POWER PV TECH

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BEYOND COVID

How the solar industry has tackled the pandemic, and the role it can play in a green recovery, p. 12

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Introduction

Welcome to volume 23 of *PV Tech Power*. In my last editor's introduction, I spoke of a solar industry changing and evolving at near breakneck speed, adapting to whatever application was required of it. Little did I, or anybody else, know how quickly those attributes would be called upon.

The continuing COVID-19 pandemic has, in just a few short months, changed global economies beyond recognition and as countless analyses have stressed of late, the energy sector is no different. The International Energy Agency's Global Review pulled no punches when it remarked that not since the Great Depression of the 1930s had the world seen such a dramatic change to the power market and chief executive Fatih Birol was unequivocal in his stance that whatever power sector emerges from the coronavirus crisis will look significantly different from the one that preceded it.

As a result, there was little competition for the subject of this volume's cover feature. Pages 12 through 21 document not just the pandemic's impact, but how the industry has reacted. You won't be surprised to read just how quickly the sector has responded to the crisis. Furthermore, we take a glance forward at what the emergent global economy will look like once the crisis subsides and, crucially, the role solar may play.

At this point it would be remiss of me not to mention the tragic impact the novel coronavirus has had on countless lives. Everyone at Solar Media wishes our readers well throughout this period.

Elsewhere in this volume of *PV Tech Power*, and firmly on the back of a recent spate of 'net zero' announcements from the oil and gas majors, we explore just how close renewables investment is to reaching a tipping point where investors desert fossil fuels in their droves (p.24). We've also expert analysis from the likes of Fraunhofer ISE, whose researchers provide a technical briefing on vanadium flow batteries (p.76), and we look to the skies for an in-depth view of how using drones for aerial plant surveying is taking off (p.46). And as subsidies in numerous markets contract, we get exclusive insight from Solarcentury on the design and modelling decisions necessary early on in a project's lifecycle that can help get merchant solar projects to the finish line.

The pandemic has brought the world a situation that's rife with uncertainty. At this stage there are more questions than answers, and the unknowns – particularly around what the future may look like – vastly outnumber what we can be sure of. But in reading this volume's cover feature, and indeed the pages that follow, it's clear that the renewables industry stands ready to become a central pillar of whatever shape the future takes.

Thank you for reading, and I hope you enjoy this volume of *PV Tech Power*.

Liam Stoker
Editor in chief

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EUROPE

Surging generation

EU solar generation jumps 28% year-on-year in month of lockdown

Dynamics set in motion by the COVID-19 crisis and weather patterns have mixed to push EU solar generation to new heights, amid talk by analysts that the jump evidences the need for flexibility. Think tank Ember tried to put figures on the shift for the whole of the EU27-plus-UK group. The research, carried out for outlet Carbon Brief, found solar and wind reached a joint 23% share among these 28 states in the 28 March 2020 - 26 April 2020 period, a "record-high" figure. The 23% solar and wind share – which Ember said had not been expected until 2025 – emerged as the think tank found a 39% drop of energy-related CO2 emissions across these countries compared to the same period of 2019. Across all 28 states, solar generation grew 28%, year-on-year.


Credit: Markus Spiske / Unsplash

Solar generation grew 28% across all 28 states as CO2 emissions dropped 39%.

Utilities

RWE targets 4GW green energy push after year of solid profits and E.ON swap

RWE AG has committed to a major green energy buildout over the next three years, following the addition of E.On renewable assets in a year when profits soared. Releasing its full-year results for 2019, the group announced plans to invest €5 billion (US$5.6 billion) to add 4GW of solar and wind to its portfolio by 2022, building on the capacity it already absorbed from E.On via a complex asset swap that closed last year. The update shows net income more than doubled from €591 million (US$662 million) in 2018 to €1.2 billion (US$1.34 billion) in 2019. The year-on-year surge was due to the "exceptional trading performance" and a "strong" gas and LNG [liquefied natural gas] business, RWE said. Going forward, however, the Essen-based giant – who employs nearly 20,000 people worldwide – will double down on green energy growth.

Polish coal giant to press ahead with 2.5GW solar push despite business retrenchment

The owner of a double-digit-gigawatt portfolio of coal-fired power will continue with a shift to renewables even as it shuts down its non-essential business over the COVID-19 crisis. Polska Grupa Energetyczna (PGE), the largest utility in its home country of Poland, said it will shutter projects "outside of its core business" in a bid to shore up its finances, at a time when pandemic-driven shutdowns are hitting power use worldwide. PGE's statement did not spell out the areas it would cull as part of its "rationalisation" drive. The state-run firm made clear, however, that it will continue to implement its decade-long wind and solar growth programmes, set in motion prior to the COVID-19 outbreak.

Finance

Boss of Norway's fund giant to steer US$10.7bn green energy splurge from London

The world's largest sovereign wealth fund will tap its outgoing boss to lead a new campaign to invest billions of dollars in green energy in the space of a few years. Norges Bank Investment Management (NBIM) is to use its trillion-plus-dollar pot of oil wealth money to inject 100 billion Norwegian crowns (US$10.7 billion) into unlisted renewable projects by 2022, CEO Yngve Slyngstad said. Contacted by PV Tech, a NBIM spokesperson confirmed recent reports that it will be Slyngstad himself – CEO since 2008 but set to step down this year – who steers the green energy push, relocating from Oslo to London to coordinate efforts.

The Netherlands

Pot for spring round of Netherlands green energy subsidies doubled

Faced with the prospect of flunking its 2020 emissions reduction target and a legal obligation to its citizens, the Netherlands has doubled the budget of its forthcoming renewable energy subsidy round to €4 billion (US$4.47 billion). "By increasing the budget for the spring round, a larger proportion of available projects with a short realisation period, such as solar projects, can happen in the short term," Eric Wiebes, minister of economic affairs and climate policy, wrote in a letter to parliament. The government had previously planned a €2 billion (US$2.23 billion) pot for the subsidy round. Last December, the Dutch government was ordered by the country's supreme court to slash emissions by 25% by the end of this year compared to 1990 levels, after losing its final appeal in a six-year legal case brought by climate group Urgenda Foundation.

The UK

Solar makes long-awaited return to UK renewables auctions

The UK government has paved the way for utility-scale solar to once again compete in renewables auctions, completing a dramatic policy U-turn. The UK's Department for Business, Energy and Industrial Strategy (BEIS) announced that established, onshore renewables – effectively onshore wind and solar PV – will be allowed to bid for support in the next Contracts for Difference (CfD) tender round, slated for next year. The decision marks a significant change in policy for a government that has locked established renewable technologies out of CfD auctions since the first allocation round in 2015. In the years since, offshore wind – a less established, so-called 'Pot 2' technology – has captured the significant majority of contracts available in both the second and third allocation rounds, held in 2017 and 2019 respectively, recording significant declines in strike prices.

Greece

Greece slashes bureaucracy to unblock 29GW green energy project backlog

Greece has acted to shorten lengthy licensing processes for renewable energy projects, in a bid to free gigawatts' worth of installations facing waiting times of up to eight years. Solar players looking to deploy in the high-irradiation Southern European country may find it quicker to clear various regulatory hoops, under proposals part of a new Environment Bill presented by the centre-right government. Tabled by the Environment and Energy Ministry, the new legislation is meant to do away with the current system, which sees green energy applicants wait for 3-4 years (PV) and 6-8 years (wind) for permits.

AMERICAS

New York

New York opts for 1GW-plus of solar in annual procurement series

New York state revealed this year it has awarded 17 new ground-mounted solar projects totalling 1,090MW, alongside 40MW of battery storage projects. In mid-March, state Governor Andrew Cuomo identified the winners of New York Energy Research and Development Authority's (NYSERDA's) annual competitive procurement series, now in its third year. Among the most ambitious projects selected under the 1.278MW round were a 200MW solar project backed by 20MW of energy storage and a standalone 180MW PV plant from NextEra Energy Resources; a 270MW plant backed by 20MW of energy storage proposed by ConnectGen; a 120MW solar facility backed by Boralex; and an 80MW PV plant from SunEast Tabletop Solar.

Trade war

Confusion prevails over renewable impacts of Trump's power equipment crackdown

US green energy players grappling with impacts from the COVID-19 crisis recently witnessed the adoption of a ban targeting electric equipment purchases involving "foreign adversaries". On 1 May, US president Donald Trump added his signature to an executive order outlawing the "acquisition, importation, transfer, or installation of any bulk-power system electric equipment" if it involves a foreign sponsor and is judged to be a threat to the US. Lawyers approached by PV Tech following the order's publication were still working to interpret its scope. In a prepared statement, law firm Norton Rose Fulbright said the "order leaves more questions than it answers" but "arguably" does not apply to solar and wind components.

Utility moves

Duke Energy, Dominion Energy in major green energy push

Utilities Duke Energy and Dominion Energy recently joined the list of US players announcing green energy expansions so far in 2020, with both unveiling plans for gigawatt-scale growth. In recent weeks, Duke Energy said intends to double its renewables capacity to 16GW in the next five years, doubling the current 8GW figure as it continues to target net zero status by 2050. Meanwhile, Dominion Energy issued a Request for Proposals (RFP) for 1GW of onshore wind and solar as part of wider clean energy plans in the US state of Virginia, coupled with a 250MW storage component.

Section 201

US in fresh attempt to axe bifacial Section 201 exemption as court battle looms

In late April, the US government moved once more against bifacial solar's exemption from Section 201 tariffs, ordering its withdrawal whilst accepting the reprieve must stay until last year's court injunction is lifted. For the US Trade Representative, the attempt to remove the exclusion of two-sided solar components from import levies set by the Trump administration in 2018 is the second in the space of a few months. The government office had initially opted to spare bifacial from Section 201 duties in June 2019 but u-turned in October 2019, announcing it would axe the exemption after concluding the levy amnesty would pave the way for a sharp rise in bifacial imports.

Chile

Chile's Atacama becomes staging ground for PV plans of Atlas, Colbún, Enel

Major solar ventures have been proposed so far this year in Chile's Atacama Desert, a global irradiation hotspot increasingly targeted by industry players. First in the series was Chilean power company Colbún, which filed an environmental impact statement for the US$788 million Inti Pacha PV project, in the Antofagasta Region. Within days, it emerged that Enel too was seeking environmental approval for a 498MW new pipeline of bifacial solar in the same region. Weeks later, Atlas Renewable Energy put forward proposals for a 726MWp solar plant, also in Antofagasta.

Colombia

Solar aspires to capture Colombia's energy future with 9.47GW pipeline

The campaign to drive solar growth in one of Latin America's less-explored markets appears to be bearing fruit, with gigawatts' worth of projects coming forward over the last year alone. New figures from Colombia's planning body UPME show a 9.47GW pipeline of solar is currently registered as underway, following a surge in project proposals between 2018 (389MW), 2019 (7.85GW) and Q1 2020 (1.2GW). The analysis indicates solar developers formally launched 341 ventures in 2018, 2019 and Q1 2020. The figure means 70% of all energy projects currently recorded by UPME are solar related, far above hydro (24.7%), wind (3.82%) and thermal power (2.2%).

US solar tariffs

US solar tariffs failing to kickstart upstream turnaround, review finds

The protectionism of US president Donald Trump has failed to halt the decline of domestic PV cell makers and will not suffice to defeat China's "state capitalism", a US review found. The US market has seen "large increases" in PV cell imports and "large declines" in revenues from modules containing US-made cells despite Trump's decision in 2018 to enact so-called Section 201 import quotas and levies, according to the US International Trade Commission (USITC). The Commission – a nonpartisan federal agency advising the US government over trade policies – examined whether US crystalline silicon solar manufacturing has improved or deteriorated in the years before and after Section 201 import barriers were slapped on imports. Its review did not shed light on individual US makers but claimed all players bar Panasonic had shuttered cell-making operations when contacted by the USITC in 2019.

Credit: Gage Skidmore/Flickr.

Section 201 tariffs were adopted in 2018 and have since been wound down at annual rates of 5%.

Mexico

Industry promises legal action as Mexico blocks renewables on 'stability' grounds

The stage is now set for yet another legal dispute between Mexico's government and the renewables sector, with the former acting to freeze project connections in a supposed bid to underpin system stability in the COVID-19 era. In early May, power market operator CENACE moved to block nationwide the tests required to switch on renewable plants. The measure kicked in on 3 May, following Mexico's transition into a new lockdown phase to contain the recent escalation of virus cases. The new framework from CENACE – owned by the Mexican state – sets the rules for the functioning of the country's electricity market during over the new COVID-19 quarantine stage. The document singles renewables out as an obstacle to system stability.

MIDDLE EAST & AFRICA

Saudi Arabia

Bids of US$0.0162/kWh emerge as Saudi Arabia shortlists firms for 1.47GW solar tender

Some of the world's top green energy players have tabled ultra-low bids under the second round of Saudi Arabia's renewable energy programme, set to contract a 1.47GW all in all. The kingdom's Renewable Energy Project Development Office (REPDO) recently identified the firms and consortia shortlisted to develop a slew of solar projects across the country, with some proposing tariffs below the 2-US-dollar-cent-per-kWh threshold. At 600MW in planned capacity, the Al-Faisaliah PV project is the largest of the lot and will be either contracted to a consortium led by Saudi player ACWA Power, or a rival partnership led by United Arab Emirates-headquartered firm Masdar.

ACWA Power eyeing 'enhanced' growth as Silk Road purchase completes

Saudi Arabian developer ACWA Power has set its sights on an accelerated growth trajectory after China's Silk Road Fund completed the purchase of a minority stake in the firm's renewables arm. The deal, first announced last summer, will see the Chinese state fund take on a 49% stake in – and become a strategic partner of – ACWA Power RenewCo, which owns and operates nearly 1.7GW of CSP, solar PV and wind across the Middle East and Africa. ACWA has confirmed that the deal is complete, allowing the company to capitalise on the "rapidly growing potential" for renewables across emerging markets.

Dubai

PPA sign-off brings progress to ultra-cheap 900MW solar project in Dubai

Yet another phase of what is described as the largest single-site solar project in the world lies one step closer to completion in Dubai, after the supply deal was signed online. Saudi developer ACWA Power has penned a 25-year power purchase agreement (PPA) for the 900MW fifth phase of the 5GW Mohammed bin Rashid Al Maktoum Solar Park, contracted by the Dubai Electricity and Water Authority (DEWA). Together with supranational financier the Gulf Investment Corporation (GIC), ACWA led the consortium selected by the United Arab Emirates city in November 2019 for the project, prevailing over the 60 requests for proposals DEWA had received.

Record low tariff

Abu Dhabi claims record low US$0.0135/kWh solar tariff for 2GW Al Dhafra project

Abu Dhabi Power has claimed to have received the world's lowest tariff for solar for its 2GW Al Dhafra project. A pool of five bidders tendered for the project and the first-ranked bidder – yet to be named by ADP – set their price at US$0.0135/kWh, a sum which would rank as the world's lowest, the utility said. At that price, the Al Dhafra project comes in cheaper per kilowatt-hour than the previous solar record of US$0.0164/kWh, claimed by a bidder in Portugal's major solar tender in 2019. While the identities behind the leading bid have yet to be formally revealed, reports suggest that it is a joint bid from French utility EDF and Solar Module Super League member JinkoSolar. ADP did not comment on the speculation when contacted by PV Tech.

Credit: Image: EWEC.

The Al Dhafra project will be nearly twice the size of the existing Abu Dhabi Noor project (pictured), completed last year.

South Africa

Coal truckers lose challenge to block 2GW+ of clean energy in South Africa

South Africa's renewables sector has trumpeted the end of a years-old legal challenge by the coal lobby to nix more than 2GW of power purchase agreements (PPAs) between solar and wind developers and beleaguered state utility Eskom. The case, brought by the Coal Transporters Forum (CTF), argued that the National Energy Regulator of South Africa (NERSA) had failed to approve a mandatory authorisation for PPAs signed in 2015 in the utility's fourth renewables procurement. The group also wanted to prevent the completion of deals with three independent power producers that were unsigned when the legal complaint was launched.

Uganda

State-owned Chinese firm to build 500MW of solar in Uganda

China Energy Engineering Corporation (CEEC) plans to build 500MW of solar PV in Uganda, according to a filing on the Hong Kong Stock Exchange. The US$500 million project will be constructed in two phases. China Gezhouba International Company, a subsidiary of state-owned firm China Gezhouba Group Corporation, which is itself a member company of CEEC, will be the exclusive EPC contractor of the PV system. The EPC contract includes designing, procuring, constructing and performing trials for the project. Further details on the solar capacity and its location have yet to be revealed.

ASIA-PACIFIC

ADB to back non-Chinese solar manufacturing

Asia's leading development financier may consider supporting the setting up of PV manufacturing beyond China, in a bid to minimise the reliance on Beijing laid bare by the COVID-19 crisis. Yongping Zhai of the Asian Development Bank (ADB) recently said there is a possibility the bank could "expand its support" to member countries working to build their own PV manufacturing ecosystem, helping future-proof the region against supply bottlenecks further crises may cause. "The pandemic has exposed weaknesses in the solar energy value chain in Asia and the Pacific," said Zhai, the head of ADB's Energy Sector Group, Sustainable Development and Climate Change Department. "But there are ways to strengthen it so the low-carbon energy transition can continue."

Australia

Australia ready to embrace 75% of solar and wind by 2025

Australia could make increasingly cheap solar and wind the dominating engine of its energy system within five years if it enacts the appropriate reforms, according to the country's market watchdog. The Australian Energy Market Operator (AEMO) said solar and wind could together reach generation peak shares of 75% as early as 2025, provided that policymakers do not postpone an energy market overhaul that has become pressing. In its new Renewable Integration Study, the state agency pointed at Australia's success taking installed solar and wind capacity to 17GW at the turn of the year. Adding a further 10GW across the two flagship renewables technologies is possible by 2025, AEMO added.

Currency swings to delay up to 3GWac of renewables in Australia

Consultants at Rystad Energy have warned that currency volatility could dent global solar growth from 140GW to 126GW in 2020, with the Australian market hit hard. According to Rystad, only 530MWac of the 1-2GWac of solar it expected to hit financial close in 2020 has done so at this stage and can be expected to start construction. The remainder, the firm believes, may struggle to line up finance as currency swings hurt project economics. The widening of the US$-AU$ gap – with the latter falling 20% relative to the former since January – means developers lose out as they fund purchases with foreign currency. For Australian utility-scale solar, the result could be capex rising from less than AU$1.3/Wac to nearly AU$1.5/Wac.

Neoen clinches 'landmark' PPA to advance Australia's largest solar farm

What intends to be Australia's largest solar farm has edged one step closer to deployment after its developer Neoen clinched a major offtaker agreement. Neoen signed a power purchase agreement (PPA) that will see government-owned energy company CleanCo Queensland buy power from 352MWp of solar, built under the Western Downs Green Power Hub. The project – to be developed near Chinchilla in south east Queensland – is intended to be the country's largest operational solar farm once complete, with a total output in the region of 460 – 480MWp.

China rebound

China's solar panel exports rebound in March

China export data for March 2020 has indicated a major rebound in PV panel exports as manufacturers ramped production after the extended New Year and travel restrictions caused by COVID-19 pandemic. PV panel export figures for March 2020 were 7.49GW, up around 160% from a low of 2.83GW in the previous month. The major rebound in PV panel exports could partially be attributed to a backlog of orders already in the system but hampered by logistical issues within the supply chain and shipment delays at major Chinese container ports during the height of the COVID-19 lockdowns in the first two months of the year.

Manufacturing

Solar manufacturing expansion plans for Q1 2020 top 500GW in unprecedented record

The solar industry announced unprecedented levels of capacity expansion plans in the first quarter of the year - some 500GW - easily surpassing any total annual plans in the history of the industry, preliminary data compiled by PV Tech shows. PV Tech's preliminary analysis of upstream manufacturing capacity expansion announcements in the first quarter of 2020, across ingot/wafer, solar cell and module assembly segments combined, exceeded a staggering 500GW. To put this in perspective, PV Tech's preliminary analysis of capacity expansion plans announced in 2019 reached a combined total of over 228GW, less than half the combined figures announced in Q1 2020. The vast majority of announcements in Q1 2020 were driven by China-based PV manufacturers. In 2019, China accounted for around 94% of capacity expansion announcements, according to PV Tech's analysis.

Credit: LONGi

More than 500GW worth of manufacturing expansion plans were unveiled in Q1 2020.

India

India rekindles solar manufacturing push

India has staged the launch of a new campaign to foster its domestic renewable manufacturing scene, in a bid to curb the dependency on imports the COVID-19 crisis had laid bare once more. Letters sent by the Ministry of New and Renewable Energy (MNRE) in April asked state and port authorities to set aside land sites of 50 to 500 acres for new factories of renewable equipment, from solar cells and modules to silicon ingots and wafers, steel frames, inverters and batteries. The MNRE's engagement spree – complete with talks with Indian makers and foreign trade representatives – has yielded some fruit, the government claimed. The states of Madhya Pradesh and Odisha and port authorities in the southern city of Thoothukudi have already expressed their "keen interest", the MNRE said.

Seismic shocks as the coronavirus spreads

COVID-19 | Since its emergence, the novel coronavirus has spread quickly across the world causing untold disruption. Liam Stoker and José Rojo detail how the pandemic has affected the clean energy economy to date

After first being identified in December 2019, the COVID-19 pandemic has progressed to having profound impacts across the world. At the time of writing, there have been more than four million confirmed cases across 187 countries and territories. It is a truly global crisis, with material and lasting effects.

The solar sector has been affected like any other industry, starting in earnest in late January and early February when manufacturing of modules, components and materials in China was disrupted by the spread of the disease and efforts to contain it. The extension of the lunar new year holiday meant that while solar manufacturing continued, it stood to be stymied somewhat. Investment bank Roth Capital first warned in late January that it had encountered reports of manufacturing delays, with supply chain and logistics also disrupted.

Attempts to quell the spread of the virus ultimately failed, and by late February it was spreading out of control in Europe and the US, with Spain and Italy hardest hit. France, the UK and the state of New York were not far behind, and governments across the world enforced strict lockdown and shelter-in-place measures in a bid to contain the virus.

These measures, varying in severity as they are, have caused significant disruption to the solar industry. While the classification of engineers as key or essential workers in some jurisdictions has allowed for field operation and maintenance to continue, new project development or construction has been hit hard, with delays now commonplace.

Shelter in place

Likewise, residential solar installations have been particularly hard hit. Isolation is a central tenet to any nation's pandemic strategy, so welcoming contractors into your home to fix a solar PV system has been a non-starter for most markets.

World Health Organisation officials meet in Tehran to discuss the spread of the virus

As a result, install figures have plummeted. Enphase Energy chief executive Badri Kothandaraman told analysts during an investor call in May that industry reports he'd seen projected that residential installs in the US had fallen somewhere between 30 and 50%. A recent survey by the UK's Solar Trade Association of its members revealed similar disruptions.

Government support of business during the pandemic varies wildly, but it is certain that many thousands of jobs in the solar sector will be lost in the immediate aftermath. The Solar Energy Industries Association has repeatedly warned that up to 50% of jobs in the US solar sector – amounting to some 125,000 – could be lost as a result of the pandemic, while BloombergNEF has suggested between 16-30%. Other estimates are significantly higher. A recent survey of UK installers found that 90% had been severely impacted, with cash flow a principal concern.

