start to provide power and then as the town hits peak demand between 8 and 9pm the diesel generators automatically power up to help the batteries meet the extra power consumption of the evening. The gen-sets shut down as the peak reduces and the batteries can supply all the power necessary for the rest of the night until 5am with seven hours of arbitrage. Besides hitting peak times, the other condition that causes the gen-sets to automatically switch on is when the battery energy drops down to 10%, having completed a full cycle.

Jojo Herkito Acedera Jr., senior O&M manager for the project, says that the gen-sets use 700 litres of fuel during the rainy season (May to September) as extra cloud cover means diesel has to make up for the shortfall in solar generation, while the summer (October to April) requires just 500 litres of fuel.

An energy management system, with real-time automation controller to help integrate the power supply, was provided by SEL – 3555.

Fronius supplied 60 of its PV inverters, while the project used 6,480 polycrystalline 156cmx156cm, 325Wp modules. These panels need cleaning with soap and water once a month. While the rainy season requires a lower frequency of cleaning, it also requires the O&M team to cut the grass throughout the plot.

Credit: Tom Kenning

Jojo Herkito Acedera Jr., senior O&M manager, watches over the project performance

Credit: Tom Kenning

The project uses 60 Fronius inverters

The Tesla battery system has two inverters, each with five sets of power stages and 12 batteries per stage, meaning a total of 120 batteries connected in parallel at 1,800kW capacity. Tesla also comes in to do its own periodic O&M service on the batteries.

The 6.5-hectare plot of more or less flat land was idle before being leased to SPSB. The team's technical inspection had to focus on flooding susceptibility since a thin stream from the mountains runs through the site.

Logistics were the biggest problem with equipment needing to be transported from island to island, from Manila to Batangas and on to Mindoro, says John Oliver Micua, project development officer at Solar Philippines. Sorting out lorry drivers and access was helped by the local support for the project, however, and the government has been building an access road for general business in the area, particularly

Credit: Tom Kenning

The system already generates more power than needed

with the construction of Paluan Fish Port, which is coming close to completion. This port will further serve the region's seafood export trade.

Having used just 2.5 hectares so far, Solar Philippines has kept four hectares of land free to allow it to install another 4MW of solar modules, while foundations for doubling the battery capacity have also been installed. The system already generates too much power for the 2,848 paying consumers to absorb so the operators are performing manual curtailment. With this in mind, the team is already planning transmission capacity expansions to start supplying power to Mamburao nearby.

If this goes ahead, then the original NPC power plant will stop serving Mamburao and focus on other unserved areas.

Transmission is the biggest challenge for expanding the reach of the micro-grid since the team will have to add capacitors to minimise voltage drops. Vegetation can be an issue so clearing a distance of three metres either side of the transmission lines becomes necessary.

Leviste has already started supplying power from a large-scale solar project with one of the lowest prices in Southeast Asia and has taken the risk of supplying power to the wholesale electricity spot market (WESM) rather than waiting for the ERC to approve a PPA, and this provides a clue into the thought behind the company's initially loss-making venture into micro-grids.

"If it is acceptable for Silicon Valley companies to initially lose money as they invest in the long-term, it surprises me that not more companies take the same view for off-grid electrification, when the impact on people's lives is so much greater," says Leviste. "We're convinced of this opportunity which the solar and finance industries have largely missed, so are financing these unprofitable micro-grids with proceeds of our profitable utility-scale business, as an investment that pays off over the long term." ■

SPSB 'Solar for the country'

The House Bill (HB 8179) passed through Congress in December 2018 grants Solar Philippines, operating under the name Solar Para Sa Bayan (SPSB) 'Solar for the country', what is described as a non-exclusive franchise offering an alternative energy source from traditional utilities to Filipinos.

It is deemed a social enterprise that will bring solar-battery mini-grids, similar to that of Paluan, to locations throughout the country without subsidy. Leviste bills it as a chance to offer cheaper, cleaner more reliable electricity to improve the lives of Filipinos like those we heard from earlier in this article.

Of course, there has been some staunch opposition, particularly from the electric utilities, who claim to have an exclusive right to serve their franchise areas – a claim that Solar Philippines has disputed. Nonetheless, these electric cooperatives had to go through a lengthy competitive process to be awarded those franchise areas and so they want to protect them.

The Philippine Rural Electric Cooperatives Association (Philreca), for example, has argued that SPSB's franchise goes against the provisions of the Electric Power Industry Reform Act (EPIRA). Leviste has noted, however, that since EPIRA was passed 17 years ago, just three barangays (districts) have been electrified via the Qualified Third Party (QTP) programme and the majority of Filipinos remain either unsatisfied with power prices or want alternative options for power providers.

Through the House Bill, SPSB aims to make the process of entering these franchise areas far easier and it claims to be opening the door to other private entities to follow suit, although as already discussed, some solar developers, including those represented by the Philippine Solar and Storage Energy Alliance (PSSEA), have opposed the House Bill. PSSEA has described it as monopolistic and lacking in regulation, among a range of other issues.

While Solar Philippines argues that the House Bill will counter a monopoly already held by the utilities, Theresa Capellan, president of PSSEA, says that it is merely replacing one monopoly with another and will hurt innovation in the sector. She also questions the 'non-exclusivity' of the House Bill by claiming that the process of obtaining a congressional franchise for other developers would be extremely onerous and time-consuming.

Right now SPSB and others can still go ahead with projects, but at a slow pace as it requires a lengthy approval process in any franchise area. In the case of the mini-grid described in this article, it is located within the franchise area of the Occidental Mindoro Electric Cooperative (OMECO), but the project could go ahead partly because the Paluan area was already so heavily underserved.

Ultimately, SPSB has targeted bringing its power to half a million people this year in Mindoro, Palawan, Masbate, Batangas, Quezon, Aurora, Cagayan, Isabela, Panay, Negros, Misamis and Davao among other areas. If the downward trend of lithium prices continues in its current direction, then Leviste could be on to a winner in the long run with these projects after taking a financial hit in the first few years. It will indeed be interesting to see what kind of prices he'll be paying to replace the batteries after they have run their full 10-year life cycle.

While Solar Philippines claims that the House Bill had come under more scrutiny than nearly any other bill in the 17th Congress, Paul Pineda, head of the Philreca Resource Center, says that the bill was deliberated in just a matter of hours and discussed without any representation either from stakeholders such as distribution utilities or other players from the renewable energy sector. Pineda also claims that SPSB actually charges higher rates than nearby cooperatives. He was citing bills that Philreca has seen from 20 customers of the Paluan micro-grid during a visit to the project and its customers.

In a statement, SPSB said: "Existing utilities may be best served if, instead of trying to prevent competition, they just focused on lowering costs and improving services, so Filipinos would be satisfied with their electricity, and there would be no need for cheaper, cleaner, more reliable alternatives at all."

PSSEA had also been pushing for safeguards and an obligation on Leviste's part for a nationwide franchise and it says that the more crucial amendments proposed were accepted in the final reading.

The system incorporates a storage system from Tesla

Credit: Tom Kenning

Optimising Europe's solar plants: O&M guidelines to further solar growth

Operations and maintenance | Solar O&M is rapidly evolving as PV deployment gathers pace worldwide. Guillermo Oviedo Hernández, Elena Bernardi and Jörn Carstensen of SolarPower Europe's O&M Task Force look at some of the emerging trends, practices and business models in this increasingly critical arm of the solar industry

Credit: BayWa r.e.

As O&M's importance grows, new and innovative technologies and business models are emerging

Operations & maintenance (O&M) is key to the technical and economic performance of solar systems and plants. It is widely acknowledged by all stakeholders that high-quality O&M services mitigate potential risks, improve the levelised cost of electricity (LCOE) and power purchase agreement (PPA) prices and positively impact the return on investment (ROI) from a solar project. Today, O&M has become a standalone segment in the solar value chain with many companies specialising exclusively in solar O&M.

However, one of the main challenges facing the solar O&M industry is the discrepancies between the quality of services provided by different O&M contractors. According to a survey conducted by SolarPower Europe, two out of three solar professionals say there are "very large" or "significant" discrepancies between the quality of services provided by various O&M contractors. Reasons for this include increasing price pressure, lack of standardisation and minimum requirements, inadequate management processes, poorly qualified staff and insufficient use of digital data analytics.

Europe is the continent with the oldest fleet of solar plants, thus, proper "health care" for these plants is essential to meet performance expectations. Within this context, SolarPower Europe's O&M Task Force decided, back in 2015, to share its know-how and experience in the field, creating the first edition of the 'O&M Best Practices Guidelines'. Now, in their third edition, the guidelines have become a living document with an active community behind it, already consisting of nearly one hundred top experts from more than 50 companies. The O&M Best Practices Guidelines version 3.0 dives deeper into business models to improve O&M services with new sections on 'innovations and trends' and 'revamping and repowering'. The guidelines aim to increase awareness, consensus and encourage O&M best practice adoption by the industry, both across Europe and outside, in particular in emerging markets.

Innovations and trends in solar O&M

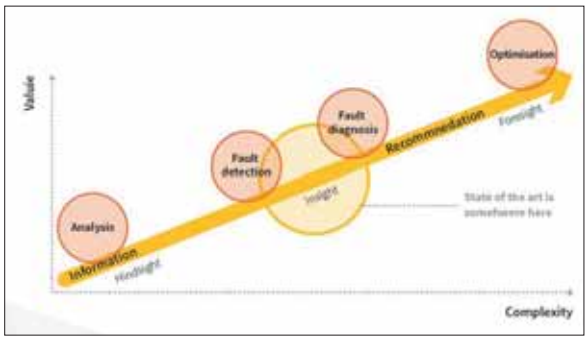
This brand-new chapter of the guidelines was motivated by the tremendous increase in solutions entering the market, which in one way or another, appealed to an innovative concept – either by doing something completely new to the industry or by doing something known, but in a smarter and more efficient manner.

According to a 2015 report from KIC InnoEnergy [1], innovations in O&M services are anticipated to reduce solar LCOE by 0.8-1.4% between 2015 and 2030. The savings are dominated by improvements in OPEX and power plant availability, and hence net annual energy production. Therefore, O&M contractors are increasingly relying on innovations to keep up with market requirements.

The O&M Task Force took on the challenge to identify and group the most important trends and innovations shaping today's O&M market. "Smart PV power plant monitoring and data-driven O&M" was identified as the most popular amongst the innovations. Let's see why.

Traditional monitoring systems generally consist of:

- On-site data loggers that collect electrical data from inverters, strings and meters;
- Meteorological stations that measure and record weather data;
- Management software then allows remote performance management, data visualisation, basic KPI calculations, reporting and alarm and ticket management.



Credit: SolarPower Europe

Figure 1. The key aspects of data mining

These systems, used on their own, commonly fail to detect the root causes of underperformance. The industry is therefore rapidly moving towards the adoption of 'smarter' solutions based on advanced data mining techniques. Data mining is the process of digging through data to discover hidden connections and predict trends. Sometimes referred to as "knowledge discovery in databases", the term "data mining" was not coined until the 1990s. Its foundation is comprised of three intertwined scientific disciplines, as shown in Figure 1.

Although data mining is not a new discipline, its capabilities are now being unleashed due to the potential of big data and increasingly affordable computing power and storage. Its potential to enable O&M contractors to move beyond manual, tedious and time-consuming practices to quick, easy and automated data analysis is now becoming more tangible [2].

Within this category of data-driven solutions, a number of innovations and trends were analysed, their purpose, advantages and disadvantages explained, and the state of play identified:

- Advanced aerial thermography with drones
- Automated plant performance diagnosis
- Predictive maintenance for optimised hardware replacement
- PV plant yield forecasting
- Internet of Things (IoT) and auto-configuration
- Future best practices in document management systems

Let's review here the first two as a teaser, encouraging the reader to refer to the newest version of the guidelines for further detail.

Advanced aerial thermography with drones

In recent years unmanned aerial vehicles (UAVs), commonly known as drones, have proven to be a cost-effective tool for conducting IR thermographic inspections of large-scale PV plants. If deployed properly, they could become a cornerstone technology for effective O&M and they would not only be an activity performed just to comply with contractual obligations.

Aerial IR thermography might seem a trivial activity, and when not conducted following a set of minimum technical requirements, it is almost of no use for effective plant maintenance. However, high-quality IR images captured by a drone and their proper post-processing allow for a detailed PV module failure analysis that could trigger conclusive maintenance decisions. Furthermore, field interventions could be optimised, and PV plant underperformance could also be better understood and addressed (e.g. faulty modules that need to be replaced can be identified with precision and high-quality IR images can be used as proof in warranty claim processes).

The demand for IR inspections is growing fast, and so is the range of services offered by new players in the market, who are now pushing aerial inspections beyond basic reporting. The general services offered can be divided into two

Drones are become an integral aspect of cutting-edge O&M practices.

Credit: BayWa r.e.

main activities: data acquisition and post-processing.

In data acquisition, a flyover is performed in which raw IR images and visual photos or videos are recorded. Depending on the provider, additional geolocation services and 3D modelling of the entire plant may be offered. Some other solutions provide additional sensors to record weather variables (usually irradiance and ambient temperature) during the flyover.

The post-processing activities consist of all the data processing and analysis techniques to be carried out to produce the final report and all the related deliverables. These activities can be done manually or automatically by means of specialised software.

The data acquisition stage is now well understood as drone technology ripens and becomes a trend. There are already many companies that offer high-quality industrial drone flights. Usually companies using drones as a daily work tool do not only conduct IR inspections of PV plants, but also industrial aerial inspections of oil ducts, off-shore oil extraction platforms, roads, bridges and wind turbines, just to name a few. Therefore, the data acquisition stage is an activity that could be easily outsourced by O&M contractors, mitigating the risks related to technology obsolescence and avoiding the costs of regular drone maintenance.

Most companies today still rely on manual data processing, which represents a big drawback for large portfolios as human error drives down the accuracy of thermal imaging assessment. This means that companies with automated solutions have a huge advantage in this regard.

Aerial inspections and their associated post-processing activities are evolving very rapidly, and the quick adoption of new technologies is of high strategic importance in today's highly competitive O&M market.

Automated plant performance diagnosis

As described in SolarPower Europe's 'Global Market Outlook', the PV industry showed in 2017 the highest growth in the energy market, with a total capacity of nearly 100GW installed worldwide. In such a context, PV plant reliability is subject to higher reliability requirements. With special consideration for ageing plants in Europe where the secondary market is growing, automating diagnostics of PV assets is crucial.

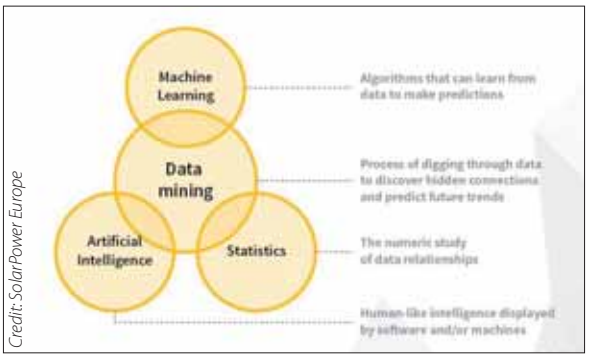


Figure 2. Automated plant performance diagnosis

Until now, plant performance assessment has typically been executed in a top-down approach, analysing low performing objects by drilling down from substations and inverters to junction boxes and strings. This process is time consuming and expert-dependent. Furthermore, the process does not guarantee revealing all underperformance issues.

Automated bottom-up diagnosis using advanced big data mining techniques can overcome the disadvantages of classic plant performance assessment by experts: time saving of expert data handling, less error prone and better diagnosis performance.

Big data mining algorithms have been successfully applied to solar plant data and have proven to reveal performance issues beyond top-down expert analysis in a semi-automated way. Further R&D into this subject area serves to make the algorithms more robust for automated application on large portfolios and capable of root-cause failure identification.

O&M for power plants equipped with battery storage systems

In recent decades, to reduce the pollution and the consequent effects on the environment, society realised that it is necessary to rethink the way in which energy is generated and used. The renewable energy resources penetration and uncontrollability has motivated the development of technical challenges to efficiently deliver sustainable, economic, and secure electricity supplies. In this context energy storage is playing an important role to assure the stability of a system creating value on the market to balance the intermittency of renewable generation.

Energy storage systems (EES) are a set of technologies whose aim is to decouple energy generation from demand. The system is planned to store the excess energy produced and release it during periods of high electricity demand or scarce production, ensuring a steady electricity supply, especially in remote areas where the national grid is unstable.

Battery technologies can be classified according to their energy density, their charge and discharge characteristics, system integration and the costs. Despite there being many forms of EES (flywheels, compressed air, thermal etc), the most mature and commonly used systems for solar plants are solid state batteries (e.g. lithium-ion) lately being improved in terms of characteristics, thanks to the automotive industry's research into electric vehicles.

Nowadays, there is a growing interest in flow batteries, in particular the vanadium redox, due to its great degree of flexibility and scalability. Their most fundamental characteristic, differing from the lithium-ion technology, is that power and energy are completely independent, which may represent a considerable advantage in specific applications.

According to producers' indications, if maintained correctly, flow batteries typically last 25 years against the 15 years of the solid state. Due to their peculiar characteristics, each technology is preferably applicable in specific scenarios where a short-term response is needed. To give an example, solid state batteries, which contain a higher C-rate, can discharge quicker and more effectively in "blackout" situations, where a large amount of energy over a short period of time is required. For their part, flow batteries are very efficient for meeting a steady, long-term energy demand such as night-time application.

The above-mentioned ESS are subject to significant health and safety risks. In order to prevent hazards or an uncontrolled release of energy, an appropriate risk assessment must be performed during the design, planning and maintenance phases. Different players in the market are developing solutions to mitigate health and safety risks, offering alternative products which are non-toxic, non-flammable and safe to transport and store. Amongst the others, salt water batteries can be mentioned for their "environmentally friendly" way of storing electricity power, despite their disadvantage of being very heavy and space intensive.

To increase the reliability of an ESS, an efficient energy management system (EMS) to track the state of components is essential. The EMS should also gather data

coming from energy meters and operating parameters, such as temperature, voltage, current, power level, state of charge, state of energy and warning messages.

Despite this, energy storage is considered a technology that has the potential to disrupt the energy market, but an additional effort is required in order to support its diffusion. The reduction of their high capital costs and a regulatory framework definition is necessary to accelerate the removal of barriers to the deployment of storage.

Major opportunities with revamping and repowering

The solar industry has seen several spiking phases of new installations as the international market has grown and regional regulatory frameworks have changed. By the end of 2018 we reached more than 500GWp of PV capacity installed worldwide. Whilst the industry is picking up speed, we see that ageing PV sites naturally develop an increasing demand for corrective maintenance with a parallel potential for repowering measures.

On the one hand, degraded or defective modules as well as inverters lead to increasing failure rates and yield losses, which makes repair or exchange works necessary. This demand is often accompanied by the fact that several manufacturers and service providers of these components have meanwhile left the market, which results in a significant unavailability of spare parts and support for plant owners.

On the other hand, technological improvements in efficiency and falling prices for these components often create feasible economic scenarios for an exchange of old modules or inverters with new and more powerful models. Furthermore, repowering projects usually include additional benefits, such as new warranty terms and compliance with the latest regulatory adaptations. This development is the reason why revamping and repowering of PV plants is getting more and more popular. That said, the increasing significance of repowering and revamping in the solar industry also gives added reason to create standardised ways to address the challenges in this field – the O&M Best Practices Guidelines offer a great opportunity to discuss and build these standards.

Defining repowering and revamping

Revamping and repowering are defined as the replacement of old power production-related components of a power plant with new components to enhance its overall performance. Revamping involves component replacement, but without substantially changing the plant's nominal power, whereas repowering involves increasing it. The difference to ordinary replacement lies in the aim of increasing the performance by exchanging all components within a functional area or a significant ratio of them. The aspects and consideration in the following sections focus on repowering but apply in most cases also for revamping and even repair and extraordinary maintenance. There are numerous ways of repowering a PV plant. In the following paragraphs we will concentrate on the two most important opportunities of module and inverter repowering.

Credit: greentech

With increasing age and wear, the likelihood of inverter failures and breakdowns increases.

"Although a repowering project is mainly technically driven, for the owner of the PV system it is a commercial re-investment case. Therefore, it is of great importance to calculate a detailed and solid business case before the project"

Module repowering

Degradation, underperformance or simple defects in modules which are not repairable or available for direct replacement on the market may force the investor to consider module repowering. This can be carried out for the entire PV plant or for specific parts. When the repowering is focused on a partial module replacement, it is recommended to exchange some more modules than technically required, to keep some intact old modules as spare parts for the future. Due to the fast development of PV technology, it is not very likely that the same components are still available on the market in the required quantity or at a competitive price. Certainly, exchanging the identical modules would make a repowering very simple, but this would also reduce the utilisation of the repowering opportunities in lower price and higher efficiency. In case different modules are to be used for the repowering project, the following aspects need to be considered during planning and executing:

Mechanical installation

- If the modules have different dimensions or weight, the compatibility with the mounting system needs to be considered. In extreme cases a new mounting structure is required.
- Adequate integration of the new modules into the grounding system.

Electrical installation

- Depending on the electrical characteristics of the new module type a new string design can be inevitable.
- A mix of different electrical characteristics at one inverter or at least one Maximum Power Point (MPP) tracker

should be avoided.
- Most likely the new module type will have different connectors. Accordingly, the string cable connector needs to be replaced.
- The dimensioning of existing cables and fuses needs to be checked and verified to be suitable for the new DC-layout.

Further considerations with regard to regulatory aspects or additional synergies are reflected in the O&M Best Practices Guidelines in more detail.

Inverter repowering

As with all electronic devices, inverters have a limited lifetime. With increasing age and wear, the likelihood of failures and breakdowns increases. If the warranty of the device has expired, a technically and economically suitable solution needs to be identified. If an identical replacement inverter, repair services or spare parts are not available, the exchange through a new component is inevitable. There are different strategies for inverter repowering which should be evaluated on a case by case basis:

Partial or complete exchange: If not all inverters are affected, a partial exchange of the inverter fleet can be an option. This potentially reduces the overall costs, but it can also increase the complexity of the repowering project.

Exchange of same or different power class: Exchanging inverters with the same power class is easier for the DC and AC integration. However, replacing multiple devices through one with a larger power class can increase the system efficiency and reduce the component costs as well as future maintenance costs.

When an inverter repowering is planned, several factors need to be considered:

Mechanical installation: If the new inverters have different dimensions or weight, a suitable solution for the installation or mounting of the inverter needs to be prepared. The same accounts for a proper cabling if DC or AC connections are changed. The manufacturer of the new device might have different requirements for the mounting with regards to fixings, distance to other components or to the roof, ventilation, etc. All requirements need to be checked and implemented. The new inverters need to be integrated into the grounding system according to the standards and the manufacturer's specifications.

Electrical installation: The integration of the DC side to the new inverters needs to follow the DC input requirements of the new inverter. Eventually, the string length and the number of connected strings need to be adjusted to suit the technical parameters of maximum current and voltage as well as ideal operational conditions. If different inverter sizes are installed, the integration to the AC side needs to be re-engineered. This includes the cable diameters, protection devices (fuses) and connectors. In any case the applicable electrotechnical rules and regulations need to be followed.

Communication system: Before choosing an adequate inverter, the compatibility with the physical communication cables should be checked. The installed data logger needs to support the new inverter's data protocol. Otherwise, an update or the exchange of the data logger will be required.

General repowering considerations

Although a repowering project is mainly technically driven, for the owner of the PV system it is a commercial re-investment case. Therefore, it is of great importance to calculate a detailed and solid business case before the project and review it during the project stages. All technical and commercial data, such as historical performance, future performance, revenues, costs, extended life span and changed maintenance requirements need to be considered to come up with a prognosis of the future income streams. With this, a classical return on investment or break-even calculation can be performed and presented to the investor as a decision basis.