Meanwhile, employee safety has taken on perhaps unprecedented importance. Key roles have shifted to become home-based, with many companies in the sector speaking of completing years' worth of technology migrations in a matter of weeks. For those roles that cannot be conducted at home, stringent social distancing measures are now compulsory.

But the pandemic poses more complicated and penetrative problems than those witnessed by the supply chain and installation to date. Indeed, as some analysis has identified, the coronavirus looks certain to reverberate around the energy sector for years to come.

Seismic shocks

Analysis of the early impacts of the virus has been clear: the world is witnessing a once-in-a-generation shift in energy demand. Established economies, pushed into recession as industries have been shuttered, are experiencing the kind of collapse in power demand the International Energy Agency described as "seismic". A projected fall in power demand of 5% by the end of the year could see renewables provide more of the world's electricity need than ever before, but at a significantly cheaper price than was previously forecast. As pages 14-16 will attest, that slide in demand is moving the goalposts for merchant-based renewables in what could constitute a body blow for tens of gigawatts of prospective capacity additions in Europe alone.

What has become clear in the months since the pandemic's spread is that there will be no corner of the global economy left untouched by its impact. COVID-19 and the ensuing crises, whether they be logistical, economic or societal, will be felt for some time yet. It's therefore of little surprise that politicians and business leaders alike have placed great significance on the need for industries not to plot a return to the old ways, but identify a new normal.

As you'll read in the forthcoming pages, the solar sector has proven itself particularly adept at this. There is also an increasingly popular school of thought that not only could the clean economy regain lost ground quickly but take a far more prominent role and become central to any recovery.

COVID-19: A Timeline

31 January 2020

Coronavirus expected to impact China's solar industry supply chain
ROTH Capital Partners tells investors new COVID-19 outbreak in China is likely to impact the solar industry supply chain, amid standstill across eight provinces through 9 February.

12 February 2020

China's solar industry getting back to work as logistical constraints emerge
China's PV industry tentatively starts to get back to work after the extended New Year holiday period, with bottlenecks and shortages still plaguing the supply chain.

26 February 2020

China solar exports witness 35% year-on-year slide in January
Official export data shows exports of solar products from China in January 2020 were around 35% lower than one year prior, reflecting COVID-19's impacts during the period.

10 March 2020

IEA: Coronavirus-driven oil rout will 'test' renewable pledges of O&G majors
Global watchdog says the crash of oil prices as the global coronavirus crisis intensifies may challenge the plans by oil and gas giants to finance a shift to renewables.

23 March 2020

India begins renewables aid campaign as crisis exposes sector vulnerability
Deadline extensions mark start of flurry of renewables-friendly policy moves, with government following by enshrining sector as "essential" and finding land for new PV factories.

25 March 2020

COVID-19 prompts solar tender recalibration across key European markets
France and Germany alter solar tender rules in a bid to adjust to a reality of project delays, while Portugal reschedules late-March tender launch to early June.

26 March 2020

US COVID-19 stimulus package passes without solar ITC extension
Attempts fail to include solar tax credits in a US$2tn federal aid package, passed one month before president Donald Trump excludes PV from a broader import tariff reprieve.

30 March 2020

Intersolar Europe 2020, SNEC 2020 cancelled as COVID-19 crisis intensifies
Europe's and Asia's top solar events are postponed as the world grapples with the COVID-19 outbreak, with SNEC being rearranged for mid-October.

6 April 2020

PV makers' expansion moves top 500GW despite COVID-19's shadow
PV Tech's preliminary analysis shows Q1 2020 expansion announcements easily surpass any previously recorded in the industry's history.

9 April 2020

Wood Mackenzie lowers global solar demand forecast on COVID-19 impact
Consultancy cites project delays and financial fallout as it slashes pre-pandemic 2020 global solar installation forecast by 18% from 129.5GW to 106.4GW.

14 April 2020

Spanish solar back in play as temporary construction freeze is lifted
Solar construction resumes in what is seen as one of the world's most promising markets, following the lifting of lockdown measures that brought work to a halt for 10 days.

16 April 2020

Solar scores generation records across the globe as lockdowns alter market dynamics
Quarantine measures against the COVID-19 outbreak set the scene for generation records by solar and broader renewables in Germany, Spain, the UK and Australia.

22 April 2020

Negative pricing triggers subsidy block for European solar players
Dutch PV players feel heat of negative power prices after regulator warns that extended periods of sub-zero tariffs will trigger subsidy cut-offs, in line with European regulation.

5 May 2020

EU solar generation jumps 28% year-on-year in month of lockdown
Mix of pandemic-driven economic paralysis and milder weather pushes EU solar generation to new heights, amid talk by analysts that the jump evidences the need for flexibility.

7 May 2020

Leak suggests renewables will be one of Europe's recovery pillars
Unpublished draft seen by PV Tech reveals plans by European Commission to make green energy one of two priorities of COVID-19 comeback, together with building renovation.

11 May 2020

SunPower, Vivint, Sunrun updates show pandemic hit yet to come
Latest results of SunPower, Vivint Solar and Sunrun underscore broader trend of top solar players faring well in Q1 but expecting setbacks in Q2.

Coping with COVID

COVID-19 | From manufacturing and logistics constraints to power price collapses, the effects of the coronavirus pandemic are being felt throughout the entire solar supply chain. Liam Stoker details the impacts on the industry and how they have been mitigated

Credit: Solarcentury

COVID-19's potential impact on the solar industry, right the way through from manufacturing to distribution to deployment, has meant the sector has had to learn to live with the virus, and do so quickly.

While the virus was first recorded in November, it wasn't until 23 January that the Chinese province of Hubei was placed under lockdown. This coincided with Chinese New Year celebrations which commenced on 25 January, with China taking the unprecedented step of extending the spring festival until early February in a bid to counter the virus' spread. That decision had a predictable knock-on effect on manufacturing, and official export data released in late February showed that exports of solar products in January fell by around 35% year-on-year, indicating the impact on the upstream industry. Around 4.45GW of solar products were exported in January 2020 compared to just over 6GW in January 2019.

Provinces affected by the virus at the time are home to various manufacturing hubs belonging to the likes of LONGi Group, Trina Solar, Q CELLS and JA Solar, providing a succinct indication as to the possible impact of the virus on solar across the globe. Investment bankers Roth Capital warned in late January of those impacts, stating that while most manufacturing facilities had been operational throughout the holiday period, they likely had "not been running at 100%".

On-site engineers have seen medical face masks added to their list of required PPE.

This would be present not just in module assembly or manufacturing, but throughout the much wider materials and component sector. Roth also noted at the time of an emerging shortage of solar wafers and module-grade glass, driving component pricing upwards in the near term.

Actual reports of infection within factories were, however, minimal. In late March GCL System Integration confirmed that an outbreak at its facility in Jiangsu, China, meant a temporary partial shutdown was necessary. While the company did not provide specific details of the outbreak, nor the partial shutdown, it did state that "anti-epidemic measures" were put into place and production resumed thereafter.

Impacts earlier in the year have already started to tell. Of those manufacturers to disclose financial results by late April, almost all have confirmed the presence of COVID-19-related headwinds. JA Solar, which has four manufacturing operations in Hubei, reported that its production and logistics cycles had been "extended" as a result. Backsheet and high-efficiency module manufacturer Jolywood too reported a small loss in Q1 2020, down from a small profit recorded in Q1 2019, which it attributed to a number of issues created by the pandemic, including the delayed restart of production as a result of employees facing difficulties in returning to work on top of logistics and transportation restrictions.

Stymied logistics and transportation within China were felt further afield. Microinverter manufacturer Enphase Energy warned in February that while its contract manufacturing facility in China was steadily ramping back up to full capacity, it had seen "some indications" that outbound logistics from China had been constrained by the outbreak. This led to the firm exploring alternative freight options – air instead of sea freight – an option taken previously. Then, in early May, Enphase confirmed that while its manufacturing facility in Mexico had been deemed "essential" and thus could continue operating at full capacity, a slide in demand caused by collapsing installation figures and shelter-in-place rules in its key markets meant that the company would need to work alongside its supply chain partners to "optimise" its inventory in the future. Mass-producing components only for them to sit in warehouses is evidently not considered a wise use of resource at this moment in time.

SolarEdge meanwhile is extending that vigilance further, stressing at its last results disclosure that it was now keeping tabs on its customers' financial health to ensure that it would be paid for each order. CFO Ronen Faier told analysts in May that the firm was cautious of providing credit to customers that it was "a little bit afraid that we will we not be able to collect".

The lessons to learn here, according to Clean Energy Associates chief executive Andy Klump, are that when it comes to supply chains, reducing risk through diversification is critical. Relying on just the one supplier for a key component bears significant risk, with CEA actively encouraging people to consider working with not just two, but three suppliers across diverse projects to protect against any short-term collapse or delay.

John Zahurancik, COO at energy storage developer Fluence, concurs, adding that the company has experienced delays in shipping of parts that have accumulated. This has been "in the order of days and weeks rather than longer", Zahurancik says, and any changes are worked through to reduce the emergence of any critical gaps in supply. "In this environment one of the biggest things has been remaining agile, remaining flexible to be able to adapt to the conditions that emerge," Zahurancik says, lessons that have been taken by many within solar and storage development.

On-site safety

As the virus spread throughout the world, it quickly hit economies where not upstream manufacturing, but downstream development was at risk. A rapid escalation of infections and lockdown measures in response raised the prospect of widespread delays, and Wood Mackenzie lowered its global solar demand forecast for 2020 from 129.5GW to 106.4GW as a result.

Continuing development has been stymied by not just delays in the distribution and delivery of components, but also national lockdown measures and the classification of the solar workforce as essential personnel. This has differed by nation, with most European countries deeming O&M engineers as key workers – and thus allowed to continue being on site – with differing attitudes to ongoing construction. Spain enforced a 10-day shutdown in April before reopening construction works, which was quickly followed by the return to action of most developers. Delays such as these have proven costly, with French developer Neoen noting that the suspension of pre-operational testing at its 375MWp El Llano solar farm in Mexico was costing the firm as much as US$2 million per month in lost generation.

Most solar companies and utilities have been active throughout the pandemic. Iberdrola switched 95% of its staff to remote working as a protective measure, a feat enabled by a sweeping digitalisation of internal processes, the utility said. Worley, which is providing engineering, technology and technical review services for the under-construction Noor solar farm in Dubai, said it adapted its offering by conducting those remotely, holding regular project meetings via videoconferencing facilities after global travel restrictions limited staff movement. Meanwhile asset managers have been able to remotely monitor site performance largely unaffected by the pandemic, with staff able to do so from home. Project pipelines are continuing to gain traction, too. Solarcentury said that while permitting of new sites had slowed since the onset of the virus, it was still continuing, with most planning authorities now having completed their own migration to remote working. Public consultations are even managing to be held, albeit online.

It is the actual nuts and bolts construction of solar farms that has changed the most, however. Oil and gas major Repsol confirmed in April that it was amongst those developers back on site in Spain with a revamped development strategy. Construction teams had been capped at a maximum of four people, with each instructing to observe a safe distance of two metres. In addition, entry to construction sites is conducted in a phased manner to reduce any congestion, while protective clothing and even vehicles are disinfected before they can be shared.

Solarcentury has followed similar practices, allowing construction tasks in open spaces to continue while delaying those that require multiple people working in close proximity. Communal areas such as canteens and break rooms have been closed and, in the interest of preventing the virus' spread, recruitment procedures adapted to minimise new personnel appearing on site.

Of Fluence's development pipeline, Zahurancik says only two or three have

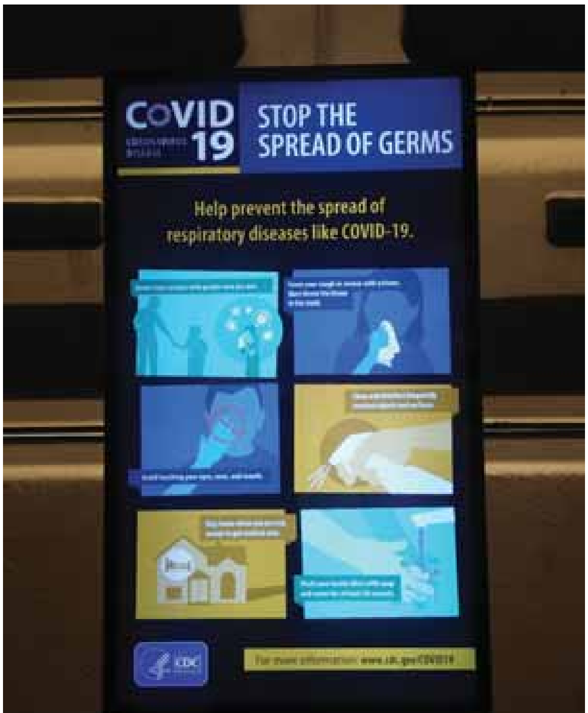
Safe solar development under COVID-19

Adapted recruitment
Prevent the spread of the virus by recruiting locally as much as possible, favouring local experts over those usually asked to travel in.

Phased entrance and exits
Reduce traffic and congestion, especially around choke points, by offering strict windows for entering or leaving the site. This includes deliveries as well as construction engineers.

"Toolbox Talks"
Designated leaders can reiterate new site safety rules as teams arrive on site, stressing their importance and ensuring they are strictly followed at all times.

Construction squads
Limit the size of teams working together at all times, taking into account the manner of the job and the area they'll be occupying. If jobs require personnel to work in close proximity to one another, delay if at all possible



Credit: H/Flicker

An electronic billboard in Washington D.C. instructing citizens to stay at home

experienced delays. The firm acted early to institute social distancing and health screening for those accessing construction sites. Anyone who exhibits symptoms is isolated. No protective equipment is shared and site safety meetings have become more regular. These additions haven't cost a considerable amount, but Zahurancik does suggest there is some cost associated with a loss of productivity. In essence, it's a ramp-up of safety practices already in place. "They're just additions to the safety practices at each site and I think we have to continue to be vigilant of those precautions. They do have some impact to the site in that you're adding some steps and procedures to follow, so there's some productivity impact but using those steps we've been able to move projects forwards," Zahurancik says.

A tumbling power price

The virus has had such a wide-ranging effect on global economies that built solar assets, or at least those that own them, have been just as impacted by its spread. As lockdown measures have been enacted, economies have considerably slowed, with numerous industries all but shuttered. This has led to power demand tumbling, with established economies with strong manufacturing bases the hardest hit.

With demand low and supply steady, the wholesale power price in most European nations has fallen considerably. Countries such as Italy, Spain and the UK have witnessed power prices fall by anywhere from 20–40% since lockdown measures have been enforced. Spanish utility Iberdrola noted in May that its Q1 performance had been affected by a 37% fall in the power price in its home market, while The Renewables Investment Group (TRIG), which owns solar, wind and other renewables assets throughout Europe, said in April that its power price forecasts show a 25% reduction over the next two years. As a result, TRIG's net asset value (NAV) has fallen by around 5 pence per share. Likewise, other European asset holders such as Foresight Group and Bluefield Solar Income Fund have also seen the value of their assets drop, reporting drops of 5 pence and 6.7 pence per share respectively.

While most asset holders in Europe derive a large portion of their revenues from subsidies – TRIG revealed that just 25% of its revenue base comes from the actual sale of power – and are somewhat insulated from falling demand, that NAVs are falling consistently is a concern for investors. Matters are further complicated with a piece of European Union legislation that means in some markets, when wholesale power prices fall into the negative for six hours or longer, subsidy payments for power generated during that time are withheld. In addition, the UK system operator National Grid, triggered by significant low forecasts for power demand, was granted special powers by the country's regulator Ofgem allowing it to instruct distribution network operators to switch off embedded generation, including solar PV of all scales, without compensation.

> "…the energy industry that emerges from this crisis will be significantly different from the one that came before"

Asset owners could also face such contractions for some time yet. Oxford, UK-based consultancy Aurora Energy Research has warned that some of its modelling shows that while a mild recession caused by COVID-19 could see power prices recover by 2022, a deeper recession would see the compression on power prices last until 2025 at least.

The International Energy Agency's 2020 Global Energy Review report compounds Aurora's analysis too. Power demand has already fallen by 5%, according to the IEA, constituting the largest fall in demand for electricity since the Great Depression of the 1930s. Describing the pandemic as representing an "historic shock to the entire energy world", Fatih Birol, executive director at the IEA, said: "Amid today's unparalleled health and economic crises, the plunge in demand for nearly all major fuels is staggering, especially for coal, oil and gas. Only renewables are holding up during the previously unheard-of slump in electricity use

"It is still too early to determine the longer-term impacts, but the energy industry that emerges from this crisis will be significantly different from the one that came before."

Indeed, the IEA's report suggests that renewables – benefitting from priority dispatch and lower operational costs – could deliver as much as 40% of the world's power demand this year, cementing the lead over coal it secured in 2019. But that lead will come at a cost, with the aforementioned collapse in power prices ripping the business models for new projects, especially those coming forward without subsidy support, from beneath their feet,. Felix Chow-Kambitsch, head of commissioned projects for Western Europe at Aurora, stresses that merchant-exposed renewables schemes will be "significantly affected" by the price contraction. Revenues of such projects could fall by as much as 50%, depending on the severity and duration of the pandemic and its impacts, implicating as much as 34GW of renewables developments within the seven countries profiled in its research.

In the face of an unprecedented situation, solar has been able to pivot adeptly and resume activity wherever possible in the short term. This, evidently, has only been possible through manufacturers', distributors' and developers' abilities to react to a constantly changing situation with all the necessary flexibility and agility. Against the context of a significantly different global energy market, it's this flexibility that looks set to become pivotal in the mid- to long-term, when, as you'll read on, solar and storage could become a central pillar to economies the world over.

Solar begins winding road to post-COVID green new tomorrow

COVID-19 | PV's rise to the mainstream finds it now inextricably linked to an economy tumbling towards recession. Players approached by José Rojo acknowledge the disruption but believe the chaos may hand the industry a chance to become a core part of a new world rebuilt along green lines

"It sounds really bad but I was a solar analyst the last time we had a global recession [in the late 2000s] and I kind of didn't notice," comes the answer of Jenny Chase of BloombergNEF (BNEF), quizzed over solar's prospects in a world fast careening into economic depression.

To be clear, the solar analyst does believe COVID-19's solar impacts may be significant. There is the drop in global growth forecasts for 2021, with BNEF itself now expecting 123GW where it had predicted 121-152GW before. There are hard-hit segments like US residential solar, facing job losses and bankruptcy risks as cash-strapped households postpone spending decisions. "We recently cut our forecast for US solar this year from 14GW to 11GW and residential is the main reason," says Chase, noting that BNEF currently thinks the sector will not meaningfully bounce back until 2022.

However, shift the lens to the utility-scale end and the analyst sounds decidedly more upbeat. "I don't think this is going to be a specific problem for solar," Chase says. "There is not really a supply issue, work hasn't completely stopped, the US is not as dependent on long-range migrant labour and I don't think funding will dry up." She concedes that across-the-board logistics disruption will delay timetables to some extent but adds: "I know developers will complain because that's what developers do but I admit I don't see anything that should stop projects from being built."

Attention is also turning to how China, the first to be hit by COVID-19 and among the first to see a way out, will fare on the downstream solar front this year. When the country acted in February to postpone its solar mega-auctions, BNEF trimmed its 2020 Chinese PV forecasts "substantially" right away. "It's not that these projects won't

Credit: Iberdrola

Experts believe the pandemic will disrupt but not derail the decade-long boom solar was set to start this year, with project giants like Iberdrola's Núñez de Balboa symbolising the new era

happen, they're just being pushed back because China responded," the analyst points out. "There is also whether China will do something else this year [to fuel growth], particularly if their manufacturers are hurting. But so far we haven't seen any sign."

India – already told pre-pandemic it was set to miss its 175GW-by-2022 renewable target – is "more of an unknown quantity", Chase says. The solar analyst explains that the COVID-19 outbreak has not yet convinced BNEF to change its forecasts of 11.6GW of solar new-builds in India in 2020, almost exactly flat on last year. She notes, however: "I think don't think many auctions have been explicitly delayed but we certainly expect this to happen. The other thing is that whereas with China the pandemic seems under control, everyone's got the suspicions that this is not India's case at all."

According to Chase, BNEF's position as of early May is that Southeast Asia and Australia should not see solar growth majorly dented by COVID-19. "Again, we haven't actually changed the forecasts for those places," she says. "We've actually increased Vietnam because of their new feed-in tariffs (FiTs) and [South] Korea could increase too as they've come up with residential incentives specifically because of COVID-19." Elsewhere, Brazil has been the only other country to see its BNEF growth forecast boosted, thanks to its generous net metering scheme. Asked about other analysts' warnings of Latin American renewables' vulnerability to the present currency chaos, Chase sounds sceptical.

"I think it's always been a risk," she says. "Currency fluctuations have long been an issue in places like Mexico and Brazil, they're always derailing deals and making banks more risk-averse – I don't see this as a specific COVID-19 factor as everyone's been hit." Quizzed over the talk of impacts for PV players having to

Credit: BloombergNEF

BNEF's Jenny Chase believes US utility-scale solar prospects are sound even if the residential segment is bound to take a hit

fund purchases with a soaring dollar, Chase adds: "We expect modules will be even cheaper than we thought given lower demand and these are the main things people buy with foreign currency anyways. Honestly, I think people can sometimes overstate currency risks."

Merchant takes hit as free-market link proves costly

Solar players time-travelling from the earlier global recession of the late 2000s would find the industry changed beyond recognition. The transformation has been quantitative – worldwide installed PV capacity has boomed from 40GW in 2010 to 580GW in 2019, IRENA believes – but also qualitative in nature.

As even the optimistic Jenny Chase acknowledges, the looming crash finds the sector far more intertwined with the wider economy than it was a decade back. The link to the free market – a connection via consumer sentiment and power prices – has proved costly as the pandemic squeezed the global economy. Firms relying on household spending have been pushed towards mass layoffs while merchant ventures have seen revenues sapped by the power price plunge. Some in the latter group might, Chase believes, find sense in mothballing projects for a "couple of years".

For Europe's merchant solar star, the pullback has been clear. Spain, reports José Donoso of PV association UNEF, is currently seeing a retrenchment of banks, with low power prices stifling the appetite to grant loans and highly leveraged funding packages. How investment funds will factor the tumbling prices into their analysis remains to be seen but for now, the impacts on Spain's hitherto buoyant solar PPA scene have been noticeable, says the general director. "No off-taker" will currently accept the longer PPA timeframes and the €38-42/MWh prices Spain had seen until now, he adds.

On the other end, the solar financier view seems upbeat, however. Director Roger Font of Banco Sabadell does echo the predictions of a slow power price recovery – the bank expects "there won't be a return" to €50/MWh this year or next, he says – and accepts that a lower price curve will see less debt provided to solar projects. However, he brushes aside talk of merchant solar activity coming to a standstill. "I can't

According to PVEL's Jenya Meydbray, the crisis won't likely dent China's solar manufacturing dominance nor slow down the current R&D race

say we are seeing the [funding] taps being closed," Font says, adding that Sabadell has closed three renewable deals so far despite COVID-19, and expects more before the summer (turn to p.** for a full interview with Font).

However disruptive they end up proving, low prices might be a reality solar has to live with well after COVID-19 fades; according to UK-based Aurora Energy Research, full recovery in Europe may not arrive until 2025. An earlier comeback is both the prediction of BNEF's Chase – economic growth may arrive in 2022, she believes – and UNEF's Donoso, who expects prices to start bouncing back in the short- to medium-term. Until then, Donoso agrees that shaving O&M costs through technology and hedging risks through energy trading venues are both strategies firms can follow, but adds: "It does help but ultimately it's all about cash flow and that comes from power prices."