As an additional analysis, it is recommended to calculate the sensitivities of the most important factors. This will provide a better understanding of the influence of changing conditions, e.g. if the costs for the project will change or the projected performance will be different to the assumptions.

Each repowering activity should be approached as an individual project with clearly defined project phases, responsibilities and budgets. A sample project structure can be found in the O&M Best Practices Guidelines.

Conclusion

Responding to the discrepancies that exist in today's solar O&M market, the SolarPower Europe O&M Best Practices Guidelines make it possible for all to benefit from the experience of leading experts in the sector and increase the level of quality and consistency in O&M. These guidelines are meant for O&M contractors as well as investors, financiers, asset owners, asset managers, monitoring tool providers, technical consultants and all interested stakeholders in Europe and beyond. SolarPower Europe is committed to supporting the industry to improve best practices to deliver the most efficient, innovative and cost-effective solar healthcare services. ■

SolarPower Europe's O&M Best Practices Guidelines can be downloaded at www.solarpowereurope.org

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After working with an international business consultancy in the utility industry, Jörn Carstensen joined the PV Industry in 2006. He worked in different positions at Conergy and became director of international sales and business development in January 2010. In 2014, he started working for greentech as general manager and director of sales & marketing. Mr. Carstensen developed the UK market for greentech and acts as managing director for the greentech subsidiary in the UK.

Is LeTID degradation in PERC cells another degradation crisis even worse than PID?

Modules | Light- and elevated temperature-induced degradation – LeTID – is emerging as a potentially serious problem affecting PV modules employing PERC technology. So why isn't the industry more aware of it, ask Radovan Kopecek, Joris Libal and Lejo J. Koduvelikulathu of ISC Konstanz

Credit: Hanwha Q CELLS

Solar PV is quickly becoming the lowest-cost electricity source around the world. Levelised costs of electricity (LCOE) of around 2ct/kWh have been reached, with one bid in Saudi Arabia from EDF/Masdar being the first to be below US$0.02/kWh [1].

In the coming years we will reach numbers of around US$0.01/kWh and below – and then everyone can afford electricity. This is also the achievement of new high efficiency but low cost technologies such as PERC, PERT and bifacial modules in simple tracking systems such as HSAT (horizontal single axis tracking).

However, many solar cell and module producers are suffering these days. Asia-based producers are potentially entering a second large crisis due to overcapacity, first experienced in 2011. This second downturn can be attributed to upgrades of existing production lines to PERC.

In 2017 the total solar cell and module production capacity was around 125GW of which 35GW was based on PERC technology. At the time of writing, it was expected that by the end of 2018, the total production capacity would reach 160-170GW of which 60-70GW would be PERC [2].

However, the downstream PV demand in 2018 is expected to stay below 100GWp [3]. This means that many cell lines could be standing idle and many GWs of modules in inventory.

As already mentioned, new innovations are necessary to further reduce the LCOE. Yet the transformation to PERC was conducted so fast that there are many PERC producers that should also put their focus on product quality.

PERC is a mature technology with a relative simple process and therefore benefits from low cost of ownership. With PERC technology, a record efficiency of 23.6% was reached by LONGi (March 2018) with a busbar-less metal contact design and surpassed later with 23.95% by JinkoSolar (May 2018).

Manufacturers such as Hanwha Q CELLS are producing anti-LeTID modules in recognition of the potential problem it poses

Record efficiencies are nice but what counts are conversion efficiency averages in volume production and process stability over time. Average efficiencies in production for the major players such as the 'Silicon Module Super League' members (Hanwha Q CELLS, JA Solar, LONGi, Trina Solar, JinkoSolar and Canadian Solar) have between 21.5% and 22% conversion efficiencies, which are outstanding compared to standard Al-BSF technology, which had dominated the market for decades and where the best average efficiencies hardly exceeded 20%.

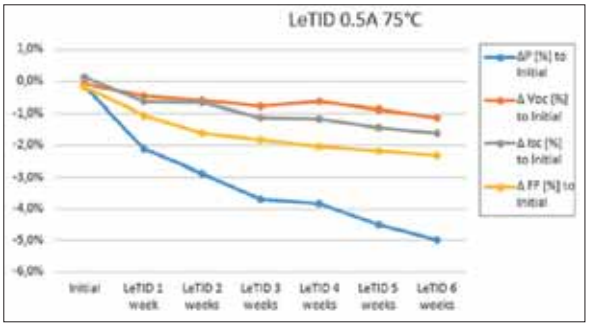
Regarding degradation, we are not sure if all PERC producers have understood the challenge to cope with all the degradation effects that this device can additionally suffer from. And this is what this article is about.

Understanding of dominating degradation mechanism in PERC solar cell

When we visit conferences and industrial players, we are very often surprised how many responsible scientists for PERC production have never heard about the severe degradation effects that PERC devices can show, in particular when talking about LeTID (light and elevated temperature-induced degradation), alias carrier-induced degradation (CID).

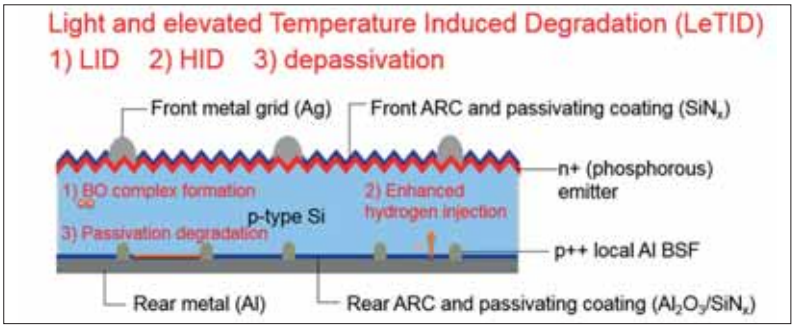
Even at the "4th PERC Solar Cell and Bifacial Module Forum 2018" [4] LeTID was not really a topic.

A common response on LeTID we hear: "LeTID? No – we have no LID: we are stabilising." Or some of them – who are more



Credit: PI Berlin

Figure 1. Influence of module parameters on LeTID tests of a commercial mono PERC module measured at PI Berlin in 6 weeks testing



Credit: ISC Konstanz

Figure 2. Three major degradation mechanisms in PERC during LeTID: 1) LID, 2) HID and 3) depassivation of rear dielectrics

informed – say: "LeTID only affects mc-Si PERC – we produce Cz-Si PERC."

None of these statements are true. Even if LeTID had first been observed on mc-Si PERC cells [5], it is an effect which is also visible and detrimental in Cz-Si PERC modules [6] causing very severe degradation, sometimes more than 10% relative in power after weeks of accelerated LeTID degradation.

Due to this, PI Berlin tested and is continuing to test LeTID on many PERC modules available in the market. Most of the different tested modules (around 10 so far) degraded after six weeks of exposure to accelerated degradation by 5% or more relative in power – the degradation curve did not seem to have reached saturation.

In addition, we have heard of many PERC PV systems "out there" where the modules degraded close to 20% after two to three years of operation, which is simply a tragedy.

Figure 1 shows a typical degradation curve measured at PI Berlin, which has been presented at the German workshop "module-tests", dealing exclusively with LeTID and bifaciality organised by PHOTON at Intersolar Munich in June 2018 [7].

You can clearly see that after six weeks at 75°C with an injected current of 0.5A this commercially available Cz-Si PERC module degraded 5% relative in power and the degradation still seems to be continuing. There are a couple of groups that claim that also nPERT devices might have such problems [8]. We are currently running accelerated LeTID degradations experiments on our BiSoN (nPERT), MoSoN (nPERT rear junction) and ZEBRA (IBC) cells without seeing such severe degradations so far.

Possible degradation mechanisms in PERC solar cells and modules

What is happening there in the PERC device? Why do the PERC solar cells still degrade even if people think that they have understood boron formation and can even control this effect? The degradation mechanisms of more advanced devices start to get more complex, as it used to be with simple Al-BSF (back surface field) cells.

Not only are the efficiencies at a different level – but also with more complex device structure, more potential to degrade and thus degradations are becoming more visible. And in case of PERC it is certainly the rear side dielectric which is on the one hand boosting the efficiency but also can cause trouble if it is not adapted not only for highest starting efficiencies but also for long-term device stability.

Figure 2 shows a typical PERC device cross-section and summarises the three most severe degradation mechanisms which are known about so far.

LID: The very well-known and mostly understood degradation, light-induced degradation (LID) is based on the formation of BO (boron-oxygen) complexes [9]. It can be partly eliminated by a couple of measures which are described in Table 1.

HID: Hydrogen-induced degradation (HID) as a cause of LeTID testing was first found in mc-Si PERC devices as reported in [5] and also reported to occur in mono-PERC devices [6]. What is known today is that this degradation is based on too-high hydrogen content in the device, which is also beautifully summarised with the bucket theory analogy of the late Professor Stuart Wenham [10].

This is the case because the rear side passivation is in most cases realised by a rather thick (compared to front side passivation) hydrogen-rich dielectric. With firing, the released hydrogen into the Si-Bulk bonds weakly, passivating the defect states. With temperature and illumination, these bonds are easily broken, freeing the weakly bonded hydrogen at a faster rate, and thus leading towards degradation.

Over time, a saturation state is reached followed by a recovery process activation, wherein the released hydrogen starts to bond back and passivate the defects with a stable bond, unaffected under LeTiD testing conditions. As for HID, the measures that can be taken to minimise it are summarised in Table 1.

Passivation degradation on bare Si-wafer: It is very difficult to find out the real dominating cause of degradation. Recently A. Herguth and his team at University of Konstanz have discovered that the observed degradation in PERC solar cells is also partly based on the de-passivation effect of the rear side dielectrics [11]. This degradation effect was already observed in IBC solar cells on the front side.

In case of the IBC cells at least a shallow FSF (front surface field; i.e. a phosphorous diffused layer in case of n-type Cz-Si based cells) was needed in order not to see this effect.

Figures 3a and 3b show testing examples at different places where, on the one hand mc-Si PERC modules (top), on the other Cz-Si modules (bottom), showed severe degradation behaviour.

As during the LeTID testing all the three (or two) described effects are possibly activated and a more detailed examination of all modules with problems has to be conducted in order to find the most critical degradation mechanism in that device. When it is identified, solutions for degradation reduction can be tested.

Possible solutions for degradation mechanisms in PERC solar cells and modules

As described, the degradation in PERC solar cells and modules is very complex and cannot be easily understood or connected

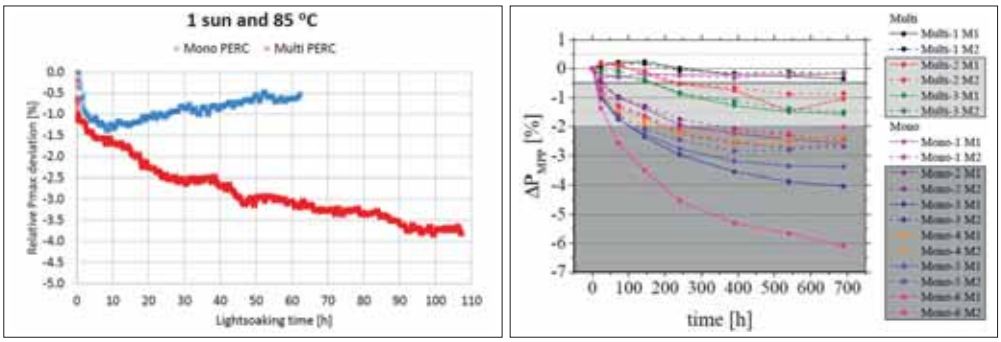


Figure 3. LeTID testing at Eternal Sun (left) [12] and Frauhofer CSP on mc- and Cz-PERC modules (right) [13]. Note that for the test by Fraunhofer CSP, all modules have been stabilized with respect to LID, accordingly, degradation due to formation of B-O complexes is not included in the Pmpp decrease shown in the right graph

	Light and elevated Temperature Induced Degradation (LeTID)		
Degradation mechanism	LID	HID	Passivation degradation
Cause	BO complex formation	High hydrogen concentration	Depassivation of dielectrics on undiffused surfaces
Reduction on cell level	✓ Low oxygen Si material ✓ High resistivity Si material ✓ Stabilisation process ✓ Ga-doping ✓ n-type devices	✓ Use of H-poor dielectric layers ✓ Adapted process temperature kinetics ✓ Low firing temperatures ✓ Thin wafers	✓ Use of low doped BSFs ✓ Upgrade to PERT

Table 1. Summary of PERC degradations and possible solutions

to only one degradation mechanism. Therefore, as PERC modules also seem to be more affected at elevated temperatures, TÜV has also now established this testing in its quality testing procedure. Table 1 summarises the most severe degradation effects and possible solutions to reduce them to pass the TÜV testing.

There is of course still potential-induced degradation (PID) that has to be controlled, but this degradation is related to all modules with the migration of Na and other impurities from glass towards the solar cell surface causing shunts or de-passivation [14].

This degradation can be minimised at the cell, module and system level and is mostly taken care of at the module level by choosing high-quality encapsulants, such as suitable EVAs or even switching to polyolefin films, mostly found with double-glass modules.

We hope that we have provided enough awareness of quite new degradation mechanisms in mc-Si as well as in Cz-Si PERC solar cells.

With this article we want to motivate PERC solar cell and module producers to better adapt their devices regarding lower degradations and to warn small rooftop installers as well as large utility-scale EPCs to make the right choice (performing the right tests on selected modules) for their PV systems.

The awareness of this issue by the main players, i.e. cell & module manufacturers on the one hand and system installers on the other, will be important to avoid a flood of claims relating to dramatically underperforming PV systems and therefore a potentially severe negative impact on the credibility of PV as a whole.

Good luck, choose wisely and continue to reduce our CO_2 emissions so that we can save our great blue planet. Soon we will arrive at a total installation of 1TWp; we hope with few, if any, degradations issues. ■

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Fixed-tilt versus single-axis tracker arrays in India

Trackers | India has become the the world's second largest market for trackers as it chases its ambition of installing 100GW of solar by 2022. Geoffrey S. Kinsey, Madhusudan Partani, Mukund Kulkarni, Brijit Shetty, Rubin Sidhu and Jie Zhang report on efforts to better understand the performance benefits of trackers over fixed-tilt mountings

Looking north at 22MW of fixed-tilt and 3MW of tracker arrays in Andhra Pradesh, India

For ground-mounted PV systems, the path to higher generation and availability is paved with trackers. To deliver a higher return on investment as well, the additional generation revenues from trackers need to more than offset the higher costs in equipment, installation and operations and maintenance (O&M). Estimates vary, so uncertainty in these variable costs increases the risks of investment and slows deployment.

Nowhere is understanding the cost/benefit tradeoffs more critical than in India, with over 20GW of PV installed and now the world's number two market for trackers [1]. Precise data on the performance from fixed racks versus trackers is, however, somewhat elusive. At one plant in southern India, trackers co-located with fixed-rack arrays have shown enhanced energy yield of more than 15%.

The 25MW plant shown in the main image was commissioned in 2016 with approximately eighty thousand Hareon Solar 72-cell multi crystalline silicon modules, connected to 31 inverters of about 800kW each, four of which convert energy for the tracker block located in the center of the site. The single-axis trackers are aligned horizontally on a north-south axis; the fixed-tilt arrays are south-facing to within a few degrees of the local latitude (15.6°).

Performance

The power output of the fixed-tilt and tracker arrays is compared in Figure 2. As seasonal variation follows the symmetries of the annual solar cycle, data is grouped by "solar season", where seasons 1 and 3 are centred on the vernal and autumnal equinoxes and seasons 2 and 4 are centred on the summer and winter solstices, respectively. Seasons 2 and 3 are characterised by higher peak power outputs and, for the tracker arrays, occasional inverter clipping. Seasons 1 and 4 present lower peak powers, but also less variability due to clouds, since India's monsoon typically runs from May to September. Around the winter solstice (season 4), the modules mounted horizontally on trackers obtain peak powers below that of the modules tilted southward. Year-round, the squarer shoulders of the tracker output indicate more consistent grid support throughout daylight hours.

The daily plane-of-array irradiation for the fixed-tilt and tracker arrays was used to calculate the "measured" performance ratios in Figure 3. The "expected" performance ratio for the tracker arrays uses the rated module powers and measured site conditions: daily plane-of-array irradiation and the irradiance-weighted module

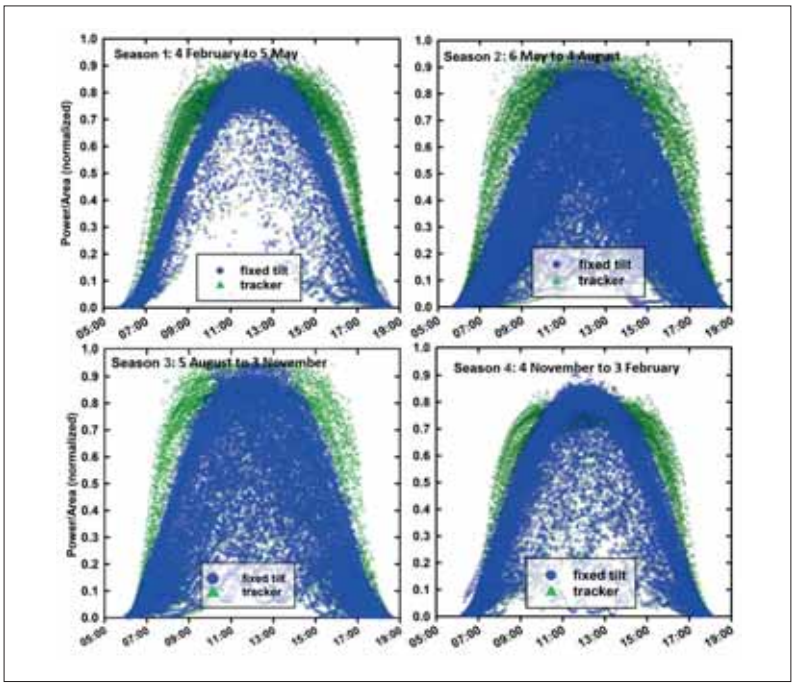

Figure 2. Seasonal variation in AC power output (five-minute mean values)

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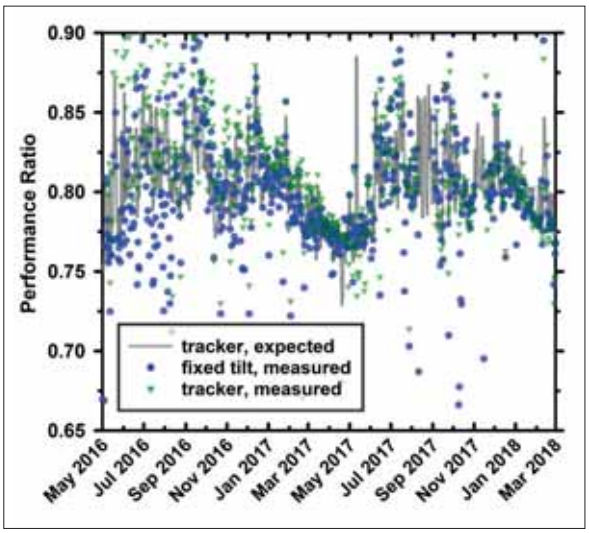

Figure 3. Daily measured DC performance ratios compared against that expected from the tracker plane-of-array irradiance and the irradiance-weighted module temperature

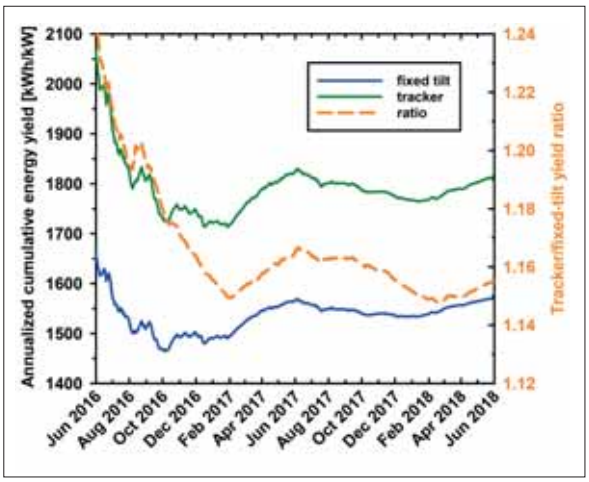

Figure 4. Comparison of the DC energy yield. The tracker yield peaks in May, just before the monsoon. The ratio is currently 1.16

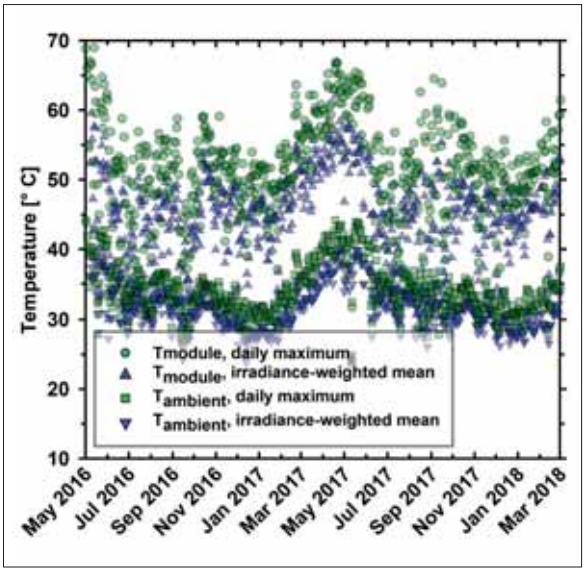

Figure 5. Daily module and ambient temperatures: maxima and irradiance-weighted means

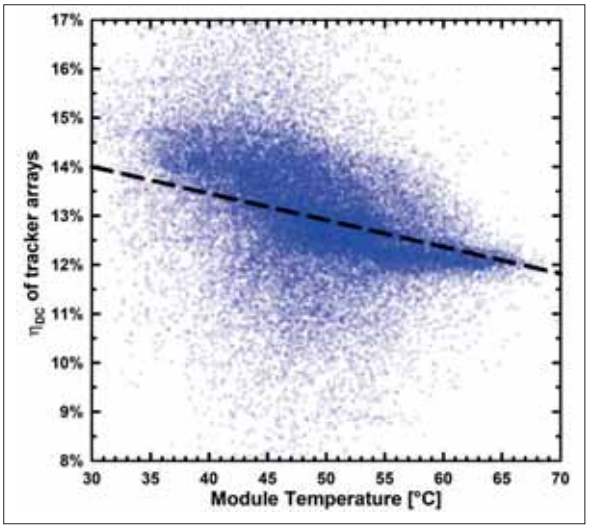

Figure 6. Array DC efficiency as a function of temperature (five-minute intervals, E>400W/m²). The line illustrates the power temperature coefficient of -0.41%/°C specified for these modules [6]

temperature. A lumped de-rate factor of 12% was applied to account for various losses for arrays in field operation. Typical component losses (and representative values) include: light-induced degradation (2-5%, in year one), annual degradation (<1%), soiling (2-4%), shading (2-8%), module-level (1%) and string-level (<1%) mismatch, and ohmic cabling losses (1-2%).

The "annualised" cumulative energy yield shown in Figure 4 is obtained by dividing the cumulative generation by the rated power and days in operation. Initially, this energy yield is strongly season-dependent, but, as the days in operation accumulate, it approaches its long-term value. As might be expected, energy yield for both fixed-tilt and tracker arrays is greatest during the months around the summer solstice (season 2), though monsoon cloud cover contributes to the decline beginning in early (rather than late) June.