While it waits for the waters to calm, European solar finds itself in need of a growth driver that does not rely on a crashing economy. Already seen pre-pandemic as a key enabler of steep renewable targets, auctions are currently talked about as a critical stepstone for the sector to revive. In France – where installed PV must boom from today's 9.5GW to 35.1-44GW by 2028 – operators tell PV Tech Power of their success persuading the state not to fully delay tenders. Spain, where auction-free growth seemed a less-distant possibility pre-COVID, will need them now in the short-term, Donoso says. "If well designed, it is the only way there is right now to bring stability and steady growth."

COVID-19 no match for China's upstream dominance

Across the upstream-downstream divide, the Asian solar manufacturers that bore the initial brunt of the COVID-19 disruption will be largely fine in the long run, says PVEL CEO Jenya Meydbray.

Interviewed by *PV Tech Power,* Meydbray bases his assertion on three core dynamics, starting with demand. "I think solar demand will generally continue and that is what ultimately matters the most to keep things afloat," the CEO says. Like Chase, Meydbray believes utility-scale will be less impacted, pointing at the fact that US players are still building through the national quarantine. He acknowledges segments such as residential will see a near-term drop but believes certain dynamics – a rise in corporate responsibility, the oil sector crash – will see demand rise in the longer run.

Second in Meydbray's list is technology leadership. On this front, he expects solar makers to focus on innovation rather than the "same old 72-cell PERC lines". From Trina's 500Wp addition to LONGi's seamless soldering or milestones around busbars, product releases have followed one another and the pace is not likely to relent if demand holds, PVEL's CEO says, adding: "These announcements are all trying to one up each other and it's effective – talking to developers, they're all really interested." He can see n-type production rising in the post-COVID era. "Large-scale planning for n-type production is probably starting now, and investment and build-out will come next."

According to Meydbray, access to capital is the third – and "harder to gauge" – axis of solar makers' post-COVID future. On the one hand, governments will likely be out of money but on the other, low interest rates mean commercial debt will remain an option for financially solvent manufacturers. "With crises you tend to see a flight to quality. Weaker players may be hit disproportionately with access to capital," he says. "Those who've been less responsible with capacity moves will likely have strained balances, higher debt load. If they hit the pause button for long, they die."

COVID-19 and solar started off as a supply chain story and many wonder now what the long-term impacts will be for module prices. According to Meydbray, the US is distorted by tax policies and may see prices crash until PV players manage to use up the major inventories they built to qualify for safe-harboured investment tax credits. Quizzed over Europe, PVEL's CEO points at the campaign for a green COVID-19 recovery, a cause backed by heavyweights including German chancellor Angela Merkel. "It's an inflection point for solar but there's a time component too," he says. "We'll probably see a short-term price drop and come the second half of 2021, a resurgence of demand and prices."

Some like the Asian Development Bank have said COVID-19 is a chance to rethink the global reliance on Chinese manufacturers, but Meydbray remains sceptical. Pandemic-recovering countries will likely lack the cash to sponsor a new industry and even if they did, unseating China after its "painful and expensive" years building the full solar supply chain would take more than that, he says. Run by Chinese firms themselves, Southeast Asia's solar segment will continue the earlier growth trajectory, PVEL's CEO believes. "Look at LONGi's takeover of Vena Energy, the contract manufacturer for pretty much all other Chinese firms," he says. "Come 2021, they're all going to find an alternative. Vena was 7GW of a 30GW market – that gap needs to appear out of nowhere real fast."

Solar's chance as world dares to dream green new future

The latest headlines around a world that awaits the other side of COVID-19 make for sobering reading. The worst economic recession since last century's Great Depression. Some US$9 trillion of cumulative GDP losses worldwide. Nearly 195 million of jobs wiped out across the planet. While only drops in a sea of incalculable human and economic losses, solar's recent actions in the face of the emergency have offered some relief. At hospitals, greenhouses and isolated communities, PV panels have helped keep the lights on at a time of need.

Listen to global experts, though, and it soon becomes clear the industry could do much more if given the chance. Green energy body IRENA could be expected to say what it did in late April – the agency claimed investing in renewables could unlock a US$98 trillion global GDP boost by 2050 – but IEA's verdict was perhaps more surprising. The agency, attacked in the past for "underestimating" renewable growth, recently said renewables will be the only segment to grow following the "historic shock" the power sector is facing. The new decision of Total and other oil and gas majors – hardly solar enthusiasts until recently – to double down on green spending, even as COVID-19 decimates revenues, emphasises that faith in renewables' future role is becoming ubiquitous.

The mix of shuttered economies and sunny weather of April 2020 showed much of the world what a solar-powered reality looks like: abundant, cheap electricity fuelled by cleaner skies. And yet the so-called "postcard from the future" has a less-rosy side, documented by various analyses. The cannibalisation happening today because of lower demand – prompting a subsidy cut-off for Dutch PV players – may repeat in later years due to higher renewable supply. From the UK's ESO asking for powers to switch off embedded systems to Australian regulators warning they will have to disconnect solar if the grid is not updated, the COVID-era power market is already offering a cautionary tale around the risks from failing to adapt to high green energy uptake.

UNEF's Donoso believes the time has come for regulators to address the "elephant in the room". "Our power market was designed last century and continues to revolve around variable costs when renewables lack these," he says. "What will happen when we become fully renewable? I think COVID-19 has offered a little experiment of the years to come." Asked if reform on this front is likely in Europe, Donoso concedes EU authorities are now aware of the problem but are struggling to find a solution that benefits everyone. "It's complex but someone has to put this on the table – this model doesn't assign prices efficiently, it is incompatible with the energy transition," he says.

Whether or not along the specific lines of the market reform Donoso proposes, Europe's appetite for a renewables-powered COVID-19 comeback is clear. Documents leaked in early May, seen by PV Tech Power, show the European Commission is listening to the rising chorus: together with building renovation, green energy is reportedly one of the two recovery pillars the EU executive plans to focus on. As BNEF's Chase notes, whether the US and Australia will too embrace a green comeback is equally important. The latest actions of US president Donald Trump – insistence on solar tariffs, a clampdown on power equipment imports – suggest the road ahead will be bumpy.

Highlights such as Portugal aside, can IRENA's and IEA's talk of a green COVID-19 response materialise in a world where inwards-looking protectionism is spreading? PV Tech Power's questions on this front to either agency were met with silence. However, some of the signs do suggest that the post-COVID green new tomorrow the world is heading towards is a place where solar can prosper; the very premise is apparent in the closing remarks of various interviewees.

BNEF's Chase stresses she does not want to use the words 'silver lining' for a crisis that has claimed hundreds of thousands of lives so far, but adds: "My suspicion is that it won't affect deployment that much. It's true that residential solar firms may go bankrupt without help and I think the government should help workers because I generally think they should, but I don't think it matters to the overall buildout of clean energy."

For his part, UNEF's Donoso links his long-term optimism to his background. "Back when I worked as an economist, we used to look at two key questions: whether there's an objective need for a firm's products and whether the firm has competitive advantage," he says. "Going forward, there will be an objective need of clean, cheap electricity – and those are things solar can provide." ■

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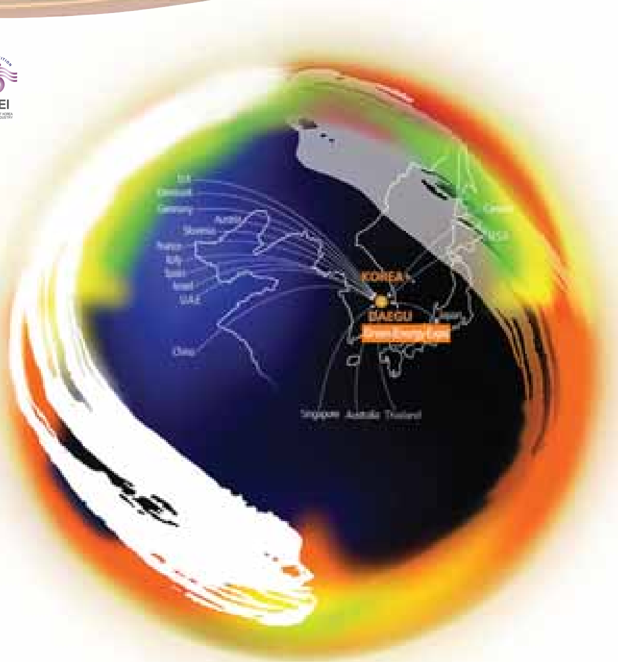

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Financing the transition

Investment | An increasing number of banks are turning away from fossil fuels and towards renewable energy financing. As Catherine Early reports, despite the chilling effect of the coronavirus pandemic on the industry, hopes are high that a tipping point is nearing

As renewable energy technologies have evolved over the years, they have become a compelling investment proposition. Global investments in new renewable power have grown from less than US$50 million a year in 2004, to around $US288 billion a year by 2018, according to a report by Bloomberg New Energy Finance and the UN Environment Programme.

Despite the fact that this was an 11% dip from the previous year, it was still triple the level of investment in coal- and gas-fired generation capacity combined, the study found. Solar PV and wind power accounted for 90% of total renewable power investments in 2018.

Emerging and developing markets, in particular China, have been attracting most of the renewable investments since 2015, accounting for 63% of those in 2018. India, Brazil, Mexico, South Africa and Chile have also seen sizeable chunks of financing, according to the report.

But despite these finance surges, there is still a vast gap between what is being supplied and what is needed. In January, the International Renewable Energy Agency (IRENA) stated that annual investment in renewables needed to reach US$750 billion to meet the goal of the Paris Agreement to aim to limit temperature rises to 1.5C compared with pre-industrial levels.

Much of that could be met by redirecting planned fossil fuel investment, IRENA said, noting that close to US$10 trillion of non-renewables related energy investments are planned to 2030. Fortunately, this shift has already started to happen, with the number of banks that have announced restrictions, exclusions or divestments from coal mining and/or coal-fired plants growing.

The Institute for Energy Economics and Financial Analysis (IEEFA) has tracked more than 120 banks, insurers and asset managers with more than US$10billion under management that have made this move. Two of the most notable in recent months are the European Investment Bank, which in November announced a decision to align all its policies with the Paris targets, phasing out fossil fuel funding by the end of 2021 and new financing for renewables of US$1.6 billion.

Then in January, asset management giant Blackrock announced that it was to realign its investments with sustainability, and halt support for coal projects. In May, Australian bank Westpac said it was to phase out coal investments by 2030 and provide AU$3.5 billion of new lending to climate change solutions over the next three years.

This trend has been significant, explains Tim Buckley, IEEFA's director of energy finance studies, since once these institutions make such policies, they tend to tighten them up consistently to exclude more activities, for example, investment in Arctic drilling and tar sands, and simultaneously shift sizeable chunks of lending to more sustainable assets, he says.

"There is evidence that it is starting to come through to renewables," Buckley says. For example, Standard Chartered bank announced its first coal exclusion policy in 2016, and in February 2020 then launched US$35 billion of project financing, advisory and debt structuring services for solar and wind projects.

The shift is complicated by the value of renewable energy technology investments, which tend to be dwarfed by those needed for fossil fuel plants, meaning that they were struggling to find alternatives to which to allocate their funds, he explains. But banks were tending not to find the opportunities because they had not been actively pursuing them, he says.

"Now that they're looking, it's interesting how opportunities are emerging. It's only with the banks, investors and insurers promoting their sustainable lending criteria that projects are coming to the fore," he says.

However, Raj Prabhu, chief executive at analysts Mercom Capital Group points out that the investment shift to renewables varies according to country: "Every market in every country in the world understands that fossil fuels are bad and that we need to switch to renewable energy. But what they're doing about it is different."

Credit: 8minute Solar Energy

The shift of capital from fossil fuels to renewables is gathering pace

For example, some governments have renewable energy policies because they have to, but public pressure on politicians to switch to clean energy is lacking. Electricity from renewable generation is still more expensive than coal in places such as India, he says. "The tipping point there may come in the next two or three years when renewable energy is so cheap that they don't have to worry about intermittency," Prabhu says.

Global totals flowing specifically to solar from a variety of private sector sources reached US$11.7 billion throughout 2019, a 20% jump on the US$9.7 billion secured the year prior, according to data from Mercom. Venture capital funding reached US$1.4 billion in 53 deals, a 1.6% increase compared to US$1.3 billion in 65 deals in 2018, it noted. ReNew Power raised US$300 million, while Hero Future Energies raised US$150 million, and Avaada Energy US$144 million.

Public market financing activity came to US$2.5 billion in 18 deals, compared with US$2.3 billion in 21 deals in 2018. Meanwhile, debt financing increased 29%,

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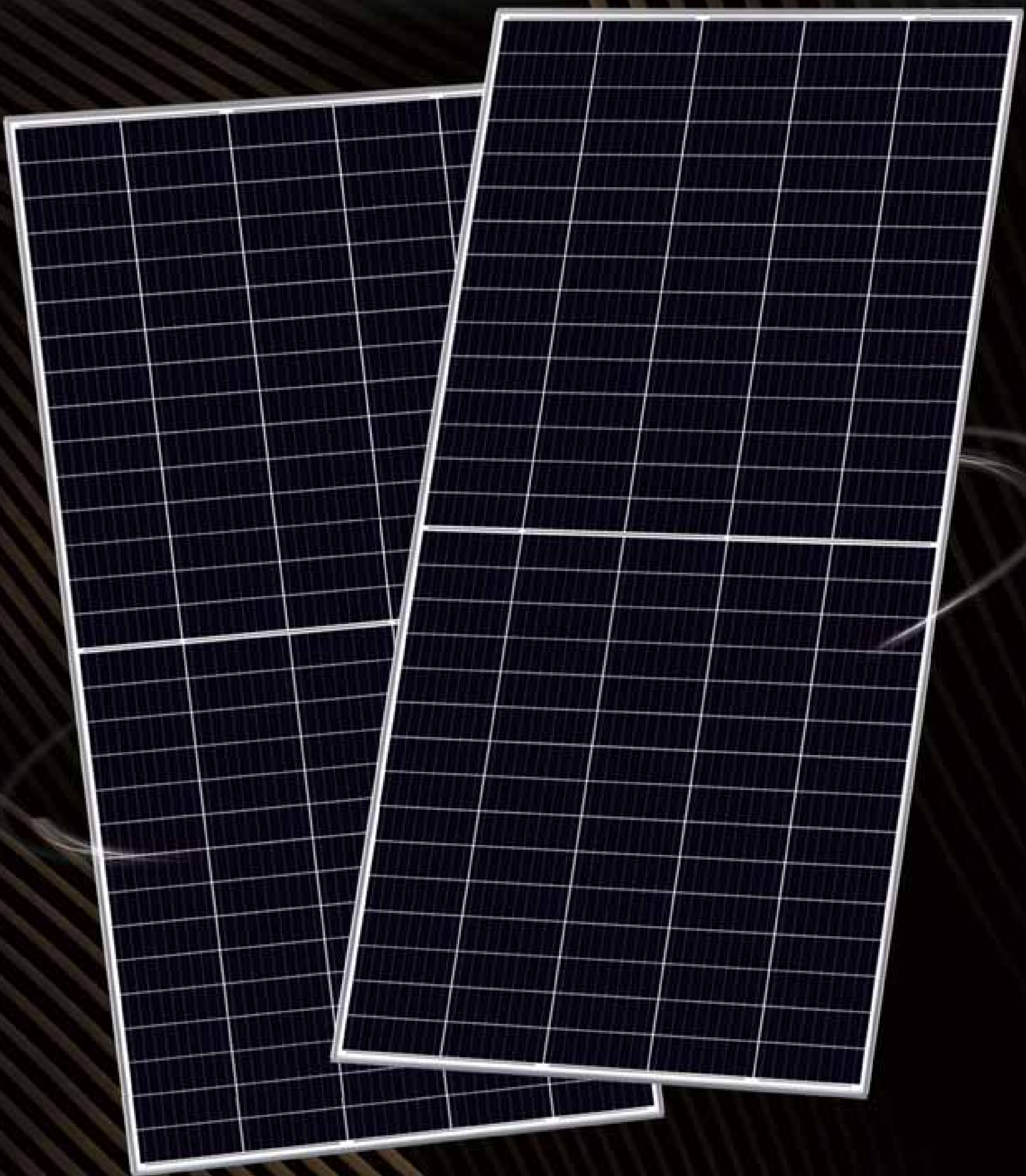

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with US$7.8 billion in 46 deals compared with US$6 billion raised in 53 deals in 2018. And large-scale project funding came to US$16.1 billion in 152 deals in 2019 compared with US$14.1 billion in 184 deals in 2018.

Last year's investment performance was largely down to the strength of the companies and the general market, according to Prabu. "All of the solar publicly traded companies were doing well, and when that happens it becomes easier to sell shares or raise debt because your stock is up."

Green bonds surge

Alternative sources of finance are increasingly playing a role in funding renewable energy. Green bonds – fixed income securities whose proceeds are allocated to assets such as renewable energy – emerged in 2007, primarily driven by multilateral development banks.

These have now been joined by social and sustainability bonds, which fund a combination of environmental and social projects, and sustainability-linked instruments, which issue debt where the cost of capital is tied to a company achieving certain sustainability targets, such as renewable energy capacity. A newly emerging instrument is the transition bond, which carbon-intensive companies can issue to help them fund environmental improvements.

Though these financial instruments serve different purposes, all are experiencing growth, according to Moody's. The performance of green bonds has been particularly strong – the ratings agency tracked just over US$260 billion issuance globally last year, compared with around US$40 billion in 2015, says Matthew Kuchtyak, Moody's assistant vice president of environmental, social and governance (ESG).

"It's tough to get granular data until the funds are fully deployed, but roughly a third of investments in green bonds have gone to renewable energy over the past few years, primarily solar and wind, and hydro to a lesser extent," he says.

Issuance of green bonds is now dominated by big corporations and financial institutions, but they are also offered by public and private institutions, including governments and government agencies. European companies account for just below half of issuance, with North America and Asia-Pacific responsible for around a quarter each, says Kuchtyak.

Other emerging markets such as Latin America are becoming more active, and general support for sustainable policies will trickle down to increased green bond activity, Kuchtyak believes. This could take the form of defining market standards, governments encouraging public and private issuers to participate in the market, or multilateral development banks investing or providing credit enhancement, he says.

Another source of potential funding for renewable energy is that held by institutional investors – pension plans, insurance companies, sovereign wealth funds, foundations and endowments. IRENA estimates that this group manages around US$85 trillion, an amount that has been growing by around 4-7% annually over the past decade.

Analysis by the agency of over 5,800 institutional investors and their renewable investments over the past two decades revealed that around 20% had made any investments into renewable energy via their funds, while only around 1% had invested directly in projects.

The number of renewable energy projects involving institutional investors has increased from three in 2009, to 73 in 2018, and 39 for the first two quarters of 2019, according to IRENA. However, while this source of investment was increasing, it represented only around 2% of total renewable project investments in 2018, it noted.

The agency concluded that there was significant potential to scale it up, but this would require incentivisation by policymakers, such as by mandating long-term ESG targets for such organisations and adopting analysis and disclosure of climate change risks. Institutional investors also needed training on the impacts of climate change, and their role in minimising the impacts, IRENA said.

Coronavirus caveat

Of course, all predictions for the short- to medium-term future for the financing of renewables now come with a significant caveat. The economic turmoil caused by the COVID-19 pandemic has only just begun, and commentators agree that it is too early to judge the full ramifications for renewables investment.

However, Bloomberg NEF (BNEF) has cut its global solar demand forecast for 2020 from 121-152GW to 108-143GW. If this transpires, it could make 2020 the first down year for solar capacity addition since at least the 1980s, it said.

So far, banks do not appear to be raising the cost of finance as they did after the financial crisis, notes Angus McCrone, chief editor at BNEF. "Interest rates are pretty near to zero in developed countries anyway, so the question is what happens to the margins that banks charge on project finance, and we don't have a good indication of that at the moment," he says.

McCrone predicted that investment deals would slow down due to the difficulties of bringing people together and carrying out site visits, and that equity investors, bankers and developers might be more cautious. Green bond issuance is down so far this year, likely due to companies having more immediate priorities due to the pandemic, he adds.

"That may change in the coming months, though the delay of UN climate talks at COP26 may impact green bonds, as there's always been a rush to issue them just before climate discussions so that companies can demonstrate their green credentials," he says.

Moody's has also noted a 49% slump in green bond issuance in the first quarter of the year, and now anticipates that volumes will total US$175-225 billion, down from its original US$300 billion forecast. "I think that's more to do with some of the uncertainty in the financial markets that issuers are dealing with, rather than a long-term divergence from thinking about climate investments. Everything is slightly on pause right now, and that's leaking into the green bond market," Kuchtyak says.

Corporate funding in the solar sector, including venture capital, public market and debt financing, has also taken a blow in the first quarter of 2020, reports Prabhu. Totals from these sources came to US$1.9 billion, 31% lower compared to the US$2.8 billion raised in Q1 2019.

However, there were 12GW of solar project mergers and acquisition transactions in Q1 2020 compared with 6GW in Q1 2019, which proved that solar was a safe long-term bet, he says. In fact, Mercom has noted an increasing trend for oil and gas majors to buy solar projects, with just under 6.5GW bought in Q1 2020, compared with 4GW bought by investment firms.

"Oil and gas companies are seeing where the trends are – they have capital and they are increasingly making acquisitions in solar assets," Prabhu says.

Buckley predicts that the dramatic

Sovereign guarantees

In developing countries, the degree of investment risk is often associated with the country itself, or the energy off-taker, rather than the actual project. Such risks can include lack of creditworthiness of the buyer, or fears that the tax or legal environment may change.

In the past, investors have asked for sovereign guarantees, where governments guarantee payments in cases such as a state-owned enterprise buyer defaulting, changes in taxation or currency transfers becoming restricted.

However, these have become rarer in recent years as some countries lack the means to honour them, according to IRENA. There are alternatives, but these are not well known. For example, the agency points to initiatives to improve the creditworthiness of the off-taker, by recapitalising it, improving its management and operations, and ensuring that its revenues match its expenses so that it can invest in infrastructure.

Though this requires significant commitment and resources, several initiatives to achieve this exist in Africa, led by the World Bank, the African Development Bank and the Millennium Challenge Corporation.

falls in the price of oil and liquid natural gas caused by the twin crises of COVID-19 and the oil trade war between Saudi Arabia and Russia could prove a boon for renewables. Investments could increasingly flow towards clean energy as both oil and gas companies and the financial markets flee the volatility of fossil fuels.

"I think this will prove to be a pivot point for global finance to say that it cannot tolerate the volatility and ongoing wealth destruction in the fossil fuel sector, and will go and evaluate alternatives. That to me becomes a catalyst for investing in renewable energy infrastructure," he says.

Oil and gas companies have annual capital expenditure budgets of US$150-200 billion, but they will now need to find alternatives for some of that, with the obvious option being clean energy. Shell, which has stated that it wants to become the world's biggest electricity company, has already pledged to shield its new energies division from spending cuts so that it is well positioned for the acceleration of the energy transition which it expects to follow the economic crisis.