The annualised cumulative energy yield stands at 1,810kWh/kW and 1,570kWh/kW for the tracker and fixed-tilt arrays, respectively. The ratio of tracker to fixed-tilt energy yield has peaked just below 1.17 and now approaches 1.16. For prospective sites, this ratio can help determine the net benefit of tracking, along with other local factors such as differences in latitude, racking cost, O&M costs and the availability of time-of-use electricity rates or pricing for grid support.

With a grid capacity of 340GW [2], India's efforts to expand and modernise the grid are being coupled with a push to over 175GW of renewables capacity, including 100GW of solar, by 2022 [3]. While the nation's energy deficit has been below 5% since 2013, and a surplus is forecast for 2018 [4], a remarkable 5GW of diesel backup power is still being added annually to cope with grid instability and occasional outages [5].

Where grid instability remains a significant issue, the enhanced ability of tracker arrays to provide ancillary services will become an asset. While trackers are usually operated to deliver maximum power, tilting trackers away from their maximum power point would provide one means for additional frequency control, or even the renewables equivalent of "spinning reserves" [7].

Temperature

The ambient temperatures at the site are compared against module temperatures in Figure 5. Module temperature is measured using thermocouples attached to the back of a module mounted on a tracker. Though the temperature of a fixed-tilt module is not monitored at this site, temperatures for the fixed-tilt-mounted modules are likely to remain at or below the values for the tracker modules.

For evaluating the effect of temperature on energy generation, it is useful to calculate temperature as weighted by the irradiance. Hourly means of one-minute data were weighted by the mean irradiance over the same period to determine the daily mean values shown in Figure 5. To date, the mean, irradiance-weighted ambient and module temperatures are 32°C and 47°C, respectively.

The difference between the module temperature as measured on a backsheet and the cell temperature inside the module is sensitive to the sensor type, the thermocouple mounting method, and the ambient temperature [8]. Applying the linear regressions for sensors 1-3

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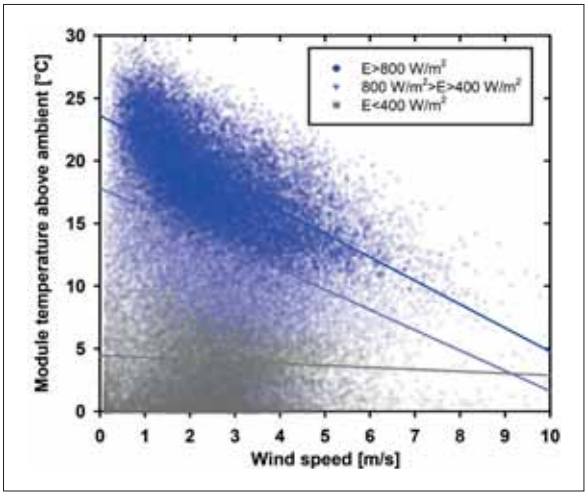

Figure 7. Impact of wind speed on (tracker) module temperature for three irradiance levels (five-minute mean values)

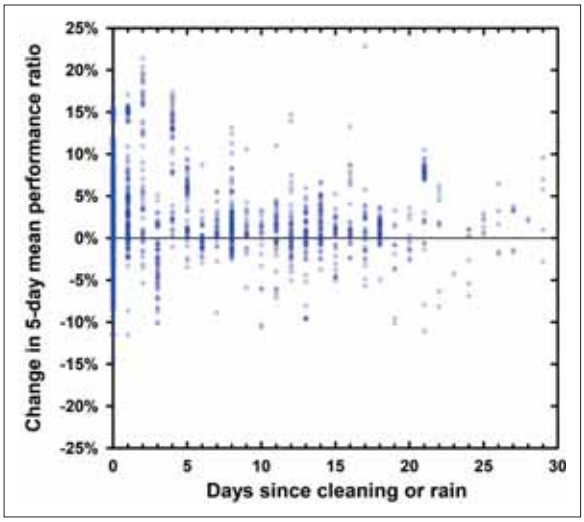

Figure 8. Relative change in DC performance ratio before and after cleaning and rain events, using a five-day mean

obtained in [8], the mean, irradiance-weighted cell temperature is 50° C (18° C above ambient). For a power temperature coefficient of -0.41%/°C [6], this corresponds to a power de-rate of 10% relative to standard test conditions (25°C cell temperature). The impact of module temperature on array performance is evident in Figure 6.

A weather station at the site monitors wind speed (but not direction). The cooling effect of wind speed on the tracker module temperature is illustrated in Figure 7. The increase in module temperature above ambient is greatest at high irradiances and the cooling effect of wind is correspondingly most pronounced. For irradiance conditions above 800 W/m2, the mean, irradiance-weighted, module temperature above ambient is 19°C, suggesting a cell temperature above ambient of 22°C. The linear regression line for E>800W/m2 can be used to calculate the module temperature for different wind conditions: at the standard wind speed of 1m/s, the expected module temperature above ambient would be 3°C higher. This difference due to the local wind conditions corresponds to a power difference of more than 1%, enough to suggest incorporating wind studies as a part of site selection and predictive performance modelling.

Soiling

The same wind that cools the modules may also exacerbate soiling. Plant performance is maintained via regular (staggered) cleaning of the arrays in each inverter block. As the resulting soiling losses are relatively low, extracting an accurate, plant-wide soiling loss rate from the performance ratio data is challenging. To assess the impact of soiling, five-day means of the daily performance ratios for each inverter block were compared before and after a cleaning event (Figure 8). A linear regression to the data with more than five days of soiling yields a soiling loss rate of 0.17% per day.

Conclusion

Quantification of the cost-benefit trades between single-axis tracker and fixed-tilt arrays is ongoing. After two years of operation, the difference in cumulative energy yields is around 1.16. While providing insight into the effects of temperature, wind speed and soiling, plants like this one, which injects over 36GWh into the grid each year, help to electrify the country and continue to chip away at India's dependence on fossil fuels. ■

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Dr. Rubin Sidhu is the managing director at Hareon Solar and heads the company's solar projects business in the US and India. Prior to joining Hareon, Dr. Sidhu worked in R&D and product development at BP Solar and Advanced Micro Devices (AMD). Dr. Sidhu holds master's and PhD degrees in electrical and computer engineering from the University of Texas at Austin. He has published more than 35 papers in technical journals and conference proceedings.

Dr. Jie Zhang is the CEO of Hareon International, responsible for Hareon's PV project and manufacturing investments in nine countries as well as international sales. Prior to Hareon, Dr. Zhang held research, engineering and management positions at Cypress Semiconductor and nVidia Corporation. He received his M.S. from Tsinghua University and his PhD from Arizona State University.

Presented to you by: Energy Storage NEWS

STORAGE & SMART POWER

Introduction

Welcome to the latest Storage & Smart Power section of the journal, which the team at Energy-Storage.news is proud to present to you – the combined might and brains of the solar and storage industries – each quarter.

They're the kind of industries that attract problem solvers, those who never say die. Even when climate change means that there's a fair chance that that might happen to us much sooner than we'd planned if we all fail.

As I write that, I can't believe it's not a joke, or melodramatic fake news on my part. Much wiser people than I acknowledge that this is the truth, and while energy storage or solar on their own cannot help us meet the 12 year timeframe we may only have to arrest the fatal rising of global temperatures, the technologies have a vital role to play.

I recently heard one such commentator say that pushing the climate case catastrophe scenario without due emphasis on the also-very possible rescue act that humanity could still perform was the one area in which scientists had 'failed'. Well, we certainly still need you, scientists, but there's a challenge to all of us to prove that solutions are more important than doom and gloom. As doomy and gloomy as it is, the news section, just a sampling of recent Energy-Storage.news articles, shows that the first quarter of 2019 is one many can be proud of.

As solar and storage are not all of the solution in themselves, gas peaker plants do not in themselves pose the entire climate change – or air pollution – problem. But with around 120GW of peaking capacity in operation in the US alone, the way we 'used to do things' means that operators are often most reliant on these plants in their most polluting start-up, stop and ramp-down phases to make money.

Instead, here is one so-called 'niche' opportunity for energy storage that actually means a huge amount environmentally, economically and socially. I spoke with Alex Morris of Strategen Consulting, while 8minutenergy CEO Tom Buttgenbach gave us the developer's eye view on how solar and batteries can beat those pesky peakers, from the sunnier states onwards. There's also a look at how a few projects of that nature are already sprouting up in Arizona and California and many more are set to follow.

The hard realities of climate change are going to need a diverse set of technologies, not necessarily a competing set and cryogenic energy storage systems look like they could be another part of the overall toolkit. So argues Highview Power CEO Javier Cavada, who took the time to contribute 'Cryogenic, long duration energy storage in a 100% clean energy future'.

Coming up this quarter we have the likes of the Energy Storage Summit in London at the end of February and the Energy Storage Summit Americas event coming up in March from the events team at our publisher, Solar Media, while we are also looking forward to supporting our media partners' worthy events throughout the year.

Andy Colthorpe
Solar Media

UAE makes mega-deployment of NAS batteries

Credit: NGK

The NAS batteries' internal temperature is 300 centigrade, meaning they do not require the same thermal management systems as lithium

Sodium sulfur (NAS) batteries produced by Japan's NGK Insulators are being put into use on a massive scale in Abu Dhabi, the capital of the United Arab Emirates.

The company's battery systems have been deployed across 10 locations – 15 systems in total – adding up to 108MW/648MWh in total, with each system able to store energy for six hours. The total undertaking includes 12 x 4MW systems and three 20MW systems.

The 15 systems, described as forming a 'virtual grid battery', can be controlled as a single plant or controlled individually when local support to the grid is needed".

Sunrun's home solar-plus-storage to provide 20MW capacity in New England

Solar-plus-storage systems in ordinary households will provide 20MW of energy capacity in New England, with Sunrun announcing the award of a contract from state's ISO (independent system operator).

Aggregated as a virtual power plant, around 5,000 customer systems will be able to contribute to meeting peaking capacity demand on the network, the most polluting - and expensive – energy on the grid. ISO New England figures forecast peak load between 1 June 2019 and the end of May 2020 of as much as 25,528.391MW during the peak hour of 4pm to 5pm.

While the residential solar leasing company's initial contribution to the value of the entire opportunity is fairly modest, it is among the largest VPP's projects announced to date as well as the first capacity contract in the US from an ISO to a home storage operator.

UK's National Grid adds DERs controls

National Grid, in its capacity as the UK's Electricity System Operator (ESO), has launched a new 'Distributed Resource Desk' in its control room in a move hailed as a "huge step forward" for electricity flexibility markets.

The desk enables the ESO's power system engineers to issue instructions to owners and operators of distributed energy resources (DERs): smaller power generators, battery storage operators and demand side response (DSR) providers, quicker than before. It enables smaller market players to participate much faster and builds on National Grid's opening up of the Balancing Mechanism (BM) market last year.

Described as "Great Britain's core flexibility market", the BM, worth an estimated £350 million (US$444.2 million) a year to participants, rewards those able to increase or decrease generation or consumption.

CATL adds 100MWh battery to 'China's largest' mixed renewables power plant

A 100MWh battery energy storage system has been integrated with 400MW of wind energy, 200MW of PV and 50MW of concentrated PV (CPV) in a huge demonstration project in China.

Luneng Haixi Multi-mixed Energy Demonstration Project has been described as "the world's first and China's largest electromechanical energy storage station with virtual synchronous generator," by the chief scientist at the China Electric Power Research Institute, Dr Hui Dong.

China's Contemporary Amperex Technology (CATL) provided batteries and the complete battery energy storage system (BESS) as the exclusive supplier to the project. A prolific supplier to automotive industry sectors, CATL began exploring grid-scale storage relatively recently.

Community grid-scale battery joins Queensland's VPP

A new 4MW / 8MWh energy storage project has been announced in an area of Queensland, Australia which may also be soon getting a battery 'Gigafactory' before long.

The first community-scale battery planned for Townsville, Queensland, a region described as a solar hotspot, will help provide backup power and aid the integration of renewable energy onto local networks.

The virtual power plant project will be publicly-owned by the community and is expected to utilise Tesla Powerpack lithium-ion battery energy storage devices. Queensland's acting energy minister Mark Furner said it was a "small but significant addition to Queensland's publicly-owned electricity system, a system which is delivering cheaper prices on average compared to other mainland states in the National Energy Market (NEM)".

BHEL and Libcoin in final talks over Indian lithium-ion battery gigafactory

Indian state majority-owned firm Bharat Heavy Electricals Limited (BHEL) and Libcoin are in final stage talks over setting up what they have dubbed as a lithium-ion Gigafactory in India.

Libcoin is a consortium including Sydney-based firm Magnis Energy, Duggal Family Trust and New York-based lithium-ion battery specialist Charge CCCV(C4V).

The Government of India, via the Ministry of Heavy Industries and Public Enterprises, has endorsed the project that would start at 1GWh capacity and is set to be scaled up to 30GWh over time, according to a release from Magnis Energy.

Magnis said it has plans to build three further large-scale Gigafactories globally, in Germany, the US and Australia.

First phase of China's biggest flow battery put into operation by VRB Energy

VRB Energy, a maker of flow batteries headquartered in Canada, has said the first phase of a 40MWh flow battery project in China has now been commissioned.

VRB Energy (VRB), 82% owned by High Power Exploration, a base metals-focused exploration company led by noted mining financier Robert Friedland, provided Energy-Storage.news with a progress update from Hubei Province in early January.

The company said that it has now successfully commissioned a 3MW/12MWh vanadium redox flow battery energy storage project which represents Phase 1 of the Hubei Zaoyang Utility-scale Solar and Storage Integration Demonstration Project, set to be 10MW/40MWh when completed.

Chinese national government and local government officials have conducted an official inspection of the 12MWh system, thought to be the largest system using this technology in China in operation to date.

Peak time to take action

Peaker plants | In the hierarchy of grid needs, peaking power is often a priority in terms of providing resiliency and balance to the network. This is usually provided by natural gas turbines, which come at a high environmental and economic cost. Andy Colthorpe charts the rise of the solar-plus-storage peaker plant

What on earth can we do? The sense of frustration and fear felt right now over climate change – where it seems like half of the world now believes science to be some sort of political conspiracy – is understandable.

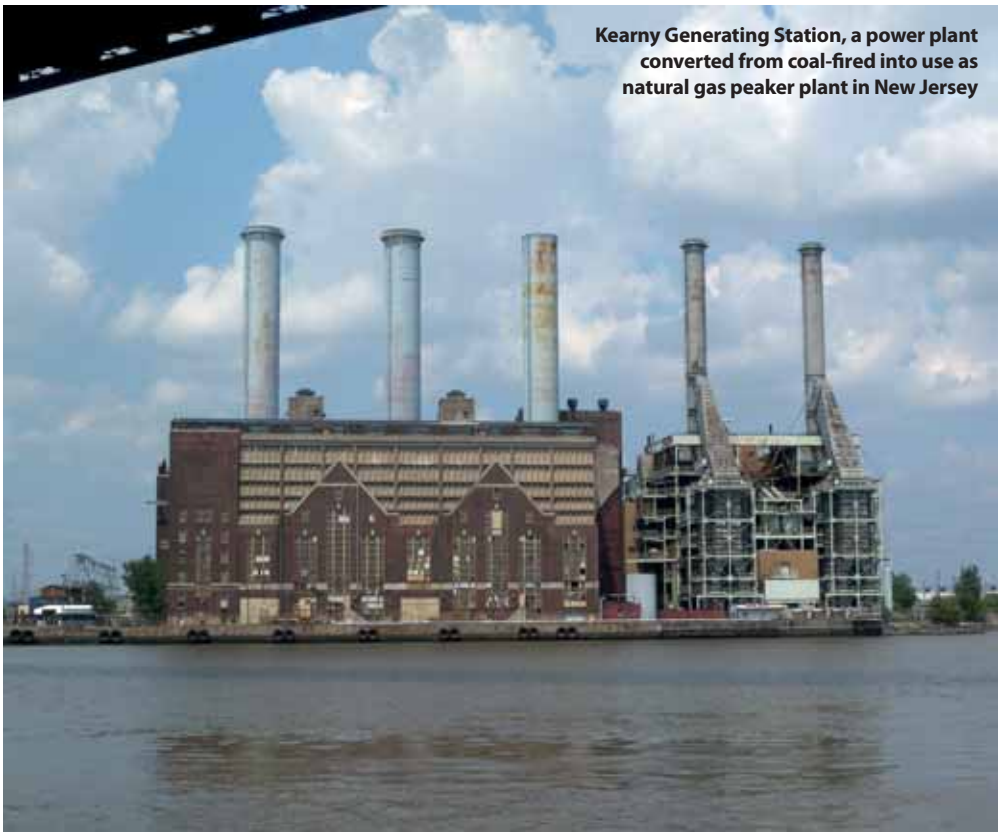
Unfortunately, as much as we've become aware that technical solutions to humanity's biggest existential challenges exist and the will to deploy them is strong, the existential threat to the fossil fuel industry appears to be more of a priority for some.

In the 'Solar Briefing 2019', Volume 17 of *PV Tech Power*, we wrote that energy storage arrives on the electricity network to fill niches as they become economically viable and/or unobstructed by policy and regulation. Mandates and support schemes to deploy energy storage have given huge kick-starts to the industry in the likes of the US and Australia, where governments – often regional rather than national – recognise the technology as vital for a high renewable penetration electricity mix.

At the moment, other front-of-meter opportunities to use a combination of energy storage and renewables to displace fossil fuel usage have to be based on meeting grid needs and expected demand. In some cases this can provide merchant opportunities, as in the case of providing peaking power to grids, mostly done with natural gas peaker plants.

Natural gas is of course not as bad as coal, but not as good as renewables. Nonetheless, many would still have it that there is a need for peaking capacity that can grow with renewable penetration and as the so-called baseload provided by coal is retired. Peaker plants are only fired up for perhaps less than 20% of their operating lifetime, but they are at their most polluting in the period during which they ramp up, spewing pollutants and greenhouse gases (GHGs) into the air. Solar-plus-storage is now starting to fill that niche.

"There's good reason to think that's an extremely competitive combination," says Alex Morris of Strategen Consulting.



Kearny Generating Station, a power plant converted from coal-fired into use as natural gas peaker plant in New Jersey

Credit: Wikimedia user: Jim Henderson

"Certainly it may depend on the grid needs and the timing of those needs and so on. But I think it's great…and the prevalence of how these things are being deployed is a good market signal."

Transition signals

We could have as little as 10 to 12 years left to arrest the most catastrophic global warming scenarios. It may already be too late. Yet it simply isn't possible to take every fossil fuel generator offline immediately, for a number of reasons. It's not that it isn't technically feasible, we just know that it's not going to happen for economic – and increasingly – political reasons. However, in a webinar hosted last summer by the US Clean Energy Group's Resilient Power Project, Elena Krieger of Physicians, Scientists and Engineers for Healthy Energy said that peaker plants are perhaps the most obvious candidate for immediate replacement.

Natural gas peaker plants do not pollute all of the time, because they do not run all of the time. As the name implies, they run when the network experiences a peak in demand and there is not enough generation to meet that demand. However, when they are running, they are among the dirtiest power plants of all, particularly when they start up, shut down or during ramping. For this and, as we will see later, for reasons of economics, Tom Buttgenbach, CEO of US solar developer 8minutenergy has become a fierce advocate of 'solar peaker plants'.

"The reductions in GHG emissions are tremendous. One point that folks often overlook if you look at a gas peaker is what kind of emissions a gas peaker actually produces as you fire them up," Buttgenbach says.

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Credit: AES.

AES' Lawai Solar project in Hawaii delivers dispatchable solar energy into the evening peak using battery energy storage at just US$0.11 per kWh

"We all know the numbers of a combined cycle gas turbine (CCGT) are roughly half of a coal plant in carbon emissions per megawatt hour, but that's not true when you fire them up. Gas peakers' emissions profile is pretty bad. Especially in the ramp-up, they run kind of 'dirty' like a cold car engine does until the catalytic converter comes up to temperature."

Economics is the kicker here

"On certain days you need resources that can help to get those last increments of power to meet customers' needs. We call that peaking power. You can have solar and storage provide that and completely offset the need for other, more traditional resources like what we call peaker plants," Strategen's Alex Morris says.

As coal plants become an ever-diminishing contributor to the grid and renewables penetration increases, the need for peaking power increases. Natural gas turbines have been considered the easiest and quickest way to provide that power, which tends to only fall on short and infrequent periods of a couple of hours spread sometimes across weeks or months but nonetheless put extreme demand on constrained grids.

When the grid is "stressed" in sunny parts of the US such as California or Texas, Buttgenbach says, the high penetration of solar has started to make life difficult for gas peaker plant operators. Peak demand during the daytime is now covered by an abundance of solar. So where a gas peaker might in the past have had an eight hour window during which it might be called upon, it now only has a window of around 5pm until 9pm – a much shorter time during which to earn its living.

"That means their utilisation has gone down, that means their cost goes up per megawatt hour and there are quite a lot of fixed costs like O&M and staff that have to be amortised over a shorter time. So their costs keep going up, our costs keep coming down with solar technology," Buttgenbach says.

"However, to fill that evening peak, we need storage. You start looking at the economics and power prices in that evening peak can be very high, just because these peakers, typically gas peakers, are now pushed into a shorter period to recover their fixed costs. So pricing levels can be well over US$100 per MWh and we can build a solar plant with a four hour battery to service that peak – we can build that somewhere in the US$50 to US$60 per MWh range."

The big squeeze

Emitting both carbon dioxide and nitrogen oxide, gas turbine peakers are an unfortunate relic of the fossil fuel era that won't go away quietly. But as Buttgenbach points out, a battery storage system, able to ramp up in milliseconds, can outperform a gas peaker which at best is likely to take a few minutes, minimum. Long term, that will mean the economics are safely hedged against the rising price of natural gas. As we went to print with this edition the US announced more open LNG export policies which could exert upward pressure on gas prices domestically, while solar-plus-storage projects have free fuel for the duration of their lifetime and lower O&M costs too.

"The squeeze gets harder and harder for those gas peakers; as you have more solar-plus-storage coming online, that squeezes them even more and it's also going to start depressing the price points, so eventually, even the existing plants will be replaced. It's kind of a death spiral. The economics are just dying for those peakers," Buttgenbach says.

Even if the environmental benefits are not yet being valued as highly as we might hope for, batteries can meet or exceed technical performance criteria and still win on economics. In a competitive, open solicitation process last year, utility Arizona Public Service (APS) awarded a 15-year power purchase agreement (PPA) to First Solar for a 50MW/135MWh battery energy storage system combined with 65MW of PV.

Not only did it outdo its competitors on price, but in that instance all project proposals submitted to APS had to guarantee the dispatch and availability of power during the afternoon to evening peak, from 3pm to 8pm each night. APS was clear that its selection of the First Solar tender was also partly a hedge against gas price volatility as well as an opportunity to diversify its portfolio.

It seems regulators increasingly 'get it', too. California utility Pacific Gas & Electric (PG&E) in November last year saw a proposal approved by the state Public Utilities' Commission to replace three gas peaking power plants with four lithium-ion battery storage systems, including the 300MW/1,200MWh (four hours) Vistra Moss Landing project.

The solar-plus-storage solution still pencils out best in sunnier locations of the US, but overall there is something like 120GW of peaker plant capacity online in the country, including 3GW of ageing peakers in New York alone. Some of the fleet runs on oil or a combination of gas and oil, even more polluting and expensive than gas peakers alone, particularly for nitrogen oxide emissions. Reciprocating internal combustion engine (RICE) turbines meanwhile, the 'cleanest' generators of electricity from gas, are not cost-effective at scale for peaking capacity applications either. It is not simply hoped that the domino effect will bring the economic proposition of solar peakers from sunny states to the rest of the country; according to Tom Buttgenback, it is instead an inevitability.