Politicians, businesses, investors and campaigners around the world have called for post-pandemic economic stimulus plans to boost the clean energy transition. Members of the European Council have already identified the central role of the Green Deal in its Roadmap for Recovery from the COVID-19 pandemic.

Sean Kidney, chief executive of the Climate Bonds Initiative, says that green stimulus plans will benefit solar PV by incentivising investors to green their portfolios, especially if they use the new classification system for environmentally sustainable investments, which will formally exclude gas plants without carbon sequestration from the definition of a sustainable investment.

Up till now, gas companies have marketed themselves on the basis that governments can achieve their energy transition using gas, but they will no longer be able to do this, he says.

"The new European taxonomy has caused quite a significant stir in other countries – none have changed their policies yet, but they're now having discussions about what Europe has said and what that means for their climate targets," Kidney says.

Despite the short- to medium-term uncertainties caused by the pandemic, commentators remain optimistic that renewables will emerge healthy from the economic crisis, and that the financing gap will be narrowed.

"This year will probably be a bit of a lost year because of the pandemic, it all depends on how economies end up doing," Prabhu says. "But my personal opinion is that that the gap will close, it's just a matter of time." ■

Chile reaping the rewards of the desert sun

Market update | Recently name checked as among the cheapest places in the world to develop solar, Chile has emerged as a particularly popular destination for solar finance. But as the country proceeds towards a 100% renewables target, political instability and legacy network issues stand in its way. Molly Lempriere explores how Chile can leap those hurdles on its way to a green grid

Credit: Atlas

The Javiera solar project, developed by Atlas Renewable Energy, has a 69.5MW output

Chile boasts some of the sunniest places on earth, with areas like the Atacama Desert in the north of the country getting almost 356 days of clear skies. Coupled with high solar radiation and low humidity this makes it one of the best areas in the world for solar PV.

The country is "blessed" with vast amounts of sunlight said José Ignacio Escobar, Acciona's director of energy for South America.

"The country has a healthy and stable long-term investment climate as well as a growing and sustained electricity demand, ambitious decarbonisation targets and a heavy dependency on imported fossil fuels. For all of these reasons, Chile is leading Latin America's clean energy revolution."

In an effort to diversify its energy sector, to drive decarbonisation and increase security, Chile began to move away from hydro-electricity and thermal generation at the beginning of the decade. In 2008, the government brought in a requirement for energy companies to include at least 5% of their generation from non-conventional renewable energy sources by 2010.

This first step proved successful, with 7% of the country's electricity coming from renewables by 2012. From this point it has seemingly gone from strength to strength, with the Chilean government then setting a target of 20% renewable energy by 2025.

As of today, the country has already hit this target, with the total share of wind, solar, biomass, geothermal and run-of-river averaging 20% of the total electric energy produced according to the Asociación Chilena de Energías Renovables y Almacenamiento (ACERA), the country's renewables trade association. This includes peaks of 45% at certain times of year, driven in particular by the booming solar sector.

Chile is now aiming to be 100% renewable by 2050, but challenges remain, not least with ensuring the energy can reach areas of demand.

Falling costs, resource wealth and PPAs

Chile's first solar plant – a 3MW project – was installed in 2012. Now – just eight years down the line – there is 2,945MW of PV operating and a further 2,845 MW under construction, according to ACERA.

This growth has been driven by dramatic reductions in price. Atlas Renewable Energy's general manager for Chile Alfredo Solar explained that in his experience, when the solar industry first started in Chile nearly a decade ago, the levelised cost of electricity (LCOE) stood at US$100/MWh. This has fallen to almost US$20/MWh, a fifth of the price.

That assertion was corroborated by recent analysis by Bloomberg New Energy Finance, which found that the cheapest PV projects in the last six months will be able to achieve an LCOE of US$23-29/MWh. BNEF continued that in the best solar markets globally, of which in Chile was listed alongside the Middle East and China, projects will be pushing below $20/MWh before 2030.

While the price of solar the world over has fallen, this dramatic reduction is aided by the northern part of the country having the "best solar resource worldwide", says ACERA director of studies, Darío Morales.

"According to an estimation made by the Chilean Ministry of Energy and Germany's international cooperation corporation, the Gesellschaft für Internationale Zusammenarbeit (GIZ), the country has a solar energy potential of 1,300GW. This potential, together with the reduction of the investment costs of solar technologies, transformed… PV technology into one of the most competitive [energy] technologies operating today in Chile."

The Chilean market differs from other solar hotbeds such as in Europe as there are no subsidies for any energy technology. This level playing field has led to a highly competitive solar sector, and the technology has become the cheapest form of power generation.

The majority of projects rely on power purchase agreements (PPAs) with large customers and energy distribution companies currently. This has helped avoid price cannibalisation thus far, as solar companies target large-scale industries such as mining companies for offtake agreements.

But Morales adds that due to the competitive nature of solar, it will start to provide an increasing share of the power mix, driving down the cost of energy tariffs from 2021.

The country has now committed to completely phase out coal-powered generation by 2040, further incentivising the push to support solar generation.

Co-location in Chile

Energy storage could help Chile fully capitalise on its solar resource and reduce transmission constraints. According to Morales, it will play a "fundamental role" in the energy system, providing balancing services, reducing system congestion and supporting the participation of more distributed generation, such as solar.

At a roundtable hosted by the Ministry of Energy last year, the National Power Coordinator suggested that 3,000MW of storage will be developed in Chile over the next 20 years.

But there is currently very little solar-plus-storage in the country due to prohibitively expensive prices. "Everyone is waiting for batteries to reduce in price, and we expect this to happen in three or four years," says Atlas' Solar. "At that moment, the combination of solar plus storage will be the most practical, but we're not yet there."

This is beginning to change, with an increasing number of storage projects coming online to support the grid such as NEC Energy Solutions' 2MW/2MWh battery energy storage system commissioned in 2019.

There are also solar and storage projects moving forwards, like Valhalla's 561MW solar PV plant which features a 300MW pumped hydro storage system. The project received financing from the Green Climate Fund in July 2019 and is expected to reach final close. If successful, the plant will be built by 2025, and help to provide baseload power.

Along with pumped hydro, lithium-ion battery systems are increasingly popping up as the country seeks to bolster its energy system and take advantage of its mineral wealth. Already Engie Chile is pursuing projects and AES Gener has three operational projects. With the success of such, it seems sure that solar-plus-battery-storage cannot be far away.

Atlas set to begin colossal 230MW desert sun project

One of the biggest projects under development in Chile is the Sol del Desierto solar plant, which is due start construction at the beginning of May 2020 in the municipality of María Elena in Antofagasta. The colossal 230MW project is Atlas Renewable Energy's third solar site in the country.

The company was set up in 2017 with a specific focus on Latin America by a group of executives who had been working for SunEdison with financial backing from Actis, a private equity firm based in London.

Atlas now has 2,000MW of contracted projects in Latin America. This includes 1,000MW that is already under operation, and 1,000MW under financing or construction throughout Chile, Uruguay, Mexico and Brazil.

Sol del Desierto will be the company's biggest to date in Chile, with construction planned over the course of 18 months. Atlas has secured a PPA with French utility giant Engie for the project, with the company taking 80% of the power that will be generated at the site.

Spanish conglomerate Acciona celebrated the completion of its Almeyda solar project at the end of 2019. The 62MWp facility uses 187,620 modules in fixed structures with horizontal tracking, which will allow the company to maximise the capture of solar radiation for energy generation. While these technologies are commonplace in the Chilean solar sector, Acciona says what sets the project apart is its operations in the region.

"The key differentiator, from our point of view, is how solar plants are operated, and how to integrate these plants in the economic, social and environmental fabric of local communities," says Escobar. "We consider these factors to be Acciona's main strengths."

The project, which sits in the municipalities of Chañaral and Diego de Almagro within the Atacama Desert, covers 150 hectares. It has an estimated annual generation capacity of 167.5GWh. Acciona Energía signed an electricity supply contract with National Mining Company to take the power generated by the project, choosing a PPA to ensure security as Atlas has.

The project is Acciona's second in Chile's Atacama region, following the El Romero Solar project. Up until 2019, the project was considered the largest in South America, boasting a capacity of 246MWp and covering 280 hectares.

An evolving transmission system

One of the key challenges that remains for Chile's solar sector lies in the country's transmission network. While there is abundant solar resource in the north of the country, transmitting the power to the capital Santiago and other demand hubs is challenging.

In 2017, the country inaugurated the Sistema Eléctrico Nacional, a nation-wide electricity transmission system. Up until this point, Chile had two separate networks, the Central Interconnected Systems (SIC) and the Northern Interconnected System Grid (SING). This system made it increasingly hard for the country to take advantage of the burgeoning solar generation, with periods such as in June 2016, where electricity was given away for free as there was too much generation and too little accessible demand. The new system covers 3,100km and connects 97% of the population. It formed a key part of then-President Michelle Bachelet's government's focus on the energy sector.

Despite the unified transmission network easing the challenge, more work will need to be done to develop the system.

"If Chile wants to reach a 100% renewable energy mix in the coming decades, the country will need to establish a robust, flexible and modern transmission system that can easily adapt to new generation technologies as they appear," says Acciona's Escobar.

The inability of the transmission grid to truly meet the needs of the growing solar industry is partly because of the country's previous reliance on large-scale hydroelectric plants. In the 1990's, environmental concerns coupled with the impact of drought on energy security and increasingly cheap gas from Argentina, however this thermal generation has also been hit by insecurity.

Given the fluctuation in its generation profile, the transmission network has struggled to be sufficient for the country's needs. But as old thermal generation in particular becomes obsolete, Escobar continued, there are increasing opportunities for new transmission networks for solar, wind and other renewables as part of a modernised energy sector.

"Regarding distribution, Chile's new regulatory framework is currently under discussion," he adds. "The new framework will aim to modernise the sector, promote energy efficiency and self-consumption and easily adapt to new emerging technologies, such as electric vehicles and smart meters."

As the country looks to grow its renewable energy sector a more modern, flexible grid capable of coping with intermittent generation from more distributed sources will be the next big requirement. This will most likely need to be coupled with storage, to ensure Chile can make the most of sunny periods without having to fall back on gas generation.

Political unrest, international investment and the stabilisation fund

Concern for the sector's continued success was raised in 2019, when Chile descended into political unrest. The country has attracted a lot of international investment and development from companies like Acciona, partially because it is one of the most stable countries in South America.

However, in October last year protests around a planned 3% increase to metro fares in Santiago escalated into widespread unrest. The protests spread throughout the country, and by the end of the month, 18 people had died in the violence while 7,000 people had been arrested in the most unsettled period the country has seen in decades.

The demonstrations shone a light on the inequality within Chilean society, in particular given a recent spate of corruption cases involving businessmen and the country's federal police force along with the leadership of billionaire president Sebastián Piñera, who himself was hit with a demand for unpaid land taxes in 2019. While many in the country have benefitted from the country's wealth of natural resources, in particular copper, many protestors felt this wasn't fairly distributed as they faced rising transport and utility costs.

With unrest spreading, there was concern that the solar sector could become less attractive, hurting further expansion for the sector. This is not something that concerns the ACERA however, thanks to a stabilisation fund introduced by the government.

"Because of the existence of old and expensive PPAs with distribution companies and the US Dollar/CLP exchange rate, the energy tariffs to the final customer were supposed to dramatically increase from January 2020 and to naturally decrease form 2021, mainly because of the PPAs signed with renewable energy companies," explains Morales. "To avoid these fluctuations, and due to the social unrest situation, the government passed a law that created a stabilisation fund of U$1,350 million that has to be paid by all the generation companies."

Morales continued that renewable energy companies that fund their investments through project finance schemes had to find ways of funding additional costs following the unrest. While much of this is private, "conversations between companies and investors have gone well, despite the fact that the COVID-19 crisis imposes new challenges", he continues.

Indeed, projects such as Atlas' Sol del Desierto solar plant, announced following the unrest, seem to confirm the appetite for solar investment has not been quelled by the unrest.


Credit: Atlas

The Quilapilun solar farm was connected by Atlas in 2017

'No doubt' Chile will go 100% renewable, but when?

Chile has undoubtedly taken huge steps towards greening its energy sector, supported by the phenomenal resource base and positive governmental policy. Despite challenges therefore, it looks sure that the country will reach its 100% renewable target.

"A few years ago, the discussion was whether or not it was economically feasible to have high shares of renewables energies," says Morales. "Today, the discussion is about when we are going to achieve a 100% of renewable energy share. The most optimistic states that is going to be in 2030 and the less optimistic say that by 2050. We believe that, with the right set of public policies, 2040 is achievable."

This optimism is shared by Escobar, who says: "There is no doubt in my mind that Chile has the potential and determination to achieve a 100% renewable energy mix by 2040."

Such declarations are supported by the tendering process, with all of the energy tenders in the last couple of years going to renewables. This is significant according to Atlas' Solar, and highlights a positive shift in the country's trajectory. He added that there will still likely be natural gas in some capacity on the system for moments when renewables cannot provide power for a while, suggesting a similar transition to Spain with gas becoming a back-up technology could be likely.

To truly become 100% renewable, the country must move on from such systems, says Escobar. "On a whole, we believe many more topics need to be addressed, such as the closure of natural gas and diesel facilities, which are today considered as back-up sources of power in the system.

He continues: "On top of this, progress is also needed in regulation for sustainable energy storage and electricity system flexibility. And last but not least, a new and ambitious green tax revision is urgently needed in Chile, which would allow the country to correct the negative externalities of fossil fuel generation."

Seemingly the biggest challenge for renewables in Chile is not the renewables themselves, but the transmission system. Flexibility, broader and more modern networks, and storage to manage intermittency are the next steps for a truly renewable energy sector. ■

THE SMARTER E SOUTH AMERICA – LATAM's innovation hub for the new energy world

The global energy industry has been undergoing a radical transformation in recent years. Millions of decentralized renewable energy plants and storage systems as well as consumers acting as "prosumers" will secure the energy supply of the future. Solar and wind energy are becoming key pillars of tomorrow's energy world. The rise of renewables is bringing about a transition in the structure of our energy supply.

In order for the fluctuating amounts of electricity generated from renewable sources of energy such as solar and wind power to be used efficiently, the electricity, heating, cooling and mobility sectors, which once operated in isolation, will increasingly converge thanks to the use of cogeneration, electrical heating systems, electric mobility hybrid power plants and other technologies. Like innovative energy storage systems, these new solutions mean that energy no longer has to be consumed as soon as it is generated.

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With three parallel energy exhibitions, The smarter E South America is LATAM's innovation hub for the new energy world. It takes a comprehensive approach to the topics of the transformation of the energy system by presenting cross-sector energy solutions and technologies. The smarter E South America creates opportunities to address all key areas along the value chain. Focusing on the generation, storage, distribution and use of energy and the ways in which these aspects interact and can be intelligently combined, the event brings together international stakeholders of the energy future from across the world's most influential markets.

In 2020 over 380 exhibitors and more than 28,000 visitors are expected at The smarter E South America taking place at the Expo Center Norte in São Paulo, Brazil, on November 16–18, 2020.

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The Exhibition for Electrical Infrastructure and Energy Management

Eletrotec+EM-Power is the exhibition for electrical infrastructure and energy management. The exhibition focuses on technologies for electrical energy distribution as well as services and software solutions for energy management at grid, utility or building level.

Aimed at professionals and companies in the areas of design, assembly and maintenance of electrical infrastructure: Distributed generation with renewable sources, aerial and underground distribution networks, transforming substations, street lighting, industrial and building facilities.

Ready for take-off

Commissioning | Commissioning should be as integral to the installation of a PV plant as a pre-flight checklist is to an aeroplane journey. Sara Verbruggen reports on the latest tools and technologies being deployed to ensure a smooth commissioning process and a project that operates safely and optimally

Commissioning is the process of assuring that all systems and components of a PV plant are designed, installed, tested, operated, and maintained according to the operational requirements of the project's owner or final client. In the utility-scale PV industry, where the entity that developed, or built, the plant, is unlikely to be the plant's owner, or sole owner, throughout its operational life, or where there are different investors – lenders as well as equity shareholders – commissioning procedures are important to ensure the asset performs reliably and safely while output is optimised.

Done thoroughly and properly commissioning helps improve safety of the plant and quality control, as well as ensure the asset meets relevant grid compliance codes and standards, and will perform as expected. The tests that are performed in some of the commissioning procedures can also provide a benchmark against which periodic inspections and routine maintenance activities are carried out during the PV plant's entire operational lifetime.

DNV GL senior engineer Ralf Meyerhof says: "Commissioning ensures that the PV plant investors' expectations are achieved. From an investor's perspective a successful PV asset is designed, constructed and operated to achieve optimal output, maximising revenues. Projects, therefore, have financial and economic considerations where the operational strategy is looking to maximise revenues and financial performance. Commissioning, prior to connecting to the grid, identifies any issues or problems that need to be rectified and also ensures the plant will operate safely."

According to PV plant commissioning practitioners and specialists, such as Enertis, DNV GL and Alectris, commissioning is also key phase from a contractual point of view, whereby the title of the project transfers from the contractor to the owner, documented in the form of a provisional acceptance certificate (PAC).

The PAC is critical for the warranty period, which is typically two years, according to DNV GL solar section head Ruben Ron. "Once the PAC is obtained the engineering, procurement and construction (EPC) provider is responsible for fixing any faults etc that occur within the warranty period."

Credit BayWa r.e.

Commissioning is vital in ensuring a PV power plant operates as expected over its lifetime

"If commissioning steps are missed, the risk is that you don't pick up module cracking, damaged cables for example," says Ron.

Commissioning concept

While commissioning can seem like an exhaustive process of checks, done properly it becomes a key procedure throughout the plant's installation, from the moment that components are delivered to site.

Meyerhof uses the analogy of a tree to explain how the commissioning process should ideally be conducted: the strings are leaves, inverters are branches and the substation is the trunk. You commission from the leaves to the trunk. You don't just commission the substation at the end. The correct approach to commissioning occurs subsection by subsection, to ensure that all components are working properly.

"When we talk about subsections we mean strings, which comprise about 25-30 modules. In strings for example you are testing for voltage and current."

Commissioning procedures have become common practice since the early years of Germany's solar market, Meyerhof explains. "When average system sizes were in the kilowatts, then megawatts, then multi-megawatts and eventually up to plants with capacities of 100MW or more, that we see today....the practice is fundamentally the same in that you start by commissioning from the smallest subsystems until the largest," he says.

How commissioning can influence long-term financial performance

Performance ratio (PR) is the ratio of measured output to expected output for a given reporting period based on the PV plant's name-plate rating.

To objectively measure the plant's PR it is important to have a suitable procedure in place from the contract phase and to demonstrate the plant has been commissioned and has reached a state of operation in which all equipment is functioning normally, explains Enertis owner's engineer manager Jose Merlo.

He says: "Once this has happened, the main thing is to ensure that the equipment from which the inputs for the PR calculation are collected are working normally, for example, the plant meter or the meteorological stations. These are sensitive pieces of equipment so must be cleaned and handled with care.

"This project performance check is important in order provide the first benchmark to the owner that the plant is operating in conditions consistent with the design and financial considerations that were originally specified."

Cold commissioning and hot commissioning steps

PV plant commissioning occurs in two main phases: cold commissioning and hot commissioning. The latter occurs when the plant is temporarily grid connected, to enable critical checks of how the plant and specific components within it perform when energised, as the PV plant is an electrical asset.

Cold commissioning

In cold commissioning, also referred to as mechanical completion, the aim is to carry out all the necessary tests on all the plant's systems. These include the medium voltage cabling, the alternating current and direct current low voltage cabling, and junction and combiner boxes, in order to ensure that the subsequent commissioning phase can be carried out safely.

According to Alectris' Roberto Vallavanti: "Once the civil and electrical works are done and all equipment is delivered and installed, the cold commissioning is carried out.

"This includes testing each single component and the check list is usually detailed, referring to every component that is not energised. For example, checking modules, tightening cable connections, as well as checking for any breakages during the installation, checking the mounting system, which can include ensuring bolts and screws are sealed. Then there are string boxes, checking things like the section switch is open, that the fuses are in place, with no damage. Then the inverter, including checks to see if the station has sustained any damage, and isolation tests for all AC and DC sections."

Additionally, cold commissioning should also extend to checking any communications infrastructure, as well as fencing

Credit: SMA Solar

The temporary energisation of inverters is among the stages involved in 'hot' commissioning

around the PV plant, roads, lighting systems, surveillance systems, safety signage, to ensuring all components and equipment are correctly labelled, as well as all documentation, drawings and designs are in order.

In short, everything that is related to installation and civil works has to be checked during cold commissioning. The output of all these checks and measurements is called mechanical completion. Mechanical completion provides an assurance that the plant is built to the design and the expectations of the owner/investor.

Hot commissioning

In hot commissioning, once the PV plant is energised, specific tests are carried out in order to verify that the plant is fully operational and compliant within the design parameters for which it was conceived, according to Vallavanti.

In the case of hot commissioning, the main objective is to check and certify that once all the plant's systems are energised, they work as expected, both in terms of performance and also functionality.

"The start-up of the plant, as the final phase of the project, must have been preceded by an exhaustive control of the construction of the plant. This control must have verified all the construction sub-processes, with special emphasis on the quality control of the plant, which is closely related to the commissioning itself," he says.

"As one example, during start-up it is very common to make random checks on the tightening torque of the tracker, which in turn should have been controlled during the construction phase of the plant according to the quality procedures," says Vallavanti.

"Mainly, it comprises the temporary energising of the inverter prior to its configuration. You would carry out a test of the safety switch, the auxiliary power supply, emergency buttons, as well as check capacitors, polarity of the connection, as well as whether the cabling from site is properly sealed, which may require using a thermal camera to check for a hotspot, which if not addressed could eventually heat up and burn. You are also testing the system operates at the grid's voltage," he says.

Checks to the inverter within hot commissioning are typically carried out by technicians employed by the inverter manufacturer onsite. "During energisation, you should also ensure the monitoring system is properly set up and check the availability of equipment and that everything meets what is set out in the supplier's, or manufacturer's documentation," Vallavanti says.

The hot commissioning phase is key because it is the only time, prior to fully energising the plant for operation, in which faults or failures can be detected that could be due to intrinsic defects in the equipment itself, such as internally damaged modules, or burned out fuses, or due to a failure in construction, such as overstretched DC cabling.

"At the end of the commissioning, a takeover 'punch list' is also good practice. This is where every single finding is listed,

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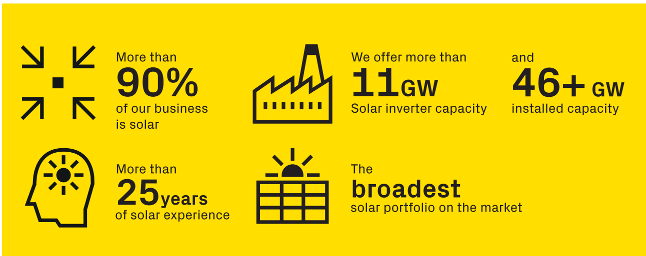

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detailing the corrective action that needs to be taken and the timeframe in which it needs to be taken by," Vallavanti says.

Provisional acceptance certificate signing and handover

Then, the PAC is signed. Usually the PV plant's financial investors, such as banks, require this certificate as it provides a date from when the warranty begins and the point at which the PV plant becomes 'bankable'. In other words, it ensures the construction has been done according to best practice and that the plant is expected to generate according to its design specification.