"For over 100 years, power plant operators and grid planners have looked to their 'toolkit' to build solutions that keep the lights on for everybody. It's very true to say that solar-plus-storage is now clearly a resource that can be considered and it's more and more included in that 'toolkit'," Strategen's Morris says.

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Storage-plus…. gas?

One technical alternative that always elicits controversy is batteries-plus-natural gas. An existing gas peaker can be hybridised with a battery to improve its efficiency and drastically reduce the number of times it has to start or ramp up and similarly reduce the time it takes when it does.

In light of global warming in particular, the smartest solution for the transformation of the electric grid's fleet of generation capacity would be as aggressive in its pursuit of renewables goals as possible, Alex Morris argues. In practical reality, that's not what we would expect to see. Some of the existing plants are tied not only to already sunken costs borne by ratepayers; others have a kind of protected 'must run' status due to their accepted role in keeping the lights on.

"A lot of money has been spent to build the grid and the fleet that we currently have. It's prudent to consider how best to evolve that fleet and grid," Morris says.

In some cases this will mean the retirement of ageing peakers and replacing them with solar-plus-storage peakers, which can also provide energy capacity to the grid at other times and provide ancillary services too. In other cases, where it is too expensive to retire an ageing peaker, hybridisation may be a better option than business-as-usual.

"I don't think there's a single general rule about it. You generally want to be aggressive but also cost-conscious as you pursue this grid transformation," Morris says.

Yet even switching on a gas turbine comes at a price every time from an O&M perspective, and, as Tom Buttgenbach points out, "folks in the gas peaker business are not in the natural gas business, they're in the business of servicing peaks".

A battery might even enable peaker plant operators to catch the very short but higher value peaks that gas cannot. Solar prices continue to tumble even in lower irradiance markets of the world and battery prices – including longer duration solutions such as flow batteries – are coming down in price too on a continual basis.

"At some point you're going to have the question of why do you have the gas peaker, sitting there," Buttgenbach says.

"The [short-term] reality is you already have the interconnection and all of the permits so it makes it a lot easier to participate in the market with the battery. But in the long term I wouldn't think of them as gas peakers, I would think of them as a gas peaker converted to a battery."

Inaction threatens existence

Due to their very nature as assets that serve loads quickly and locally to meet network demand, peaker plants are often also located in more densely populated areas than other types of thermal power plant. This means storage, charged by clean energy, can have positive impacts on air pollution for those populations too.

Unfortunately not every jurisdiction has policy makers and regulators able or willing to price externalities, and widespread enforcement of the polluter-pays principle or carbon pricing mechanisms still seem like some way off. We can only hope it becomes more widely recognised that, as Morris says, the cost of inaction on global warming is far more expensive than the cost of action:

"It's unfortunate that there are still parties that have a hard time evaluating the science on that because really, if you're being smart, you would try to work with the science and then look at the least-cost path forward and no action is extremely expensive. Because of all the global warming side effects, it's sub-optimal to allow that to go on."

In the same auction last year in which Nevada utility NV Energy brokered a PPA for Battle Mountain (101MW PV, 25MW/100MWh battery storage), a project to replace natural gas peaking capacity, to Cypress Creek Renewables, 8minutenergy was awarded a deal for the 300MW standalone Eagle Shadow Mountain. Eagle Shadow Mountain came in at US$23.76 per megawatt hour, locked in for 25 years, while Battle Mountain's levelised cost of energy (LCOE) also competed and won at US$30.94 per megawatt hour. The existential threat to the fossil fuel industry appears to be real after all, and peakers are next in the firing line. ■

Utility Arizona Public Service decided that the advantages of battery energy storage include a hedge against fossil fuel price volatility

Credit: APS

Cryogenic, long-duration energy storage in a 100% clean energy future

Storage | A key missing piece in the clean energy puzzle is the question of how to provide baseload power in an electricity system dominated by intermittent renewables. Javier Cavada of Highview Power examines cryogenic long-duration storage as a possible solution

Credit: BHE Renewables

An energy system dominated by solar and wind will require new measures for providing baseload power

A future where 100% of the world's electricity comes from clean energy sources isn't just wishful thinking – it's mandated by the hard realities of climate change. Getting energy from fossil fuels is a hard habit for humanity to break, but the good news is that momentum finally is on the side of renewable energy and energy storage. Renewables targets at every level of government, new capacity market rules being implemented by grid operators, and the availability and cost-effectiveness of long-duration energy storage resources are all helping create a major paradigm shift in the energy industry.

Across the United States, several states and more than 100 cities have adopted ambitious 100% clean energy goals. Xcel Energy made a landmark announcement in late 2018 as the first US utility to commit to fully providing clean energy with a pledge to supply 100% carbon-free electricity by 2050 across its service area in eight US states. Europe has made even greater progress. Most European countries have set similar renewables targets, and some have made significant headway. Germany gets 36% of its electricity from renewable sources, Denmark gets over 50% and Iceland generates the most clean electricity per person on earth, with almost 100% of its energy coming from renewables.

The quantum leaps we're seeing in the market are also possible because the cost of renewable energy is on par with fossil-fuel generation. The levelised cost of electricity (LCOE) for utility-scale solar fell 85% from US$350/MWh in 2009 to US$50/MWh in 2017, and according to the National Renewable Energy Laboratory, is expected to drop to US$37/MWh by 2050. The wind industry saw similar price drops, with the mean wind energy LCOE dropping to US$45/MWh in 2017.

Competitive prices are helping to spur unprecedented levels of renewables deployments. The U.S. Energy Information Administration projects that from 2020 to 2050 utility-scale wind capacity will grow by 20GW and utility-scale solar photovoltaic capacity will grow by 127GW in the United States alone. With these market drivers making renewables smart business, it's clear that the march toward 100% clean energy is much more than a political movement.

To successfully incorporate ever greater amounts of renewable energy into the grid while maintaining reliability, energy storage assets will need to be capable of steadily injecting electricity into the grid for much longer periods of time than is currently the case. Grid operators are turning to long-duration energy storage (more than four hours) to help improve power generation economics, balance the grid and increase reliability. The promise is to enable renewables to become baseload power – a feat that is nearer in the timeline than many believe.

Cornerstone to 100% renewables – long-duration energy storage

One challenge in adding more renewable energy sources to the power grid is figuring out how to deal with the intermittent power generation from these sources. Consumers, of course, demand reliable power. But if the whole system is lacking enough generation, short-duration energy storage resources simply would not be able to sustain sufficient power output for a long enough period of time to meet power demands. The good news is that with at least eight hours of capacity, energy storage resources are equivalent in performance to – and could replace – a fossil fuel power station. Such long-duration energy storage resources can also support the electricity transmission

and distribution systems while providing additional security of supply.

The benefit to the grid – and more importantly, to our planet – is that longer-duration energy storage will enable grid operators to maximise renewable energy penetration without needing fossil fuel generation to make up for intermittency.

> "The promise is to enable renewables to become baseload power – a feat that is nearer in the timeline than many believe"

This makes replacing gas peaker power plants with a combination of solar, wind and energy storage a viable reality and truly sets the stage for a future where 100% of the world's electricity comes from clean energy sources.

What options are available today?

Many energy storage technologies are already in use, but each presents its own challenges for grid-scale, long-discharge storage.

Pumped hydro and cavern-based compressed air storage have been used effectively for very large-scale energy storage projects, but both have siting constraints. Pumped-hydro requires close proximity to two large bodies of water with hundreds of feet of drop between them; compressed air storage calls for injecting compressed air into airtight, geologically stable structures, such as caverns or depleted oil or gas fields, which can be difficult to find.

Lithium-ion batteries have been used for stationary energy storage applications, due to their high energy density and relatively low upfront cost. However, the longer the discharge period for a given capacity, the more batteries you need. At the hundreds of megawatts scale, the economics for two or more hours of discharge is a challenge. Lithium-ion batteries are also tough on the environment; after a relatively short life, their components are difficult to recycle. They also can pose a fire risk if not properly managed, and they rely on diminishing metal resources (such as cobalt) which come with mining risks.

Flow batteries are often more economic than lithium-ion, and they don't degrade as quickly. However, there is a cost to scaling to higher power capacities. Like all batteries, they are limited in their ability to reliably provide the synchronous inertia and voltage control in the way that is possible for traditional power plants with spinning generators. This means that, as more and more solar and wind power is added to the grid, battery storage is limited in its ability to respond to large imbalances between electricity supply and demand while keeping frequency and voltage stable.

One emerging, long-duration energy storage option, with the potential to mitigate many of the constraints posed by other systems, is cryogenic energy storage technology.

A versatile, environmentally friendly option emerges

Cryogenic energy storage systems, which use liquid air, are better suited to provide grid-scale storage than pumped hydropower or compressed air because they are freely locatable systems that can be sited just about anywhere. Cryogenic energy storage plants have a small footprint, don't use any hazardous materials, have no associated fire risk, and can easily meet strict urban building codes.

The technology uses liquid air as the storage medium by cooling ambient air (using conventional industrial refrigeration) to lower than -270°F (-170°C), which results in a 700-fold contraction in its volume from gas to liquid. The process is similar to that used to liquefy natural gas, but because these cryogenic systems use only air, the entire charge/discharge cycle is completely free of carbon emissions.

The liquid air is stored in conventional insulated tanks at low pressure (such as those used for liquid oxygen or nitrogen storage at facilities such as hospitals). When energy is needed, the liquid is warmed and pumped to pressure, then expanded back to gas with a 700-fold increase in volume. The expansion takes place through a standard expansion turbine connected to a generator to generate electricity, thus releasing the stored energy. There is no combustion – the only thing released into the atmosphere is clean air (Figure 1).

These cryogenic systems are the only long-duration energy storage solution available today that offer multiple gigawatt hours of storage. That represents weeks' worth of storage, not just hours or days.

Modernising the grid to remove barriers to renewable power

A critical benefit of this giga-scale storage is that these systems can provide services at all levels of the electricity system—supporting power generation, providing stabilisation services to transmission grids and distribution networks, and acting as a source of backup power to end users.

Cryogenic energy storage can help power systems deal with operational limitations that prevent large amounts of variable renewable generators from being integrated into the energy mix at any given time. These limitations are related to the speed at which resources can respond to imbalances between electricity demand and supply.

One of the main tasks of grid operators is to keep electricity generation

Long-duration energy storage systems based on cryogenic technology are well suited to providing grid-scale storage

Credit: Highview Power

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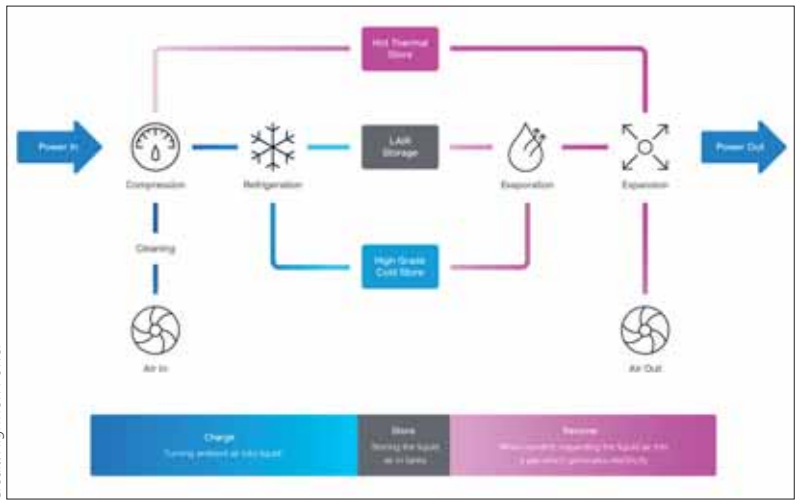

Credit: Highview Power

Figure 1. How cryogenic energy storage systems work

and demand balanced at all times since sustained imbalances result in blackouts and system failures. Currently, most electricity systems rely on a form of energy storage known as synchronous inertia to help overcome imbalances between electricity demand and generation. Basically, synchronous inertia functions much like shock absorbers on your car that limit the impact of bumps or holes in the road.