According to Vallavanti, "From that moment the company that is operating and maintaining the PV plant becomes responsible for the maintenance of the plant. It underpins the operations and maintenance (O&M) agreement and provides the basis of a warranty for the investor. After about two years from the plant's commercial operation date the warranty finishes and a final acceptance certificate (FAC) is then provided if the performance guarantee is in line with the expectations signed in the PAC."

Commissioning in practice

Supervisory control and data acquisition (SCADA) monitoring systems at PV plants can help ensure commissioning is done more efficiently, as some checks can be carried out remotely via the SCADA system. Otherwise tools and instruments in the field are used to take measurements, of power curves, for example and test different components.

"During commissioning the various measurements taken that detail radiation levels, temperature, weather and other parameters can be used as a benchmark for any future measurements taken during the plant's operation," says Meyerhof.

When the modules are installed insulation resistance tests are carried out to check, for example, whether there is adequate insulation between the module and the frame. "Also, you would run module thermal inspections using electroluminescent (EL) testing, to detect cracking that is invisible to the naked eye. It is possible to test groups of modules with EL tests, as opposed to single ones. These days you tend to test two, three, four strings, rather than individual modules, which saves time," he adds.

Sample testing is also used. "There are different approaches such as sample testing, which is more common as PV plants have increased in size. You wouldn't 100% EL test a 500MW PV plant but you might sample test 5% of modules," says Meyerhof.

Mechanical tests such as cable inspections are important because if a damaged cable is missed this will impact the operational lifetime of the plant. Meyerhof says: "Finding out any faults or problems as you go along is the only way, otherwise they won't be detected if you just commission only when the plant is built. If you address these issues then the asset has a better chance of operating for 20, 30 even 40 years."

Usually equipment and tools for administering tests and checks of utility-scale PV plants, including any tests for commissioning, include electrical power testers, insulation resistance testers, digital mustimeters, PV characterisation testers, I-V curve tracers, irradiance meters, infrared (IR) cameras and IR thermometers, digital cameras, portable computing devices, as well as power tools.

Merlo observes that the trends in the PV industry to optimise cost as much as possible have also influenced commissioning, but points out there are some testing processes that are difficult to optimise with regard to time and cost, such as testing the insulation of plant cabling or testing the operation of trackers.

"However, there has been a tendency to develop new commissioning procedures or technologies that allow certain testing to be carried out at much lower costs," he adds. "A good example of this would be thermographic camera inspection with drones."

Commission costs tend to be included in the construction cost and the cost of performing tests is very low, says Meyerhof. "In terms of time, commissioning can be a month or two months of technicians on site depending on the size of the PV project."

Traditionally the plant's engineering, procurement and construction (EPC) service contractor will do the commissioning. While having a third-party technical adviser to support or oversee commissioning is not mandatory, it is becoming more common, as the industry places more emphasis on PV plant bankability, in a post-subsidy market. Such providers, which support owners and investors, have expert knowledge and know what issues to look for during the commissioning of each subsection.

Merlo says: "Steps during both cold and hot commissioning are critical and additional resources for a project can be quite useful during these phases.

"It should also be noted that if a proper control of the project has been maintained throughout engineering and construction then commissioning is typically less chaotic or burdensome. During commissioning the total transfer of the asset is approaching. It is very important, both for the contractor to demonstrate compliance, but also for the owner to be able to acknowledge compliance. Specific additional resources from both parties related to performing or witnessing tests, confirming as-built documentation, O&M manuals, and so on can be quite valuable."

Conclusion

"Probably one of the biggest influencing factors on commissioning has been ongoing advances in wireless and other communication technologies, which has helped simplify commissioning in relation to certain equipment, such as trackers and combiner boxes, for instance," says Merlo.

He adds: "From Enertis' point of view, proper control through engineering and construction is the easiest way to facilitate a smooth and incident-free commissioning phase. In Enertis' experience during checks in commissioning you often see examples of trackers or mounting structures that have been inadequately assembled and issues with electrical connections."

While IEC standards provide clear guidance in terms of commissioning and are very comprehensive, Vallavanti says Alectris has been involved in efforts towards further standardisation of commissioning. The aim is to help make the process more transparent to benefit all entities involved in a PV plant, including investors, EPCs and asset managers/O&M service providers.

"Documentation, ideally in a digital format, is an integral part of the commissioning phase as well as a monitoring and asset management platform, which sits on top of the SCADA system, and acts as a repository for all documentation whilst also managing all operations of the plant and consolidating all technical, operational and financial data into a single place," he says.

Meyerhof thinks fundamentally, commissioning also needs to be considered in the context of the PV project's earliest stages, such as design and procurement. "The quality of modules, inverters, cables and other components, and the quality of the design all have an impact on whether you have a plant capable of optimal output.

"For example, define in your purchase contract that modules for your project should have zero cracking, then when you test those modules for cracks you have a contract to fall back on to ensure your project will be highest quality." ■

Project briefing

SOUTH AFRICA'S LARGEST PV PROJECT SPRINGS INTO OPERATION

Project name: Sirius and Dyason's Klip 1 and 2 (also known as the Upington solar complex)
Location: Upington, South Africa
Capacity: 258MW in total (spread between three 86MW projects)

On 10 April 2020, South Africa's biggest solar PV complex to date sprang into operation as the final phase was completed. The timing was extremely fortunate, just a day ahead of the country's government announcing a nationwide lockdown as the COVID-19 pandemic continued to spread worldwide.

The company behind the 258MW operation, Norway-based Scatec Solar, has had a presence in South Africa for the past decade, and the three-phased complex in Upington is its fourth project. South Africa has procured 1.5GW of solar power generation since the government introduced the Renewable Energy Independent Power Procurement Programme (REIPPPP) in 2011. Scatec Solar has won contracts for solar projects in the first, second and fourth round of the programme.

It signed power purchase agreements for the 258MW projects in Upington, in the Northern Cape, on 5 April 2018. The company has been the engineering, procurement and construction provider for the projects, and will provide operation and maintenance, as well as asset management services to the power plants.

The completion of the Upington projects brings Scatec Solar's total operational capacity in South Africa to 448MW, making it the leading player in the solar sector in the country. The project increased the company's asset base by 60%.

The government designed the programme very carefully to avoid problems that had been experienced in other countries, explains Jaco Uys, senior project manager at Scatec Solar. "There are a lot of legal documents to make sure that the framework for all the parties is very well defined. That provided overseas investors with enough comfort to come into the country and invest, and Scatec Solar was one of those.

"The REIPPPP is a fairly onerous process, but it's been successful to a large degree because of that. All projects have to meet strict conditions on employing local people, using equipment built domestically, labour rights and environmental issues," Uys says.

Employment and environmental protection

Projects must have environmental authorisation before they are allowed into the bid programme, he says. Authorisation covers flora, fauna and water use issues. Both the owner of the site and the builder employ their own officers to ensure that environmental conditions are met. The environmental compliance officer (ECO) reports to the environmental site agent (ESA), employed by the owner.

Considering the arid nature of the project's location, water use was the biggest environmental concern for the Upington project, Uys explains, and the company installed a water meter which was regularly monitored by the ECO to ensure it did not exceed the amount of water permitted under its licence. It also had to construct a type of culvert bridge as one of the access roads to the site crossed a minor watercourse.

The project site is in a semi-desert area, and did not involve major earthworks or disturbance, so there were no particular issues with wildlife, Uys says. There was potential for snakes and scorpions to be found on site, so Scatec Solar trained a couple of site staff as snake handlers to catch any snakes and release them on adjacent properties. This happened "a couple of times", Uys says. A bat-eared fox den was also found on the land portion, and construction ceased in the area to allow the animals freedom of movement.

In terms of complying with local employment obligations, Scatec Solar was easily able to recruit all the labour it needed from the local area, Uys says. "Constructions of these facilities always require a large amount of labour and it was therefore relatively easy for the project to achieve the numbers committed to," he says.

"It was also extremely important for the project to ensure that actual economic development objectives figures met or exceeded the tender numbers committed to, as these

By Catherine Early

numbers are audited by the Department of Mineral Resources and Energy, as well as the Independent Power Producer (IPP) Office. If they are not achieved, it leads either to significant penalties, or in the case of repeated transgressions, possible termination," Uys explains.

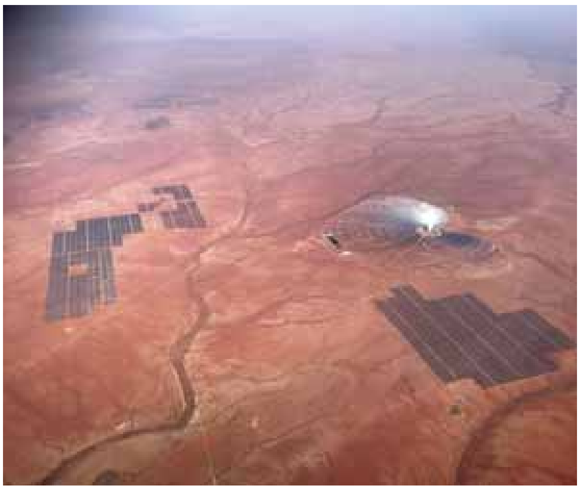
The company worked with local representatives to create a local community forum to ensure a consistent, clear and fair process of engagement with local people, Uys says. The company will have a 20-year relationship with the community, and so wanted to create an avenue to resolve disputes, he explains.

"It was quite difficult to get the forum established; it took a while to get buy-in from the community. But the moment that it was established things became a lot easier, so for us, that was a lesson learned and, in the future, we will do the same thing," he says.

The company is committing to operate in line with the Equator Principles and the IFC's Environmental and Social Performance Standards to ensure consistent practices across all projects.

"The focus of our socio-economic and environmental programmes and development mainly includes access to energy, capacity building, health and education. Over the entire lifetime of the project, a percentage of quarterly revenue is dedicated to development for all our solar plant. This work is supported by local community liaison officers, who are on-the-ground resources for the company," Uys adds.

Credit: Scatec Solar



Credit: Scatec Solar

Deal structure

Financial close for the three projects in Upington was reached in April 2018, and involved a total investment of ZAR4.76 billion. A consortium of commercial banks and development finance institutions led by South Africa's biggest lender, Standard Bank, are providing non-recourse project finance to the solar farm of ZAR3.68 billion, accounting for 77% of the total project cost.

Scatec Solar owns 42% of the project, Norfund holds 18%, the surrounding Community of Upington has five per cent, and H1 Holdings, a South African Black investor, holds the remaining 35% of the equity.

Investors were attracted to the project by the company's track record in the country; good weather and irradiation in the Northern Cape, and around Upington in particular; and community impact, since the project was judged to have potential for a meaningful impact on an under-resourced community, according to Mohamed Khalpe, Scatec Solar's asset manager.

Other factors that won over investors included the company's insight into the permitting process, making it more efficient; and the logistical benefits of the site such as being close to a relatively big town, roads, infrastructure and an airport one hour's flight away from the major cities of Cape Town and Johannesburg.

Desert construction

The semi-desert location of the site did not pose any particular issues in terms of what equipment needed to be specified for the project, Uys says. "It isn't full desert, so sand is not a problem. The major issue there is the heat, it can reach 50°C in summer, and PV modules can be less efficient under those conditions. However, the irradiance is unbelievably high and the plant is actually performing better than expected," Uys says.

The three projects at Upington use standard mono-perc 375Wp modules. Single-axis trackers are used – though trackers are more expensive, the additional yield of up to 30% more than offsets the extra cost, Uys says.

Another challenge caused by the semi-desert conditions is that the ground

Credit: Scatec Solar

is very hard, meaning that the holes in which to fix the trackers need to be drilled in advance. In Europe, pre-drilling is rarely needed, as the ground tends to be softer, Uys says. Each of the three projects at Upington needed 22,000 holes to be pre-drilled, he says. Trenches for the cable also needed to be cut with a machine instead of hand-dug, he adds.

The three phases of the project were built concurrently. Work on the access roads began in August 2018, and notice to proceed was obtained for all three plants in December 2018. The first 86MW phase was grid connected in February 2020, with the second phase following shortly afterwards and ahead of schedule. The final plant achieved commercial operation on 10 April.

The team was very fortunate that the build-out was not affected by the outbreak of COVID-19 and the nationwide lockdown, Uys says. "The very last test we had to do for the last project was the day before lockdown started. We did the test, and after that all the site crew went straight home.

"The plant was operational after that, and as power generation is classified as an essential service, the operations and maintenance team could continue working. So the impact of COVID-19 was minimal, and that was pure luck," he says.

Ongoing operations and maintenance will be handled from Scatec Solar's global control and monitoring centre in Cape Town, which keeps track of all its plants worldwide 24-7. Though there has yet to be a confirmed case of COVID-19 in the remote Upington area, the firm has developed a contingency plan for using back-up teams from other solar plants in the country, and has divided local teams to reduce the risk of a local outbreak affecting the whole team.

Positive future

The outlook for solar energy in South Africa is now looking "very positive", Uys says. Though there was a delay in between the third and fourth rounds of the REIPPPP, the fifth round is expected to be announced imminently.

The government hopes to increase the 1.5GW of existing solar capacity to more than 8GW by 2030. The Integrated Resources Plan 2019, published by the Department of Mineral Resources and Energy in October last year, outlines plans for 1GW of solar to be allocated each year in 2023, 2025 and 2028-30. It has been praised by the South African Photovoltaic Industry Association for giving a "moderate level of certainty" to the sector.

Future prospects for the solar market have been further boosted by recent government moves to relax regulations around power generation to prevent blackouts, Uys says. Mines and municipalities are now permitted to appoint an independent power producer (IPP) to generate electricity for them, rather than buying only through state-owned utility Eskom, which previously held the monopoly on both generation and distribution.

In addition, IPPs with projects generating under 10MW will have an easier application process and a greater chance of it being approved. These regulatory changes have increased the potential for solar generation, Uys says. "There's a lot more opportunities to build more solar, we're already seeing a lot more enquiries in the market. It's definitely looking up," he adds.

In an attempt to serve this market, Scatec Solar has introduced Release, a fully scalable solar power and battery solution that it says will reduce electricity costs and increases energy independence.

Scatec Solar is holdings its cards close to its chest for how much it is hoping to bid for in the round five auctions. "All developers and players in the market have various projects lined up, so we're looking forward to that. Everyone will put their bids in and we'll see what happens," Uys says. ■

Product reviews

Module | Dehui Solar's Max & BiMax Series PV panels offer up to 440Wp

Product Outline: Dehui Solar has introduced its Max and BiMax Series panels that include 166mm half-cut cells, combining 166mm-large-area p-type monocrystalline silicon wafers with a nine-bus bar (9BB) and half-cut cell configuration.

Problem: Grid parity and project bidding of utility-scale and commercial and industrial rooftop projects requires lower cost per-watt modules, which is possible through the adoption of high-performance monofacial and bifacial panels.

Solution: Dehui Solar's Max Series panels features monofacial PERC (passivated emitter rear cell) technology in half-cut 166mm x 166mm (M6) wafer size format with 9BB to provide better current collection ability with maximum power output

as high as 445Wp. The BiMax Series glass-glass module offers bifacial technology for additional energy gain from the rear side and enhanced fire resistance performance. The power outputs of the front side of BiMax modules are rated up to 440Wp.

Applications: Utility-scale PV power plants and commercial and industrial rooftops.

Platform: Dehui Solar's Max Series panels have 6 x 20 (120 pcs) cells. Panel dimensions are 1791mm x 1052mm x 30mm. The glass-glass panel, using 2mm glass front and rear with an anodized aluminium frame, weighs 24.0kg. The Max series comes with a 12-year product warranty and a 30-year linear performance warranty. Wind loads rated at 2,400Pa and snow loads of 5,400Pa.

Availability: February 2020, onwards.

Inverter | Ginlong's 110kW 3 phase inverter for commercial systems offers higher efficiency and yield

Product Outline: Ginlong Solis Technologies has released the latest addition to its 5 Generation (5G) portfolio. The new Solis 110kW brings a more reliable, efficient and secure inverter solution to commercial rooftop applications, resulting in stronger system returns and lower LCOE.

Problem: Stronger system returns and lower LCOE are required for commercial rooftop applications in the subsidy-free era. PV system design flexibility coupled to greater product efficiencies and smart solutions for grid stability and monitoring are needed.

Solution: The new Solis 110kW system is designed specifically for commercial rooftop applications. It integrates the company's 5G platform with claimed best-in-class electronic components to deliver a maximum efficiency rating of 98.7%. The efficiency advantages are claimed to increase generation by 3.5% during the project's total lifecycle. Advanced insulated-gate bipolar transistors (IGBTs) increase efficiency and decreasing losses, according to the company. Having 100% fully independent multiple MPPTs provides a wide DC operating voltage range. The 13 amps per string configuration offers high input current ratings. The system provides O&M advantages for cost-effective fault monitoring, locating and reporting, which

include advanced I-V curve diagnostics and string-level monitoring. Integrated on-board diagnostics and cloud monitoring help resolve issues quickly.

Applications: Commercial and industrial rooftop PV power plants.

Platform: An insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch that combines high efficiency and fast switching. The system has 90 MPPTs/MW, delivering high-power tracking density. The system has a 150% DC/AC ratio boosts system returns and density.

Availability: The Solis three phase 110kW string inverter is available in Asia Pacific, Europe and Latin America.

Module | JinkoSolar's 'N-type Series' high-efficiency panel has a maximum output of 405Wp

Product Outline: JinkoSolar has announced its new n-type monocrystalline all-black solar panel specifically developed for residential and commercial and industrial rooftop installations, globally. The 'N-type Series' has a maximum output of 405Wp, hitting a 21.22% conversion efficiency.

Problem: High-efficiency panels based on n-type monocrystalline wafers are becoming increasingly popular in the residential and commercial and industrial rooftop markets, due to the overall improvement in maximum output, lower degradation, better temperature coefficient and improved aesthetics, compared to multicrystalline and p-type monocrystalline products.

Solution: With high-efficiency n-type

panels, either more power capacity is possible for a given rooftop to meet energy storage and EV charging needs or fewer panels are required to meet electricity requirements, reducing installation and component costs. The 405Wp maximum output comes from using n-type mono PERT (passivated emitter rear totally diffused) silicon solar cells in half-cut configuration with JinkoSolar's Tiling Ribbon technology that aims to eliminate the cell gap to increase module efficiency.

Applications: Residential and C&I rooftops.

Platform: The N-type Series high-efficiency panel comes in a 156mm cell format (2×78) with dimensions of 1029mm (width) x 2182mm (length). Panel weight is 26.1 kg (57.54 lbs). The panel comes with a 25-year product warranty and 30-year power warranty, due to featuring one of the lowest degradation rates in the industry, which guarantees 1% for the initial year and 0.4% for the following 24 years.

Availability: Orders are currently being taken with mass-production ramp over the next few quarters.

Product reviews

O&M | RainWise's 'PVmet 500' weather station is designed for PV efficiency monitoring

Product Outline: RainWise has introduced the 'PVmet 500' weather station series for commercial and utility-scale PV power plants, which is said to be the world's first compact and customisable multi-function professional-grade weather station specifically designed for PV efficiency monitoring.

Problem: With increased adoption of high-efficiency PV panels as well as bifacial panels for commercial and utility-scale projects, greater emphasis is being placed on real-time measurement of key performance indicators such as solar irradiance, back-of-module temperature and ambient air temperatures to optimise power generation.

Solution: The PVMet 500 series supports measurement of up monitor global, plane of array albedo (bifacial PV) and diffused parameters. The series also supports up to three back-of-panel temperature sensors. The new system has the options to include all weather station parameters such as an ultra-sonic anemometer for windspeed and direction (optional), and a mini-aervane anemometer for windspeed and direction (optional), among others.

Applications: PV power plants.

Platform: This weather station is the sixth member of RainWise family of dedicated weather stations for the commercial PV market. PVmet 500 is compatible with all leading manufacturers of precision solar sensors for efficient monitoring from

Thermopile, including First Class, Second Class, and Secondary Standard to the economical Silicon Diode irradiance sensors. The product has one RTU Modbus (slave) communication protocol with an RS485 connection and is fully SunSpec certified and compliant.

Availability: Currently available.

Inverter | KSTAR's new 'KSG' grid-tied PV inverter series offers improved flexibility and reliability

Outline: KSTAR has introduced its new KSG grid-tied KSG-3000S, KSG-3000D, KSG-3600D, KSG-4000D, KSG-4600D, KSG-5000D and KSG-6000D PV inverter series for residential and commercial rooftop applications. The grid-tied inverters are designed to accurately match the voltage and phase of the grid sine wave AC waveform.

Problem: Solar system costs gradually decline as manufacturing scale increases, many residential and commercial rooftop PV systems become economically viable and popular. The off-grid inverters require the batteries for the installation, but the installation process is complicated. On the other hand, the grid-tied inverters for households are easier to install as these do not need batteries.

Solution: KSTAR's new PV inverters have multiple options for system monitoring and remote O&M, such as WIFI plug, GPRS plug and DC Switch. With the datalogger installed, customers can have access to KSTAR online smart service platform for reporting issues and troubleshooting, greatly reducing maintenance cost. Features including DC power up to 1.35 ratio, IP65 and DC/AC surge protection enhance the safety and high efficiency.

Applications: Residential and commercial and industrial rooftops.

Platform: KSTAR's new inverter series weighs approximately 10kg, much lighter when compared with older series inverters. The design provides better protection against water and dust while being aesthetically pleasing. Internally the inverter has invisible cable routing. Its smart technology and advanced internal design are optimized for its working environment, so that the inverter can work under harsh conditions, such as –25°~ +60° temperatures, salty air and humid conditions.

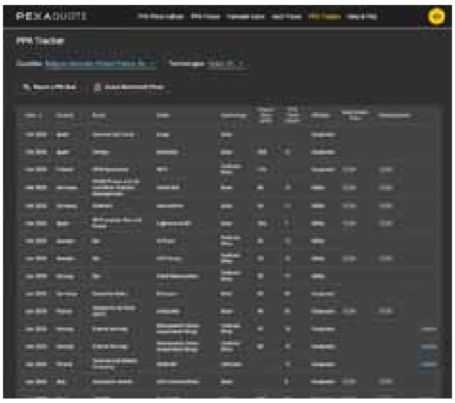
Availability: May 2020 onwards.

Project finance | Pexapark offers greater access to its 'PexaQuote' software on European PPA deals

Product Outline: Pexapark, a specialist software and advisory service for clean energy power purchase agreements (PPAs), has launched a 'freemium' version of its 'PexaQuote' software.

Problem: As subsidies across Europe are lifted, PPAs are increasingly important for developers as a strategy to manage risk and obtain financial security for a renewable energy project. By negotiating a PPA agreement with an agreed off-taker, project owners are able to secure borrowing and investment to complete the development process. Pricing proficiency is therefore of the essence for project owners to conduct an efficient negotiation process.

Solution: Pexapark's software, data, and



advisory services have been developed to create certainty for buyers and sellers as clean energy transitions away from subsidies and toward an open market. PexaQuote's freemium edition includes price indices by market and a PPA deal tracker, which records deals closed in the EU as and when they are disclosed. The software allows users to analyse the volume of deals across different technologies and countries. In addition to providing insight into pricing across the market, the freemium version also includes a new feature wherein the user can request a quote for a given PPA structure. If any sell side parties are interested, the software automatically matches them to the user.

Applications: PV power plant PPAs.

Platform: Pexapark developed PexaQuote in 2019 to analyse power price data and provide a quote based on real-time energy valuation and the specifics of a given project.

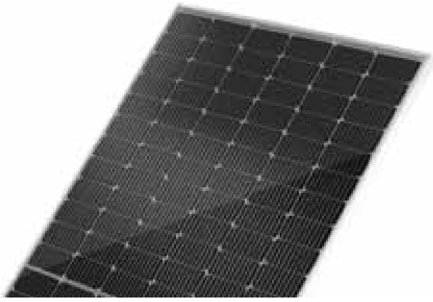
Availability: Currently available.

Module | Seraphim launches new high-performance 166mm-large-area p-type mono PERC panel series

Product Outline: Jiangsu Seraphim Solar System Co (Seraphim) has launched a new high-efficiency, 166mm half-cut cell solar panel, combining 166mm-large-area p-type monocrystalline silicon wafers with multi-busbar (MBB) and half-cut cell technology, which is also offered as a bifacial option.

Problem: Next-generation, high-efficiency panels provide lower LCOE due to lower cost per-watt as the industry transitions to larger wafer sizes that require half-cut cells or multi-cut cells with MBB technologies. Further LCOE reductions can be made when deploying bifacial modules and single-axis tracker systems.

Solution: The new panel's MBB technology enhances the mono-PERC performance,



while the half-cut cell technology reduces mismatches, internal power losses, cracking, and hot spots, improving the overall conversion efficiency by more than 5%, according to the company. The bifacial panel option has a bifaciality rate of 70 ± 5%, resulting in a theoretical maximum power of 579W, which can significantly reduce a project's LCOE. Under different ground conditions, the bifacial panel can increase electricity output by 10-30%, compared to the single-array panel with 2-7% more generation on asphalt ground, 5-10% more generation on grass, and 10-30% more generation on highly reflective surfaces. Compared to standard panel, the new 166mm half-cut cell product is claimed to save at least 5% of the cost per watt in projects above 1MW.

Applications: Utility-scale PV power plants and commercial and industrial rooftops.

Platform: The new 166mm half-cut cell PV panel has an efficiency of 20.07% and a maximum power output of 445W. Due to the large-area wafers, external dimensions are 1776mm x 1052mm x 35mm. Weight is 20.0kg with anodized aluminium frame.

Availability: April 2020, onwards

Inverter | Sungrow's 3-phase Inverter SG25CX-SA handles Brazils 220V market needs

Product Outline: Sungrow Power Supply Co has launched its three-phase 1,000Vdc commercial inverter 'SG25CX-SA' for the Brazilian 220V grid system to support the flexibility and reliability of regional grid voltage requirement in commercial and industrial (C&I) applications.

Problem: Grid operators in Brazil have to manage the integration of greater amounts renewable power sources. The Brazilian 220V grid accounts for 55% of diversified local grid voltage modes.

Solution: Sungrow's three-phase inverter SG25CX-SA is equipped with multiple MPPTs, the 25kW inverter is accessible to be installed in diverse commercial PV plants and guarantees optimal power generation even in the shade. It can be compatible with bifacial modules, offering higher yields and lower LCOE as well. The inverters ingress protection level of IP66 and an anti-corrosion grade of C5 improve efficiency and resilience, according to the company. Designed with smart forced air-cooling technology, the inverter can operate without derating at scorching weather conditions. With a built-in PID (potential-induced degradation) recovery function, the SG25CX-SA can significantly reduce power loss.

Applications: Commercial and industrial (C&I) and utility-scale PV power plants.

Platform: The SG25CX-SA enables remote firmware update, touch free commission and can co-work with Sungrow's intelligent monitoring system iSolarCloud, which offers a graphical readout of timely plant production, as well as the status of the PV array and inverter via portable smart devices.

Availability: May 2020, onwards

Module | Trina Solar offering 210mm large-area mono PERC panels with 500Wp performance

Product Outline: Trina Solar has launched its latest 'Duomax V' bifacial double-glass panel and 'Tallmax V' (backsheet) series panel. Based on the 210mm x 210mm large-size silicon wafer and monocrystalline PERC cell, the new panels enable high power output of more than 500Wp and module efficiency up to 21%.

Problem: With the 'standard' (156mm x 156mm) p-type multicrystalline and monocrystalline wafers rapidly becoming obsolete, the PV industry is undertaking and major transition to a number of larger wafer sizes that require half-cut cells or multi-cut cells with multi busbar (MBB) technologies to limit sheet resistance and provide high cell and panel output safely.

Solution: Trina Solar claims that preliminary

estimates from large-scale, ground-mounted power stations in China's Heilongjiang province, compared with conventional 410W bifacial double-glass modules, suggest the 500W Duomax V can reduce the balance-of-system (BOS) cost by 6 to 8% and reduce the levelised cost of energy (LCOE) by 3-4%. This is supported by the panel's combination of multi-busbar technology, which integrates advanced three-piece, non-destructive cutting and high-density packaging technologies. This further reduces the resistance loss and significantly improves the anti-cracking, anti-hot spot performance of the modules while maximising space utilisation.

Applications: Utility-scale PV power plants.w

Platform: DuoMax V bifacial double glass series panel has 150, 210mm cells (1/3 cut: 3 x 5 x 10) configuration. Dimensions are 2187mm x 1102mm x 35mm (86.10 x 43.39 x 1.38 inches). Weight: 31.1kg (66.4lb). The Tallmax V has 150 210mm cells (1/3 cut: 3 x 5 x 10) configuration. Module dimensions: 2176mm x 1098mm x 35mm (85.67 x 43.23 x 1.38 inches). Weight: 26.3kg (58.0lb)

Availability: Trina Solar is formally accepting orders.

How aerial inspections can improve O&M in a cost-effective manner

Credit: BayWa r.e.

O&M | The use of unmanned aerial vehicles in solar operations and maintenance can reduce costs and save hours of painstaking labour, but only if applied correctly. Aline Kirsten Vidal de Oliveira, Mohammadreza Aghaei and Ricardo Rüther explore the optimal use of aerial inspections and emerging methods for analysing the data they gather to identify faults

As photovoltaic (PV) installations increase in number and scale worldwide, the need for reliability and optimum performance of PV power plants grows as well. Thus, it is essential to develop fast and efficient inspection techniques, to perform operation and maintenance (O&M) measures cost-effectively.

With the advent of commercially available unnamed aerial vehicles (UAVs), aerial inspections were developed to be one of the novel methods for O&M which seems to be a promising approach to this challenge. This article aims to discuss the advantages and challenges related to aerial inspections in large-scale PV power plants, discussing the association of UAVs with consolidated inspection methods such as visual inspection, infrared thermography (IRT) and electroluminescence (EL).

Aerial inspections

UAVs are typically small-scale aircrafts capable of remote or autonomous operation. They were originally designed for military purposes. However, recent advances and cost reductions in the field of UAV have made such technology applicable for civil operations such as disaster relief, energy and power line inspections, and environmental, forest and mine monitoring, among others [1]. The technology has become increasingly popular, especially in the energy and agriculture sectors.

The use of UAVs to inspect large PV plants has grown significantly over the years, thanks to their superiority in field coverage, reliable imaging, quick detection, high durability, lightweight, low cost and high robustness to operate in hostile environments. They are used with RGB cameras or with cameras for infrared thermography (IRT) or electroluminescence (EL).

Drone-enabled inspections of PV power plants are increasingly popular in solar O&M

The widespread adoption of such devices also increased the availability of controlling and route planning software. The prior path definition of the flights enables a more stable, safe and effective inspection, mostly when precise GPS data of the site is available. Nonetheless, it does not detract from having a trained workforce for conducting the flight. The routes can vary in terms of height, direction and velocity, which depends on the quality of the UAV and the camera, the shape of the power plant, wind speeds during flight, and the goal of the inspection. The direction of the route, for example, can be parallel to the module rows or orthogonal to them, as shown in Figure 1. None of the two methods

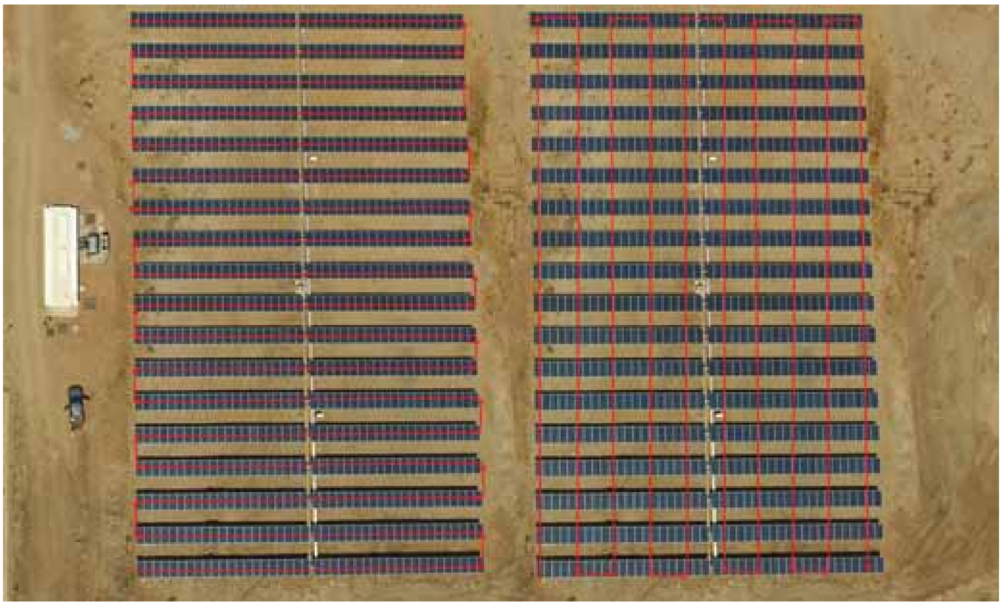


Figure 1. Different route types for aerial inspections of PV plants, marked in red. Parallel to the PV module rows on the left and orthogonal to the rows on the right

is superior to the other, but distancing between rows and power plant design factors can make one of them faster than the other. The parallel route has the advantage of facilitating the geolocation of faults, while the orthogonal route is normally more effective when flying at higher altitudes, since it covers more modules at once [2,3].

There are also attempts to determine the optimal path planning for the UAV autonomously in the literature, as in [4], developing a concept of autonomous monitoring. This is a novel concept to integrate various techniques, devices, systems, and platforms to enhance the accuracy of PV monitoring, consequently improving the performance, reliability and service life of PV systems. By this approach, the entire services of PV monitoring will be provided by a single integrated system.

For this method to be implemented, first the boundary of PV plants is determined by a neural network [5,6]. For this purpose, the neural network is trained by various orthophotos of PV plants. Subsequently, a static path planning algorithm is designed in order to create an optimal path for PV plant inspection. Moreover, dynamic path planning is created based on the flight situation and checks the UAV's abilities after any specific manoeuvre, which means if the UAV cannot complete the initial path, dynamic path planning enters in the loop to create a new optimum path according to the UAV's position and endurance [4].

Figure 2. Schematic of the concept of autonomous monitoring system for PV plants [25,26]

Aerial visual inspection

Several defects on PV modules can be detected by a simple visual inspection. The method consists of a specialist that walks around the site and looks for any faults or failures visible by the bare eye, such as yellowing, misalignment, delaminations, bubbles, snail trails and burnt cells. For the aerial case, an RGB camera is attached to an UAV and can detect almost all of these faults in a much shorter time [7]. The great advantage of the method is the simplicity and low cost because most consumer-available UAVs are suitable for the task, with no modifications, and any operator can perform quick aerial visual inspections periodically. The inspections can be carried out from high altitudes, in order to monitor the plant and check for soiling, broken modules, vegetation over the modules and other easily spotted faults rapidly. Depending on the results, further inspections and actions can be taken. Professional UAVs, on the other hand, are more prepared for inspecting large power plants, since they provide better image quality, flight autonomy, stability and insulation against interferences from electromagnetic waves.

Aerial infrared thermography

The method of aerial infrared thermography (aIRT) has already proven to be a fast and effective method for detecting and classifying faults and there is already some commercially available equipment that offer IRT cameras mounted on UAVs. The integrated solution is ideal because it normally already contains built-in image processing software.

aIRT has been successfully employed for monitoring and commissioning of utility-scale power plants [8,9]. It provides fast identification of problems caused by environmental events such as hailstorms, windstorm, lightning, etc as the example described in [10]. Its major advantage is to evaluate a significant number of modules in a short time with no system shutdown (only trackers to be in stow mode).

The measurements are conducted outdoors, under stable conditions of irradiance above 600W/m2. Other environmental variables should also be measured (e.g. wind speed, ambient temperature). The diagnosis of faults occurs by evaluating the module's thermal pattern, which is uniform for healthy modules and reveals faults by variations in the image profile (shades of grey or colours). Examples of detectable failures include cracks and hot spots, corrosion, disconnected strings, shading, dirt, etc. The classification of detected faults is performed based on IEC TS 62446-3: 2017 [11].

The most common problems found in aIRT inspections are hot spots caused by cracks or soiling and vegetation because of the shading of cells which are not always distinguishable from actual hot spots through aerial visual inspections. When a hot spot is found in a soiled module, often there is the need to clean the module in order to re-evaluate the thermal pattern to know whether the hot spot was caused by soiling or actual damage. They are not considered failures of the system but problems that cause loss of power and present fire hazard risks. A good practice is to use aIRT equipment that also provides RGB images of the modules. The combination of aIRT with aerial visual inspections can

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help discard "false hot spots" and accelerate the diagnosis step.

In the case of inspections carried out during the commissioning phase of the power plant, it is common to find several disconnected strings. These are the failures that cause the most loss to a PV power plant's energy production, since they affect many modules at once. It also slows down the inspection process, since it disguises other faults, as the only problems that can be detected in a disconnected string are short-circuited modules or substrings. Therefore, the string needs to be reconnected and the thermal pattern of the PV modules re-evaluated. The causes for string disconnections vary for different equipment defects: trackers, inverters and fuses and diodes due to extreme over-irradiance events [12], on top of scheduled disconnections for maintenance or power restrictions. Disconnected strings can be detected more easily through the power plant supervisory system when current monitoring is conducted at a string or stringbox level (depending on topology and PV module technology). As the supervisory system is quite often not fully functional during the commissioning phase, the aIRT is still a fast method to perform this inspection.

Disconnected substrings are also commonly detected and are usually a PV module manufacturing defect. The substring might become disconnected in the junction box due to thermal stress during transport, installation and operation, causing the bypass diode to take on the full current of the string. This fault might cause the loss of one-third of the PV module peak power (because typical PV modules present six rows of cells, and one bypass diode for each two rows of cells), besides causing unnecessary stress to the bypass diode.

Faults that result in hot spots are more commonly detected in PV systems that have been installed for some years or that suffered from extreme meteorological events. They appear in broken glass modules, severe cracks or soldering problems, among others. The hot spots normally do not produce a significant loss of PV performance at early stages, so they are not usually detected by the supervisory systems. However, they are a potential source of fire hazards in the power plant and should be detected and removed.

Because of its flexibility, aIRT can be applied in many ways and levels of detail. The operator of a PV plant must decide how detailed and expensive the fault inspection should be and choose the flight altitude accordingly to this decision. For example, an inspection carried out at an altitude of 50 metres can detect open strings, disconnected substrings and broken cells on individual PV modules. These faults represent the biggest part of the power losses in a PV power plant. To detect the rest of the faults, which only cause a small part of the power losses, an inspection at 20 m flight altitude would be necessary. This inspection would take about double the time to be carried out and about two to four times more time for analysing the footage, and would, therefore, be much more expensive. The more detailed the inspection is, the more faults are detected, but the costs grow exponentially with detail. In large-scale PV plants, an aIRT inspection from a higher altitude will not reveal all the faults in the plant, but it will reveal the vast majority, including open strings responsible for the largest fraction of power losses. If a plant has a monitoring system detailed enough to detect all the open strings, the aIRT inspection can only provide an additional benefit if carried out at lower altitudes, which will result in higher costs. For small-scale PV plants such as roof-mounted systems, it is recommended to do the inspection at lower altitudes to get easy access to the system and obtain a detailed diagnosis of all the detectable faults [3].

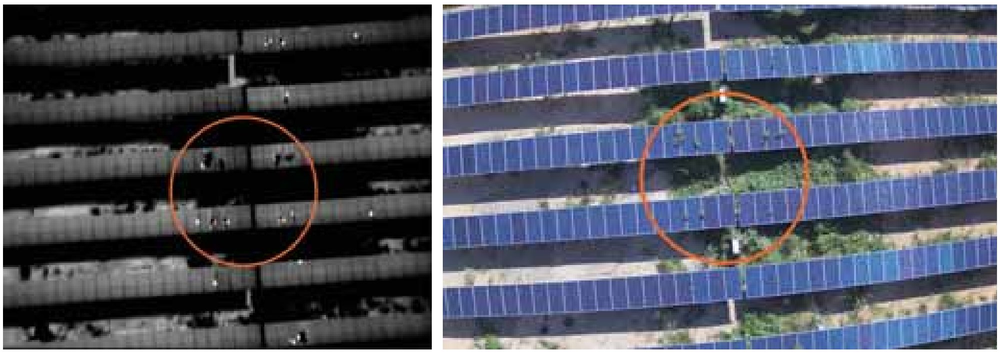

Figure 3. Vegetation over the modules detected with aerial inspections applying two different techniques: aIRT (left) and aerial visual inspection (right)

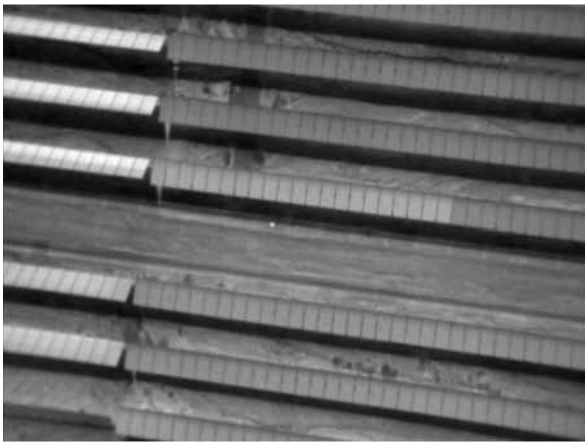

Figure 4. Disconnected string detected with aIRT on a single-axis tracking, utility-scale PV power plant

Aerial electroluminescence

EL is an effective technique for detecting faults in PV modules and requires specific EL radiation-sensitive range cameras that capture the photons emitted by the radiative recombination of charge carriers excited under forwarding bias. However, EL measurements are very time-consuming and inconvenient, since they are normally performed at night, require a mobile power source, take considerable time and are expensive to be carried out in large PV plants. For these reasons, the approach can be associated with aerial technology, such as UAVs, to employ EL for large-scale PV plants. The literature proposes different approaches for aerial electroluminescence (aEL) inspections [13,14], but most of these technologies are still costly and not broadly available.

The method simplifies the task of inspecting rooftop PV systems and allows taking images at different altitudes, so many modules can be analysed at once. In addition, during night-time, trackers in utility-scale PV power plants are set in stow mode, at a 0° angle. Taking EL images with tripods in this situation is a difficult and potentially hazardous operation, because of the necessity of placing the tripod on top of the module. Using a UAV allows the angle of the camera to be adjusted and the image can be taken at the right angle (90°).

For any EL measurement, the polarisa-

Figure 5. Broken cell detected with aEL, using low-cost aEL equipment [14]

tion of the modules through a voltage source is required. Also, for most of the cameras used, a dark room is necessary, therefore inspections in PV systems are performed during the night. For the case of using aerial equipment, when the number of modules that can be polarised at once is larger, the procedure is considerably faster and cheaper. The determination of the number of modules that can be connected at once depends on the power of the source applied. The larger the number of modules connected in series or in parallel, the higher the power which must be delivered by the voltage source. This becomes a challenge for the case of field measurements, as the power supply for the voltage source is normally a problem in large power plants that are usually built in isolated areas. In addition, the larger the power supply, the heavier and the larger the equipment, which complicates the logistics inside the power plant. A balance between the number of modules to be tested simultaneously and the cost and complexity of the inspection must be found. Another alternative is the use of switch boxes, in order to switch between strings, energising one at a time and allowing the UAV to cover the entire area quickly.

It seems ironic, having problems with power supply amid an electricity generation complex. However, this is one of the many challenges of working at night in a power plant. Other issues include the overtime costs of security and first aid teams and venomous animals. The low visibility also increases the risks of accidents and can affect the localisation system of the UAV, causing some control problems.

Despite all those challenges, the aEL procedure is effective in detecting faults and is especially useful for detecting problems that do not necessarily cause hot spots, such as potential-induced degradation (PID) and early-stage cracks. Such faults do not cause immediate loss of performance. For this reason, offering aEL services to detect them can be quite difficult. The benefit of the service comes from avoiding future hazards or warranty problems. Some extraordinary events, however, can require more sophisticated aEL inspections such as hailstorms or other meteorological accidents, loss of power because of inadequate transport of modules or even landslides that cause falling rocks over the system. In those situations, the impact of the restoration of the full performance of the power plant will pay the costs of the service.

"The overall performance improvement of PV power plants that cost-effective aerial inspections can bring will increase the reliability of utility-scale PV power plants, reduce their levelised cost of electricity and raise the attractiveness of PV technology as a whole"

Besides, there are low-cost aEL solutions with lower-quality cameras associated with consumer UAV systems that produce satisfactory results as a faster procedure that can cover extensive PV areas [14].

The challenges of data analysis

The biggest challenge of aerial inspections in utility-scale PV power plants consists of the analysis of the images. The process is very time consuming and requires expensive equipment and skilled legwork. The analysis can be performed in real-time or after all the data is collected. In real-time analysis, the UAV will manoeuvre over specific individual PV modules for a precise investigation during the flight, and the drone must be equipped with data transmission hardware, which increases payload and energy consumption, reducing range and flight time. For the post-processing option, the images are stored during the flight and then transmitted for analysis. This option is more popular, because it reduces the UAV flight time and the specialists' time in the field, therefore reducing costs. It also reduces errors for the possibility of different image adjustments that improve the fault detection.

The acquisition of data can also be obtained through still images or videos. For the case of data collected in form of pictures, thousands of images are taken, and the correct geo-referencing of each image is a complex task. The process can be made through mosaicking or creating an ortho-photo of the entire power plant [15-17] which is also computer-resource consuming.

The acquisition through videos is more convenient for the cases that a specialist will be analysing all the data manually. When observing videos, it is easier to follow the movement of the camera, detect faults and distinguish them from artificial artefacts, as the sun and object reflections. The size of the files, which can reach gigabytes per video, is an issue associated with the method, requiring suitable equipment and data handling skills. One further advantage is the avoidance of blurred or non-focused images, especially for the case of aEL.

The long hours spent on data analysis are not only a waste in resources but can also lead to false-negatives due to human error. For these reasons, the next step in the development of aerial inspections is the application of automation techniques for the analysis of IRT images. Several methods in the literature are under study, applying digital image processing and artificial intelligence [16, 18-24]. Many have shown satisfactory results and will soon be able to process the large amounts of aerial images, detect the faults and categorise them. However, the correct localisation of the defected modules and their identification in terms of string and row number is the most complicated step to automate. It requires precise geolocation, processing and correlation with each power plant design.