Synchronous inertia levels will decline significantly in the future as more renewables are integrated, potentially limiting the maximum share of renewables in the overall energy mix. Most forms of non-synchronous generation, including solar PV and wind turbines, rely on power electronics to convert primary energy into electricity. This kind of generation, while great for the planet, is not as effective at acting as a shock absorber because although the response is very fast, there is not a mechanism that ensures power stability.

System operators have defined parameters that help identify operational limits to the amount of non-synchronous generation that can be integrated into the grid at any given time. In Ireland, for example, grid operators monitor their non-synchronous penetration ratio as a way to estimate the maximum share of non-synchronous generation in the energy mix that can be integrated at any given time without jeopardising system stability. This ratio is currently estimated to be 50%.

To overcome operational limitations and guarantee security of supply, grid operators are developing new network codes and are redesigning their ancillary services markets with the aim to procure synchronous inertial response (SIR) and other auxiliary products.

Cryogenic energy storage can provide synchronous inertial response. These systems use motor-driven compressors to liquefy air and charge the energy store, and a turbine-driven synchronous generator to inject power to the grid. This creates a scenario where both the charging and the discharging units of a cryogenic system can provide synchronous inertia. Interestingly, both units can run concurrently which can be very valuable. For example, system resiliency tends to be very weak when electricity demand is at its minimum level and the penetration of non-synchronous generation is high. These events occur across the year, normally at night or on sunny summer weekends when people are on vacation. In this scenario, few conventional generators serve system load, reducing system inertia to minimum levels. Under these circumstances fluctuations from renewable generation may create imbalances that need to be resolved more quickly than normal to avoid major system failures, impacting the cost to operate the system.

Managing the costs associated with operating the system under low synchronous inertia conditions will entail minimising renewable curtailment and procuring cost-effective system services. Operating the charging unit of a cryogenic energy storage system not only helps avoid curtailment but also contributes to providing synchronous inertia. Additionally, the discharging unit could be operated at its minimum export level or even operated as a synchronous condenser contributing to system inertia and voltage control. This would result in a reduction in the amount of fast reserves needed for frequency and voltage control.

Given the operational capabilities of most electricity grids around the world, there is a limit to how much renewable energy can be integrated at any given time while maintaining grid resiliency. Operating the grid with low levels of synchronous inertia would prove to be expensive, especially when demand for electricity is low. This is where energy storage options, such as cryogenic systems that provide synchronous inertia, can help to reduce costs by reducing renewable curtailment. This could be a key element in maximising the benefits of renewable energy integration.

Conclusion

Only with giga-scale, long-duration energy storage will renewables become reliable enough to become the baseload source of power. As utilities better understand the benefits and technical abilities of long duration energy storage, we will see faster integration of renewables to help us get to a 100% clean energy future. ■

Other applications of cryogenic energy

Power generation
- Managing intermittent renewable generation
- Energy arbitrage
- Peak shaving
- Improved heat rate
- Waste heat

Transmission
- Ancillary services
- Transmission constraints
- Inertia services
- Responsible flexibility services
- Voltage support

Distribution
- Reactive power
- Voltage support
- Local security
- Distribution losses

End users
- Power reliability
- Energy management
- Waste heat recovery
- Waste cold usage

Author

Dr. Javier Cavada, president and CEO of Highview Power, is driving the international deployment of the company's proprietary cryogenic energy storage technology. He joined Highview Power in 2018 after 17 years in leadership positions at Wärtsilä Corporation, including executive roles in China, Italy, the Netherlands, Spain and Finland. In combination with these executive roles, Cavada chaired the board of Greensmith Energy Management. He has also held leadership roles within the German multinational firm Robert Bosch in the fields of automotive technology and manufacturing. Cavada holds a PhD in industrial engineering.

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next issue

Big data and predictive maintenance

Solar and erosion control

Battery storage performance

Solar takes centre stage in weaning Nigeria off diesel

Africa | Nigeria, the world's largest user of diesel gensets, also has the greatest potential for distributed energy solutions, writes Bill Lenihan, CEO of ZOLA Electric

Nigeria is one of the most promising markets worldwide for renewable energy in 2019. Its economic development is on a rapid upward trajectory, but energy access and distribution are struggling to keep pace. Nigeria's energy access deficit is immense, routinely ranked as the second largest worldwide, behind India. Today, Nigeria is home to almost 200 million people and over 20 million small businesses. The vast majority of this population receives fewer than eight hours of electricity a day, a condition that has in fact increased over recent years. For those with grid connections, the unreliability of energy supply continues to be a significant problem, with power outages occurring daily. This unreliability and uncertainty is a massive tax on its population, curbs economic productivity and, given the prevalence of diesel generators, poses a significant environmental and public health issue.

Nigeria is the largest energy market with the greatest unmet need. It is also Africa's biggest economy and oil producer, with a population growth poised to reach 400 million and surpass the United States by 2050. For these reasons, Nigeria is the market with the greatest potential for distributed renewable energy solutions.

One of the prevailing challenges that we continue to observe in Nigeria is the growing demand for reliable power in urban and peri-urban areas. As growth in the scale of urbanisation has continued to accelerate, grid infrastructure simply hasn't kept up. So, while the grid can reach these areas, it can't deliver baseload power for reliable 24/7 supply. Imagine the stove turning off halfway through cooking dinner, the lights going dark before you finish your homework or the TV switching off in the middle of your favourite show.

Homes and business have growing energy needs, beyond lighting and mobile phone charging. Distributed renewable energy solutions need to build the capacity to power refrigeration and air-conditioning, as well as power-intensive devices such as kitchen appliances, power tools and computers. Meeting these demands with distributed renewable energy is a significant engineering challenge, but growing investment in R&D and technology is driving rapid innovation in the scale and capability of new solutions.

Distributed energy solutions such as solar and storage are poised to help Nigeria tackle its energy access problem

The market response to maxed-out grid capability has been the widespread adoption and now reliance on diesel gensets. Much of the country relies on diesel gensets to meet baseload power demands. They can offer distributed energy and plug the reliability and demand gaps in a way that the grid is unable to.

As a result, Nigeria now has the largest diesel genset network in the world, with an estimated 100 million diesel gensets in use daily. Yet, they are neither convenient nor reliable. As a fossil fuel-powered internal combustion engine, diesel gensets require constant maintenance – including weekly or even daily replenishment of gas and – and break down regularly.

They are also costly to purchase and run, loud and unsightly, detrimental to the environment and hazardous to health. Some estimates of the environmental impacts of diesel generators in Nigeria peg their adverse carbon emissions at about 29 million metric tons of CO_2 each year (the emissions equivalent of roughly 6.3 million passenger vehicles).

As a continent-wide provider of distributed energy, ZOLA Electric is observing a significant demand for distributed renewable energy alternatives that don't rely on the grid architecture or fossil fuel. Nigerians want and need distributed solar + storage + inverter technologies that can power energy-intensive AC appliances, such as fridges. These solutions need to be modular and expandable so that they can grow with users energy needs. They also need to be cost-competitive, reliable and attractive to aspirational consumers with modern lifestyles.

To lead the transition away from diesel gensets, Nigeria needs integrated solar+storage+inverter systems that can provide autonomous power generation. These modular generation and storage nodes need the capability to network and interact together, as networked strings of hybrid mini-grids – networks that can interact with each other and multiple energy users, as well as existing grid-tied infrastructure – to ultimately transact power and create autonomous virtual power plants. There is huge potential for systems that can adapt to myriad use-cases and evolve as mini-grid networks. These modular systems need to be engineered to regulate voltage and current fluctuations and "island" from the grid or mini-grid for overload, surge and brownout protection.

To create customer demand and drive transition away from diesel gensets will require a modern, cost-effective and accessible solution. Distributed renewable energy through hybrid mini-grid networks, with modular and integrated solar + storage nodes, is the way forward. We expect to see the uptake of this solution rapidly evolve in 2019. This is the decentralised renewable energy solution of the future that will allow Nigeria to leapfrog poles and wires, respond to the current weak grid scenario and avoid the cost and complexity of grid expansion. ■

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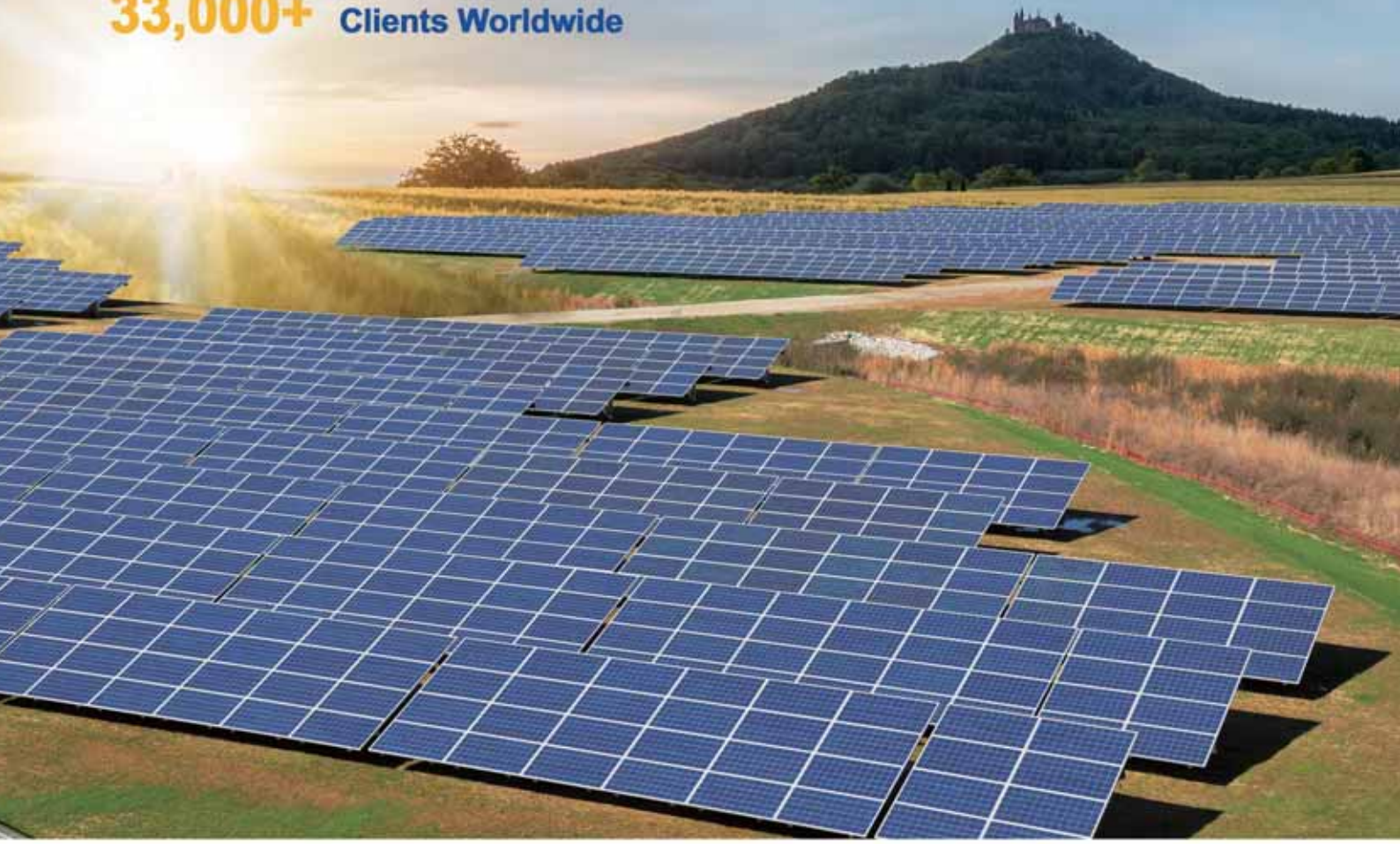

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