The automatisation of the entire process will be a huge contribution to the effectiveness and cost reduction of aerial inspections. It opens the possibility of a non-specialist pilot to perform the inspections and leave it for the software to generate an automatic report of the possible faults. The plant operator will then be able to replace defective modules, repair open strings and correct other issues quickly and with minimal effort and cost. This will reduce travel costs and PV power plant downtime and increase accuracy, performance ratios and annual energy yields. The fast recognition and repair of failures in PV components will increase the reliability and durability of PV systems.

Yet highly trained people will not lose their jobs, instead they will be used more effectively in the analysis of the most serious cases. Specialists will no longer be hired to carry out repetitive and manual labour, but to analyse more complex issues such as: Why do so many modules have their front glass broken in this power plant? Why do so many modules have disconnected substrings?

The overall performance improvement of PV power plants that cost-effective aerial inspections can bring will increase the reliability of utility-scale PV power plants, reduce their levelised cost of electricity and raise the attractiveness of PV technology as a whole. ■

References

[1] M. Aghaei, F. Grimaccia, C. A. Gonano, and S. Leva, "Innovative automated control system for PV fields inspection and remote control," IEEE Trans. Ind. Electron., vol. 62, no. 11, pp. 7287–7296, 2015.

[2] F. Grimaccia, M. Aghaei, M. Mussetta, S. Leva, and P. B. Quater, "Planning for PV plant performance monitoring by means of unmanned aerial systems (UAS)," Int. J. Energy Environ. Eng., vol. 6, no. 1, pp. 47–54, 2015.

[3] D. Amstad, A. K. Vidal De Oliveira, A. Häberle, and R. Rüther, "Fault Inspection of CIGS PV Plant using Aerial Infrared Thermography," in 36th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC), 2019, pp. 1569–1574.

[4] A. M. Moradi Sizkouhi, S. Majid Esmailifar, M. Aghaei, A. K. Vidal De Oliveira, and R. Ruther, "Autonomous Path Planning by Unmanned Aerial Vehicle (UAV) for Precise Monitoring of Large-Scale PV plants," in 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), 2019, pp. 1398–1402.

[5] A. M. Sizkouhi, M. Aghaei, S. M. Esmailifar, and M. R. Mohammadi, "Automatic Boundary Extraction of Large-Scale Photovoltaic Plants using a Fully Convolutional Network on Aerial Imagery.," IEEE J. Photovoltaics, 2020.

[6] A. M. Sizkouhi, M. Aghaei, and S. M. Esmailifar, "Aerial Imagery of PV Plants for boundary detection." IEEE Dataport, 2020.

[7] P. B. Quater, F. Grimaccia, S. Leva, M. Mussetta, and M. Aghaei, "Light Unmanned Aerial Vehicles (UAVs) for cooperative inspection of PV plants," IEEE J. Photovoltaics, vol. 4, no. 4, pp. 1107–1113, 2014.

[8] A. K. Vidal de Oliveira, D. Amstad, U. E. Madukanya, L. Rafael, M. Aghaei, and R. Rüther, "Aerial Infrared Thermography of a CdTe Utility-Scale PV Power Plant," in 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), 2019, pp. 1335–1340.

[9] C. Buerhop, T. Pickel, M. Dalsass, H. Scheuerpflug, C. Camus, and C. J. Brabec, "AIR-PV-check: A quality inspection of PV-power plants without operation interruption," in 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), 2016, pp. 1677–1681.

[10] A. K. V. de Oliveira, M. Aghaei, U. E. Madukanya, L. Nascimento, and R. Ruther, "Aerial Infrared Thermography of a Utility-Scale PV Plant After a Meteorological Tsunami in Brazil," in 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC), 2018, pp. 684–689.

[11] International Electrotechnical Commission and International Electrotechnical Commission (IEC), "IEC TS 62446-3 - Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 3: Photovoltaic modules and plants - Outdoor infrared thermography." Geneva, 2017.

[12] L. R. do Nascimento, T. de Souza Viana, R. A. Campos, and R. Rüther, "Extreme solar overirradiance events: Occurrence and impacts on utility-scale photovoltaic power plants in Brazil," Sol. Energy, vol. 186, no. January, pp. 370–381, 2019.

[13] G. A. dos R. Benatto et al., "Development of outdoor luminescence imaging for drone-based PV array inspection," in 2017 IEEE 44th Photovoltaic Specialist Conference (PVSC), 2017, pp. 2682–2687.

[14] A. K. V. de Oliveira et al., "Low-Cost Aerial Electroluminescence (aEL) of PV Power Plants," in 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), 2019, pp. 0532–0537.

[15] J. A. Tsanakas, L. D. Ha, and F. Al Shakarchi, "Advanced inspection of photovoltaic installations by aerial triangulation and terrestrial georeferencing of thermal/visual imagery," Renew. Energy, vol. 102, pp. 224–233, 2017.

[16] M. Aghaei, S. Leva, and F. Grimaccia, "PV power plant inspection by image mosaicing techniques for IR real-time images," in 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), 2016, pp. 3100–3105.

[17] F. B. John A. Tsanakas, Godefroy Vannier, Alexandre Plissonnier, Duy Long Ha, "Fault Diagnosis and Classification of Large-Scale Photovoltaic Plants through Aerial Orthophoto Thermal Mapping," in 31st European Photovoltaic Solar Energy Conference and Exhibition attached (EU PVSEC), 2015, pp. 1783–1788.

[18] A. K. V. de Oliveira, M. Aghaei, and R. Rüther, "Automatic Fault Detection of Photovoltaic Array by Convolutional Neural Networks During Aerial Infrared Thermography," in 36th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC), 2019.

[19] D. Kim, J. Youn, and C. Kim, "Automatic fault recognition of photovoltaic modules based on statistical analysis of UAV thermography," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch., vol. 42, no. 2W6, pp. 179–182, 2017.

[20] X. Li, Q. Yang, Z. Chen, X. Luo, and W. Yan, "Visible defects detection based on UAV-based inspection in large-scale photovoltaic systems," IET Renew. Power Gener., vol. 11, no. 10, pp. 1234–1244, 2017.

[21] I. Zafirovska, M. K. Juhl, and T. Trupke, "Comparison of Line Scan Luminescence Imaging Techniques for Defect Characterisation in Crystalline Silicon Solar Modules," in 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC), 2018, pp. 1364–1369.

[22] Z. A. Jaffery, A. K. Dubey, Irshad, and A. Haque, "Scheme for predictive fault diagnosis in photo-voltaic modules using thermal imaging," Infrared Phys. Technol., vol. 83, no. April, pp. 182–187, 2017.

[23] R. Pierdicca, E. S. Malinverni, F. Piccinini, M. Paolanti, A. Felicetti, and P. Zingaretti, "Deep convolutional neural network for automatic detection of damaged photovoltaic cells," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch., vol. 42, no. 2, pp. 4–7, 2018.

[24] C. Dunderdale, E. E. Van Dyk, W. Brettenny, and C. Clohessy, "Photovoltaic defect classification through thermal infrared imaging using a machine learning approach," Prog. Photovoltaics Res. Appl., vol. 28, no. 3, pp. 177–188, 2020.

[25] M. Aghaei, "Novel methods in control and monitoring of photovoltaic systems," Politecnico di Milano, 2016.

[26] F. Grimaccia, S. Leva, A. Dolara, and M. Aghaei, "Survey on PV modules' common faults after an O&M flight extensive campaign over different plants in Italy," IEEE J. Photovoltaics, vol. 7, no. 3, pp. 810–816, 2017.

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Towards a test standard of light and elevated temperature-induced degradation

Module degradation | Understanding of LeTID remains incomplete, although its effects on PV power plant performance are recognised as being potentially significant. Tabea Luka, Friederike Kersten, Matthias Pander, Max Koentopp, Marko Turek, Werner Bergholz and Thomas Pernau of the LeTID Norm consortium outline progress towards developing a standardised test for the defect, a key step in minimising its impact

In a PVEL survey of 2018, light-induced degradation (LID, LeTID) was identified as the defect that causes the greatest concern among investors implying severe financial risks [1]. One reason is that the defect is still relatively new and not entirely understood due to its complexity. To reduce these risks, the LeTID Norm consortium is working on a standard to test the LeTID sensitivity. To this end, the consortium brings together the experience of research cell manufacturers, research institutes, test facilities and PV power plant operators. Thus, the proposed test standard is based on a better understanding of the defect that is causing LeTID combined with practical applicability of the test procedure.

Light-induced degradation – the current scientific knowledge

The phenomenon of illumination leading to a loss of solar cell efficiency has been under investigation for more than 40 years. Several mechanisms causing such a degradation have been studied, including the activation of boron-oxygen-defects (BO), the dissociation of iron-boron-pairs (FeB), the degradation due to copper (Cu-LID), sponge-LID, and light and elevated temperature-induced degradation (LeTID). It is well known that all these defects are activated by charge carrier injection i.e. by illumination or current injection equivalently [2]. While most of these mechanisms are activated within minutes (FeB) or days (BO, Cu-LID and sponge-LID) during operation, it takes years until the LeTID degradation reaches its maximum [3]. Due to the significantly different timescales it is relevant to determine LeTID apart from the other LID mechanisms to estimate the overall losses during operation. A separation of LeTID is feasible as this degradation can only be observed above 50-60°C implying testing times of the order of weeks. Quite generally, the kinetics strongly accelerate with increasing temperature [2]. However, high temperatures over 75°C reduce the degradation extent, since the regeneration which occurs subsequently to the degradation is even more accelerated (see Figure 1). At a relatively low temperature of 25°C, a degraded cell exhibits a recovery of the degraded cell parameters under illumination. This recovery differentiates from the regeneration observed at elevated temperature, as it results in an instable state, which degrades again at an elevated temperature treatment [4].

Investigations have also shown that the cell process strongly affects the degradation. The higher the temperature of the firing process step (the last high temperature step in cell manufacturing), the stronger the degradation [5]. Slower cooling rates after reaching the peak temperature during firing step can reduce LeTID [6]. Furthermore, pre-annealing before the firing step or post-annealing after the firing step can reduce LeTID [7]. It was also shown that thinner wafers [8] and gettering steps for metallic impurities reduce LeTID [9]. During the last years, several publications showed that a high hydrogen content introduced into the silicon from the silicon nitride passivation layer of a PERC cell leads to faster and stronger LeTID [10,11].

At the moment, there is no common model for the cause and description of LeTID. Due to the strong influence of hydrogen on LeTID the UNSW has presented a "three-bucket/four-state model", which assumes that hydrogen is the only LeTID causal agent [12]. Schmidt et al. assume that 3d transition metal impurities are the main causal agent. In this model, the assumed state after firing is that the interstitial metal impurities are paired with hydrogen atoms and are assumed as recombination inactive [13].

Within the LeTID Norm project a model has been developed assuming that 3d transition metal impurities dissolving from metal-silicon-precipitates paired with hydrogen cause the degradation (see Figure 2). In this model, the well-known property of Co, Ni and Cu to form metastable platelet precipitates even after the fastest cooling to room temperature is used [14]. Since Co, Ni and Cu are common common impurities in PV wafers and

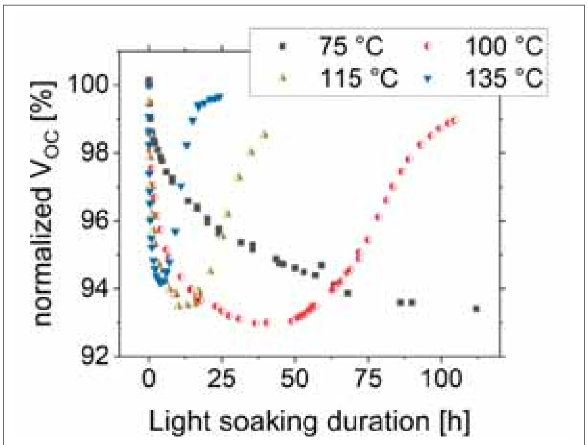

Figure 1. Typical LeTID degradation and regeneration behavior of the normalised open circuit voltage (V_{oc}) of solar cells during illumination equivalent to one sun at 75°C, 100°C, 115°C and 135°C

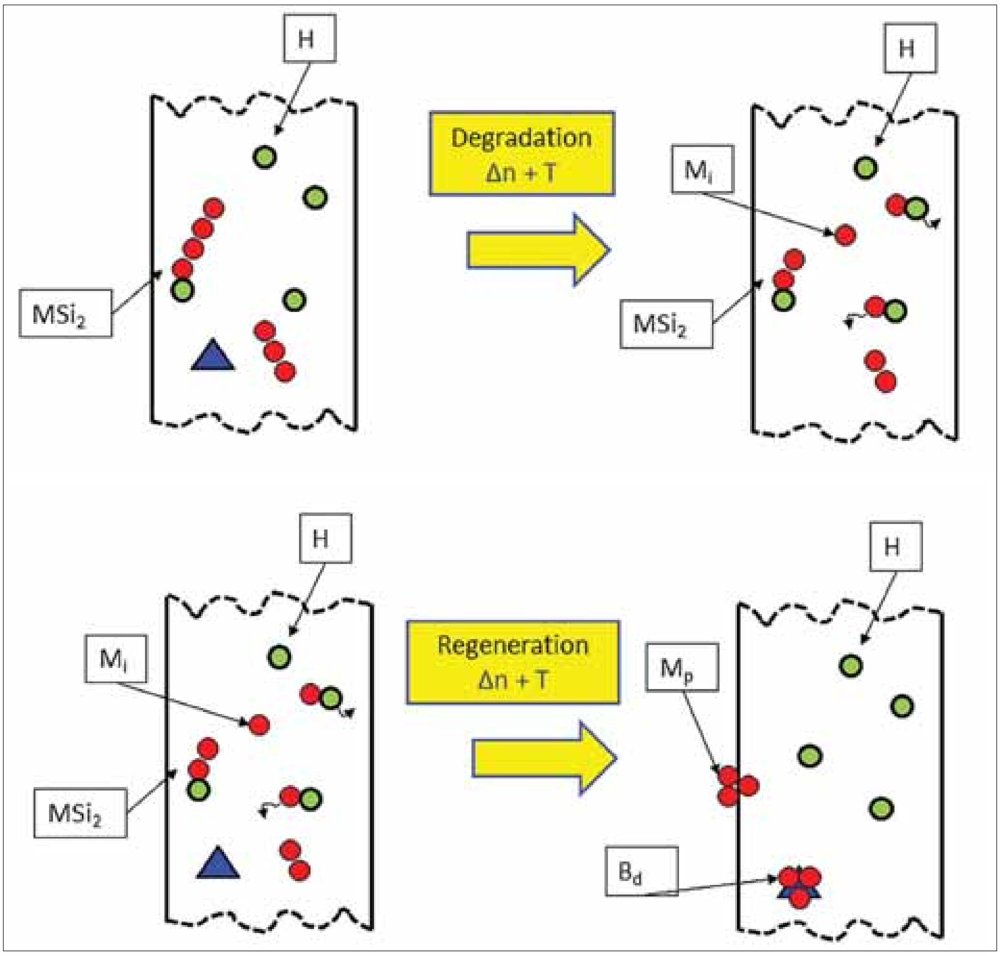

Figure 2. Schematic representation of the LeTID model suggested by the LeTID Norm consortium

cells, in typical concentrations up to or more than 10^{13} cm^{-3}, the presence of such platelets of the type MSi_2 is certain. The dissolution of the precipitates at LeTID conditions and the diffusion of the now dissolved metal impurities (recombination active!) to the sinks (recombination inactive!) is used to explain the observed degradation and later recovery of the lifetime and therefore the cell parameters, as depicted in Figure 2.

Test procedures and test setups

As LeTID is still not fully understood and thus cannot be ruled out entirely, quantifying LeTID is an important task to assure at most minor losses due to LeTID and thus reduce the risk of investors. Furthermore, from a process development point of view, it is essential to separate LeTID from other known degradation types such as iron related FeB-LID or oxygen related BO-LID. The dissociation of FeB pairs happens under carrier injection and at temperatures which is used for LeTID stress, therefore before measurement of the IV-characteristics at room temperature, storage of the devices in the dark long enough for the FeB pairing to be completed is needed to avoid the impact of this additional degradation mechanism. As for the BO-complexes, a suitable pre-conditioning is needed to clearly separate LeTID from BO-LID.

Testing throughout the value chain

LeTID-related reliability tests are relevant throughout the entire value chain. Performing the tests early in the production process allows a timely detection of the LeTID sensitivity and thus reduces financial losses for manufacturers. However, according to the current state of research, the earliest tests are reasonable on solar cells, since the solar cell process significantly influences the LeTID sensitivity. Additionally, stability tests on the finished modules should be carried out to guarantee the long-term stability of the final products, which is decisive for the customer satisfaction. Plant owners are strongly advised to demand detailed information on the LeTID stability before investing in PERC solar modules with mono- or bifacial design. Furthermore, they should keep track of their plant's performance, to observe reliability issues early on.

To generate comparable results throughout the value chain and among different test facilities, it is mandatory to use comparable treatment conditions. However, currently used test conditions differ significantly regarding the treatment conditions, i.e. temperature and injection level, and also the treatment time.

Cell producers' view

Solar cell producers started to become aware about LID in 2014. At this time, no dedicated test equipment was available, and first tests were done on existing, modified *IV*-test equipment. The temperature and injection contribution to the test was unclear. In the meantime, the testing methods and equipment have been optimised to use much better temperature and injection control.

centrotherm approached solar cell producers about light-induced degradation conditions in 2014. At that time, the test was intended to be a LID test to detect BO related defects. The light intensity for this purpose was considered to be sufficient if performed at 0.05-0.1 suns (where 1 sun is equivalent to 1,000W m^2 illumination with AM1.5 spectrum) at <40°C and for 24-48 hours while the cell is in open circuit condition, i.e. no load attached. Higher intensity and higher temperature were already identified to be able to drive a regeneration effect related to BO-LID [15].

As a first response about degradation parameters in use, only about 15% of the producers confirmed to perform tests. These tests were at 0.5-1 suns and at V_{oc} condition, cell temperature 60-100°C and 60-120 hours duration. This strong BO-LID test was accepted as an additional test by those cell makers taking care about light-induced degradation. The effort for a long test (60-100 hours) and powerful testing equipment (1 sun, >50°C) was accepted because module manufacturers requested tested cells or offered a higher price for guaranteed stable cells.

In 2017, LID came into focus also by Chinese cell manufacturers. They soon realised that the strong BO-LID testing can be compressed to 2.5-5 hours without too much loss in information. The shortened test was considered good enough. By the end of 2019, 62.5% of LID testers used a short test <6 hours. All devices in use did not control the cell temperature exactly. The cell temperature was a result of 1 sun light intensity and fan-cooled glow discharge lamps. The typical cell temperature in non-temperature-controlled testers was around 60°C.

Figure 3. LeTID test set-up designed by WAVELABS in cooperation with Fraunhofer CSP allowing quantitative LID reliability tests

Individual accelerated testing

For solar cell producers, it might be favourable to shorten the test duration to be able to regularly test a fraction of the produced cells and thus to ensure that the cell process is stable regarding LeTID sensitivity. There are different approaches to accomplish an accelerated LeTID test. A forecast of the total degradation extent based on the losses at the beginning of the degradation might be possible. Also increasing the treatment temperature and the charge carrier injection accelerates the degradation. However, a temperature increase (above 75°C) reduces the total degradation extent and the LeTID kinetics differs significantly depending on the material and the cell process [16]. Thus, for such strongly accelerated testing to be reliable, a good understanding of the solar cells is indispensable. Furthermore, the correlation of the accelerated test results to the treatment conditions, that are implemented in a LeTID standard, should be known. Thus, an in-house quick-test for well specified cells (material and process) where the correlation to the standard LeTID test is well understood could be individually developed. However, a long-term test with a wide range of applicability

In our continued survey, intentionally temperature-controlled degradation conditions showed up in early 2019, at the same time the additional light-induced degradation measurement was clearly named "LeTID" [2]. The first reporting user introduced a quick test with 4 hours' exposure and a long-term test with 200 hours at the same time. The degradation was driven by current at roughly 33% of the I_{sc}. The temperature was intentionally raised to 105°C to speed up the test. The quick test was found to be usable for selected material that already passed the long-term test. The reported LeTID tests that followed were done at I_{sc}-I_{MPP}, 75-110°C and 60% of the test procedures were intended as a quick test within 8 hours. From these surveys and from basic productivity and cost considerations, it is clear that many solar cell producers would prefer a short LID or LeTID test procedure, since the expectation to have a short test grew bigger.

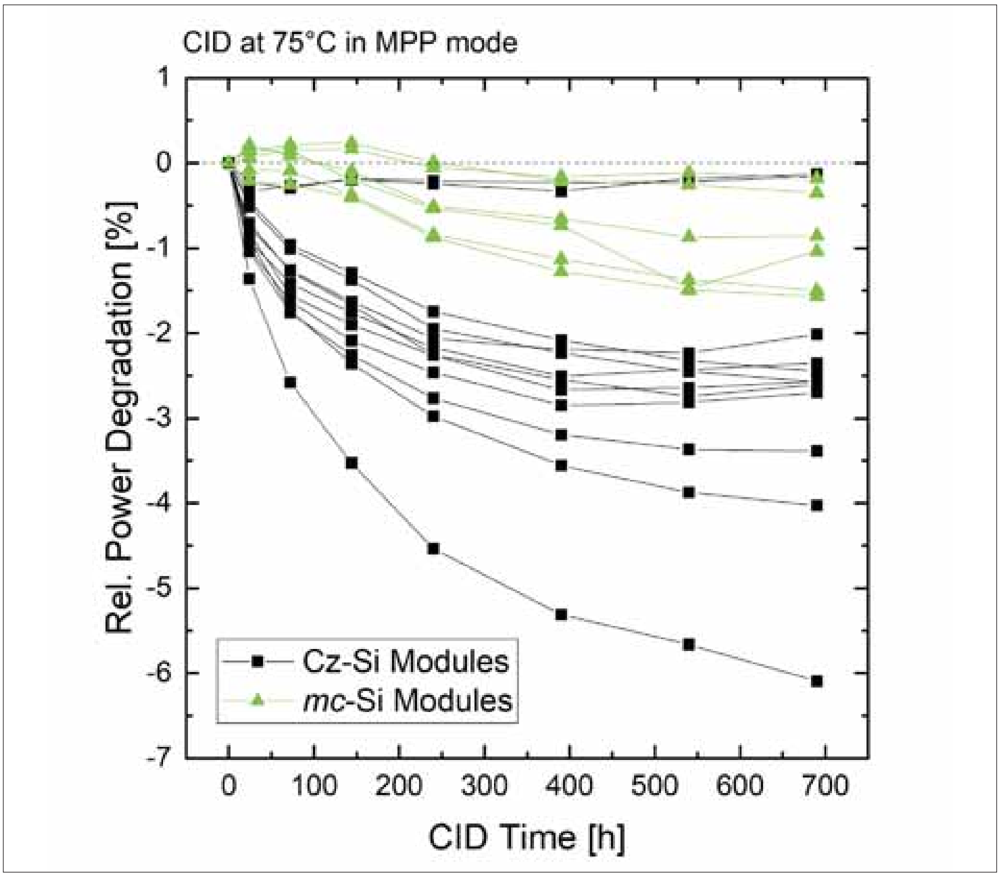

Figure 4. Results of LeTID benchmark showing the power degradation of commercial modules during LeTID test at 75°C and I_{CID} = 1.0A. Figure adapted from [17]

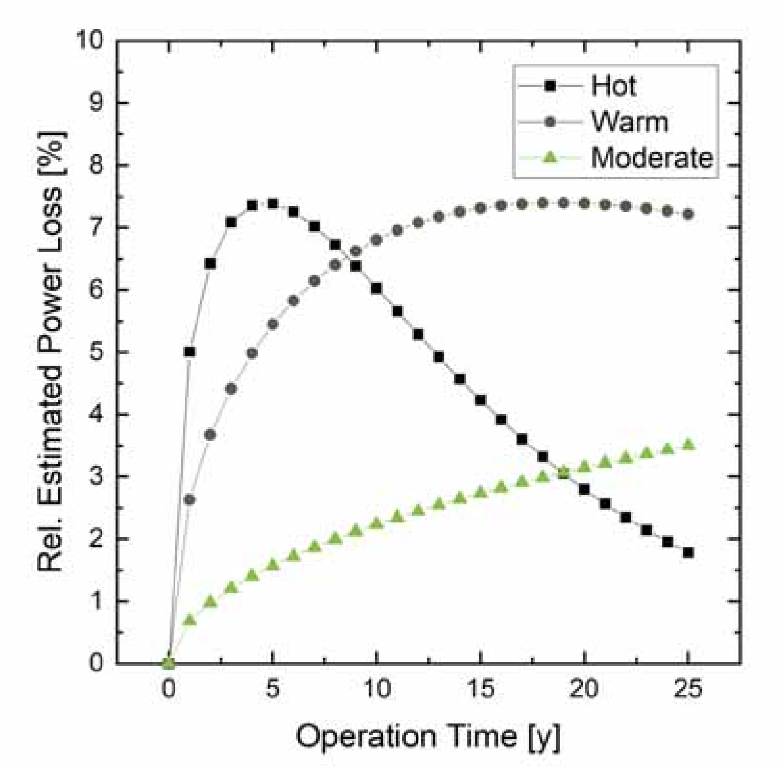

Figure 5. Estimated power loss due to LeTID for different climates for the module with highest LeTID susceptibility in benchmark test. Figure adapted from [20]

is necessary for proper standardisation and comparability of products.

Degradation setups

First test set-ups are commercially available which can be used for standardised testing as well as accelerated testing. WAVELABS in cooperation with Fraunhofer CSP has designed a LeTID test set-up allowing quantitative and user-friendly LID reliability tests (see Figure 3). The set-up allows advanced illumination techniques as well as electrical carrier injection. Both, carrier injection by light or by electrical current lead to the same LeTID effect. The LeTID behaviour of solar cells or PV mini-modules is characterised through *IV*-measurements and also through quantum efficiency measurements, that are extremely sensitive regarding losses due to LeTID.

LeTID on module level

At the EU-PVSEC 2018, the Fraunhofer CSP presented the result of a LeTID-specific benchmark test of commercially available PERC modules (see Figure 4) [17]. To separate the losses due to LeTID from other known LID effects (i.e. BO-LID and FeB-LID), a pretreatment was carried out at 25°C injecting a current of I_{CID} = 9A for one week. Additionally, before each measurement of the cell parameters the modules were stored in the dark at room temperature for at least 12 hours to avoid the effect of FeB. The LeTID test was performed at 75°C inducing the current $I_{CID} = I_{SC} - I_{MPP}$. A high degradation of >6% was found for some of the monocrystalline Si-PERC modules. Additionally, a large variation in power loss of LeTID affected modules of the same type is observed, due to different quantities of strongly affected cells inside the modules. This is a challenge for quality control and shows that at least two modules of each type should be investigated during a standardised test. Similar results were found in other investigations [18, 19]. These results clearly show that not all manufacturers are capable of reducing the degradation permanently to a minimum. If the production processes are not sufficiently under control with respect to the LeTID susceptibility, several cells in a given module can be LeTID sensitive.

LeTID field progression depending on different climate conditions

The benchmark in Figure 4 shows that there is a potential problem for system planners that can affect energy yield calculations and risk assessment. As a consequence of the potentially high power losses, the question arises how high the potential yield losses of PERC modules with LeTID-sensitive cells are in operation.

Based on the experimentally determined degradation values, an estimation was made for different locations. Three sites were selected for this yield loss assessment. The classification was based on the time in which module temperatures above 50°C occur. In a moderate climate only ~1% of the time of the year the module operates above 50°C, in the warm climate it is ~5% and ~15% in the hot climate. The temporary recovery, which is observed at lower temperature [4] and during a cold winter [3], is not considered in this estimation, due to the scarce available data on this topic. Thus, the power loss in moderate climate might be slightly lower than here estimated.

An Arrhenius behaviour was assumed to calculate a time equivalent to the field conditions in the laboratory test. The activation energy was chosen based on cell test data [9]. For each year of operation, the additional average power loss due to LeTID was then estimated (see Figure 5).

As a temperature-activated degradation, LeTID develops faster in hot climates due to increased operating temperatures. Specifically, for the highly LeTID susceptible module with over 6% relative power loss in the LeTID benchmark test, it is estimated that the maximum degradation will be reached in the first five years of operation. It is then likely that the reduction in output can regenerate over the years of planned system operation and thus the average loss in output power is reduced again.

“As LeTID can have a significant impact on the energy yield and thus the revenue of a PV system, customers as well as manufacturers urgently need a test standard in order to quantify the impact of LeTID and to qualify products”

The effect is even more relevant in warm climate zones, as the reduction in performance develops more slowly and over a longer time period. A long period of 5% and more power losses occur after five years in operations. In moderate climates the power losses increase slowly over the years and are thus difficult to separate

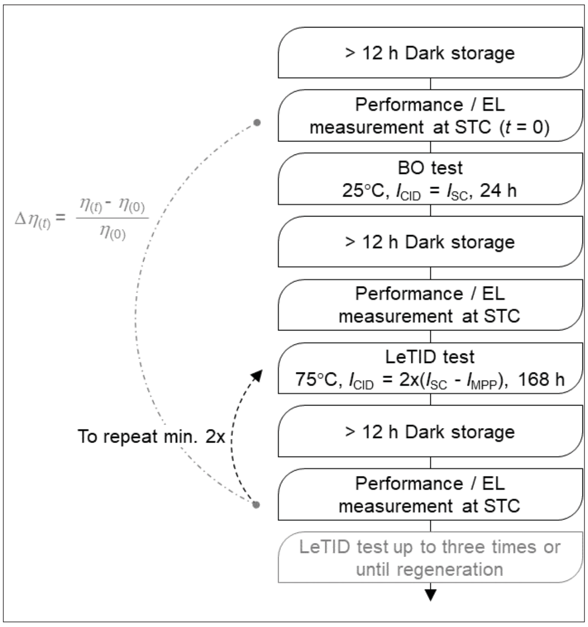

Figure 6. Test sequence of BO and LeTID test

from other reductions in performance.

These calculations show that the operating conditions and thus the LeTID kinetics differ strongly at various locations (i.e. moderate climate, or tropical climate). Furthermore, the module temperature strongly depends on the installation type (i.e. a solar park or roof-integrated photovoltaic system). Thus, testing at actual outdoor conditions is extremely time-consuming and inconvertible to appropriate test conditions. Therefore, currently the suggested LeTID tests are aligned to extreme outdoor conditions to accelerate the degradation and determine the most serious efficiency loss that is to be expected during operation.

Latest standardisation activities and our recommendation on how to test LeTID

As LeTID can have a significant impact on the energy yield and thus the revenue of a PV system, customers as well as manufacturers urgently need a test standard in order to quantify the impact of LeTID and to qualify products. Several standardisation activities are currently ongoing which all more or less employ the same or similar test conditions. IEC (International Electrotechnical Commission) as the most important standardisation body for solar industry is currently working on a LeTID test standard in its working group 2 (modules). A formal draft is expected to be circulated this spring. SEMI has already published a standard for LeTID, which is focused mainly on cells and mini modules [21]. Also, TÜV Rheinland has published an internal standard (2PfG2689/04.19) with similar conditions [22].

The test procedure recommended by the LeTID Norm project consortium as well as the conditions by TÜV Rheinland or IEC assesses LeTID on a module level by application of an electrical current at elevated temperatures rather than by illumination for reasons of practicality and cost. On cell level, illumination and electrical current can equally be used. The proposed test procedure aims at separating LeTID from BO-LID as well as FeB-related degradation phenomena which already occur at room temperature under the presence of light and on much faster time scales.

At least 15 solar cells or two modules (test specimens) are recommended for the proposed test sequence. In addition, five cells or one module from the same batch is used for reference to guard against deviations in STC measurements.

For the module test it is recommended to use a climate chamber with automatic temperature control with means for circulating the air inside and capable of subjecting one or more modules to temperatures from 25°C up to 75°C. During degradation a constant carrier injection is applied. It is recommended to log in situ the voltage of each test cell or test module, taking into account the correction for temperature fluctuations using the temperature coefficient of the sample and the measured treatment temperature. First, the samples are subjected to a BO test at 25°C for 24 h. Thereby the injected current is equal to initially measured I_{SC} (alternatively an equivalent illumination of one sun can be used on cell level). Subsequently, the LeTID test is carried out at 75°C by injecting a current I_{CID} that correlates to the excess carrier density present during field operation at maximum power point conditions (MPP)

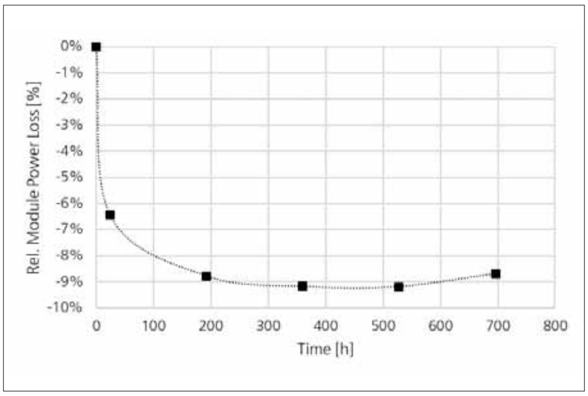

Figure 7. Module power loss due to BO and LeTID

(on cell level an equivalent illumination can be used alternatively). This current can be calculated from the short circuit current (I_{SC}) and current at MPP (I_{MPP}) by using equation 1:

$$I_{CID} = 2 \times (I_{SC} - I_{MPP}) \qquad (1)$$

The samples are subjected to one week (t_{CID} = 168 h) of stress at 75°C. During the treatment of the samples, the references are stored in the dark to avoid any degradation. After the treatment the samples are also stored in the dark for >12h in order to associate FeB. The whole test sequence is shown in Figure 6.

As shown in Figure 6 the LeTID sequence is repeated at least three times or until regeneration in terms of a performance increase begins, verified by detecting the minimum while tracking the dark voltage. In Figure 7 the test results of a BO and LeTID-susceptible module during the proposed test procedure are exemplarily shown. During CID in climate chamber the dark voltage of the module is measured. The obtained data are corrected by chamber temperature and averaged in a way that allows reproducible and accurate detection of the power degradation. When the hourly average of temperature-corrected measured voltage exceeds the sum of minimum dark voltage, then the module has entered the regeneration phase and the test is stopped. The error of not exactly meeting the stop time is assumed to be very small, since the regeneration rate under MPP conditions is very low.

The relative module power loss is calculated by using equation 2:

$$\Delta\eta = \frac{\eta_{(t)} - \eta_{(0)}}{\eta_{(0)}} \qquad (2)$$

The BO and LeTID-susceptible module in Figure 7 shows a high degradation of 6.4%$_{rel.}$ due to BO in the first 20 hours and an additional degradation after three weeks LeTID test at 75°C up to 9.2%$_{rel.}$ in total. After 700h cumulated test time in a climate chamber the regeneration of the module power had set in and the test was stopped.

This test run shows that the proposed test sequence can be used to evaluate the influence of stress on a combination of carrier injection and elevated temperature on module performance. The proposed test procedure can demonstrate the sensitivity of the sample to BO and LeTID degradation mechanisms on module level.

Summary

Light and elevated temperature-induced degradation (LeTID) is a critical topic for investors and plant owners, since it can permanently reduce the power outcome of PERC-modules. This degradation effect can be mitigated by optimising the cell process or passivating the LeTID defects. Since both metal contamination and the hydrogen content have a decisive impact on LeTID, process control has to address these two parameters in some way. However, recent benchmark tests have shown that not all module producers have the degradation under control and some commercially available products show a pronounced degradation. Thus, it is necessary that LeTID tests are performed throughout the value chain to reduce the risk of financial losses of producers due to failing modules and the risk of investors.

The LeTID Norm project consortium is working on a better understanding of the defect and a LeTID test standard. To quantify LeTID, the separation to other LID effects is recommended, which can be achieved by a pretreatment at 25°C and dark storage before each measurement. The LeTID test should be carried out at 75°C by injecting the current $I_{CID} = 2 \times (I_{SC} - I_{MPP})$ or illumination with an equivalent light intensity for at least three weeks. ■

References

[1] PVEL survey, 2018.

[2] F. Kersten et al. 2015 "Degradation of multicrystalline silicon solar cells and modules after illumination at elevated temperature", Solar Energy Materials and Solar Cells;142:83-86.

[3] F. Kersten et al. 2017 "System performance loss due to LeTID", Energy Procedia, Volume 124, 540-546.

[4] F. Kersten et al. 2015 "New light induced volume degra-dation effect of mc-Si solar cells and modules", Proceedings of the 31st EU PVSEC.

[5] D. Bredemeier et al. 2016, „Lifetime degradation and regeneration in multicrystalline silicon under illumination at elevated temperature", AIP Advances 6, 035119, 2016.

[6] R. Eberle et al. 2016, „Impact of the firing temperature profile on light induced degradation of multicrystalline silicon", Physica status solidi - rapid research letters 10, 861-865.

[7] T.H. Fung, C.E. Chan, B.J. Hallam, D.N.R. Payne, M.A. Abbot and S.R. Wenham 2017 "Impact of annealing on the formation and mitigation of carrier induced defects in multi-crystalline silicon", Energy Procedia Vol. 124, 726–733

[8] D. Bredemeier, D.C. Walter, and J. Schmidt 2018, "Possible Candidates for Impurities in mc-Si Wafers Responsible for Light-Induced Lifetime Degradation and Regeneration", Sol. RRL 2, 1700159.

[9] D. Bredemeier, D.C. Walter, J. Schmidt 2018, Possible Candidates for Impurities in mc-Si Wafers Responsible for Light-Induced Lifetime Degradation and Regeneration, Sol.RRL. 2 1700159

[10]C. Vargas et al. 2018, "Carrier-Induced Degradation in Multicrystalline Silicon: Dependence on the Silicon Nitride Passivation Layer and Hydrogen Released During Firing",IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 8, NO. 2.

[11] U. Varshney et al. 2018, "Influence of dielectric passivation layer thickness on LeTID in multicrystalline silicon", 7th WCPEC, Waikoloa, Hawaii.

[12] A. Wenham et al. 2018, "Hydrogen-Induced Degradation", 7th WCPEC, Waikoloa, Hawaii.

[13]J. Schmidt, D. Bredemeier, and D.C. Walter 2019, „On the Defect Physics Behind Light and Elevated Temperature-Induced Degradation (LeTID) of Multicrystalline Silicon Solar Cells", IEEE JOURNAL OF PHOTOVOLTAICS, vol. 9, no. 6, 2019.

[14]W Bergholz 1981, "On the diffusion of Co in Si and its applicability to the Si intrinsic defect problem", J. Phys. D: Appl. Phys. 14 1099 and J. Utzig 1988 "Properties of cobalt in FZ and CZ silicon studied by Mössbauer spectroscopy", Journal of Applied Physics 64, 3629

[15]K.A. Münzer, Proc. 24th EUPVSEC, 2CV.2.43.

[16]Tabea Luka, Marko Turek and Christian Hagendorf 2018, "Defect formation under high temperature dark-annealing compared to elevated temperature light soaking", Solar Energy Materials and Solar Cells 187, 194–198.

[17]M. Pander et al. 2018, "Benchmarking Light and elevated Temperature Induced Degradation (LeTID)", Proceedings of the 35th EUPVSEC.

[18]E. Fokuhl, et al. 2019, "LeTID – A Comparison of Test Methods on Module Level", 36th EUPVSEC.

[19]S. Wendlandt, S. Sljot, L. Podlowski 2019, „Licht- Und Temperaturinduzierte Degradation Von Pv-Modulen Mit Perc-Technologie: Praxisergebnisse An Kommerziellen Produkten", 34. PV-Symposium Bad Staffelstein.

[20]M. Pander et al. 2019, "Prediction of potential power/yield loss from LeTID susceptible modules", 36th EUPVSEC.

[21]SEMI standard doc. 6373, „Test method for accelerated cell level testing for light and elevated temperature induced degradation (LeTID) susceptibility of solar cells", SEMICON Europe ICM, 2019.

[22] TÜV 2PfG2689/04.19, "Light and Elevated Temperature Induced Degradation (LeTID) Test for c-Si Photovoltaic (PV) Modules: Detection", TÜV Rheinland 2019.

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Dr. Werner Bergholz graduated from Göttingen University in 1975 and subsequently had assignments there, at Aarhus and Oxford Universities. He joined Siemens Semiconductors 1985. Since 2002 he has been Professor at Jacobs University Bremen, his research included microelectronics, photovoltaics, QM and standards. He has leadership positions in SEMI© Standards and IEC TC 113 and co-founded ISC GmbH & Co. KG.

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Potential-induced degradation of bifacial PV modules incorporating PERC+ technology

Modules | Many of the bifacial modules now offered by PV manufacturers employ bifacial passivated emitter and rear cell (PERC+) technology, making them vulnerable to rear-side potential-induced degradation, in addition to the conventional front-side shunting type (PID-s). Kai Sporleder, Volker Naumann, Stephan Großer, Marko Turek and Christian Hagendorf of the Fraunhofer Centre for Silicon Photovoltaics report on new testing methods designed to quantify the expected power PID-related losses in bifacial PERC+ modules in the field

The idea of bifacial solar cells dates back to the 1960s [1] and describes the ability of solar cells or modules to convert light from both the front and the rear side into electrical energy. About 10 years ago, technological concepts were introduced to manufacture and mass produce the passivated emitter and rear cell (PERC) in a bifacial design – the so-called *bifacial PERC*, or *PERC+*. For PERC+ cells, bifaciality is achieved in an adapted cell process, whereby a full-area rear-side metallisation is replaced with screen-printed metallisation; thus, the rear side becomes translucent [2].

In 2020 bifacial solar cells are predicted to reach a market share of around 20%, and it is envisaged that the market share will grow steadily to around 60% within the next 10 years [3]. Bifacial PERC is expected to play a key role, because it can conveniently be produced on existing PERC production lines, since production capacity is available and is anticipated to grow further [3,4]. With the introduction of PERC+ technology, new degradation mechanisms have come under the spotlight during the last few years. In this paper, the origin and importance of potential-induced degradation (PID) of bifacial PERC solar cells will be explained.

For PERC+ cells, bifaciality is achieved by omitting the full-area metallisation at the rear side of the solar cell in favour of local contacts. However, without this metallisation there is no electromagnetic shielding of the rear side, making it vulnerable to rear-side PID. This phenomenon has been confirmed by reports in a number of scientific publications in the last two years, on laboratory tests with commercially available bifacial PERC solar cells. Two different rear-side PID mechanisms have so far been distinguished. The first – *PID-p* – is due to a polarisation effect at the rear interfaces; this effect results in a non-permanent reduction in the field-effect passivation and is mostly reversible. The second mechanism – *PID-c* – is due to corrosion of the silicon; to a large extent, this is irreversible and results in permanent and localised structural damage to the passivation layers.

PID: a short history

Depending on the polarity of the voltage and on the type of solar module, potential-induced leakage currents through encapsulating module layers can cause various degradation phenomena. For thin-film modules, it has been known since 2003 that transparent conductive oxides (TCOs) based on tin oxide can corrode under conditions of increased humidity and temperature, if the active layer is at negative potential compared with the grounded module frame [5].

In 2005 a 'polarisation effect' was reported for solar modules with back-contacted n-type crystalline silicon solar cells [6]. These modules showed a degradation in performance when they were at a positive potential relative to the module frame. It was assumed that the degradation was based on a field effect that causes deterioration of the electrical surface passivation of the solar cells. This is what is referred to as *polarisation-type degradation*, or commonly *PID-p*.

Other degradation phenomena relate to corrosion of anti-reflective layers, cell metallisation and cell connectors, which were also found to be associated with leakage currents through electrical potentials in 2010 [7]. Finally, in the same year a substantial reduction in the power output of solar modules with p-type solar cells was reported [8,9]. This significant degradation of solar modules, referred to as *potential-induced degradation*, occurs in PV systems where the solar cells are at a negative potential compared with the module frame. In this case, a strong reduction in the shunt resistance, well below 1Ω, in the affected solar cells has been observed.

Through microstructural investigations, the degraded performance was able to be attributed to a large number of nanoscopic shunts in the affected solar cells, which was then called *PID-s* [10]. An accelerated, yet realistic, test for PID-s on solar cells was developed at Fraunhofer CSP, and test set-ups for the approach became commercially available, e.g. the PIDcon testing tool by Freiberg Instruments [11].

The drop in the parallel resistance due to the PID-s shunts is, however, reversible. After reducing the potential difference, the solar cells heal slowly; this regeneration can be accelerated by increasing the temperature and applying a reverse voltage [8,12].

In subsequent years, a number of countermeasures against PID-s were developed and implemented in state-of-the-art modules and PV systems. Because of the high relevance to reliability and the increasing number of bifacial crystalline silicon solar modules, current PID research activities are now focusing on the investigation of PID effects on the rear side.

PID – a new threat for the rear side?

For standard PERC solar cells, there is no risk of PID affecting the rear side. The passivating layers and the silicon are shielded by the fully metallised rear side. However, for PERC+ cells, the electrostatic shielding due to this metallisation is missing, and cells are exposed to the same high-voltage conditions on the rear side that are known to cause PID on the front side. Thus, the rear side can also suffer from PID.

The fact that the rear side can be affected by PID was reported in various publications in 2018 and 2019 [13–15]. In these works, p-type mono PERC+ cells were investigated, with the result that similar high-voltage stress conditions on the rear side also led to performance losses because of PID. The performance losses described in these publications ranged from 12% after 40h [13], 10% to 13% [16], and up to 50% [15].

From all these published results, it is clear that PID stress can severely damage the back side of bifacial solar cells, thus reducing the overall cell performance. However, the results are difficult to compare quantitatively, and conclusions regarding yield losses cannot directly be drawn, as the test conditions were not identical: test times between 24h and 136h, temperatures of 50°C, 60° and 85°, and voltages of 1,000V and 1,500V were used in the studies. It is therefore important to identify and specify unique test conditions, i.e. by means of a standardised test procedure for rear-side PID, similar to the existing test norms for front-side PID.

Two different degradation mechanisms are currently known in the scientific literature for PID at the rear side: 1) a degradation due to depolarisation of the passivation layers, abbreviated *PID-p*; and 2) a corrosive PID type, referred to as *PID-c*.

PID-p of the polarisation type assumes that the field-effect passivation of the AlO_x layer is depolarised by charge compensation because of an accumulation of positively charged ions in the rear-side AlO_x passivation layer [13]. This interpretation was developed according to the findings of Swanson et al. [6].

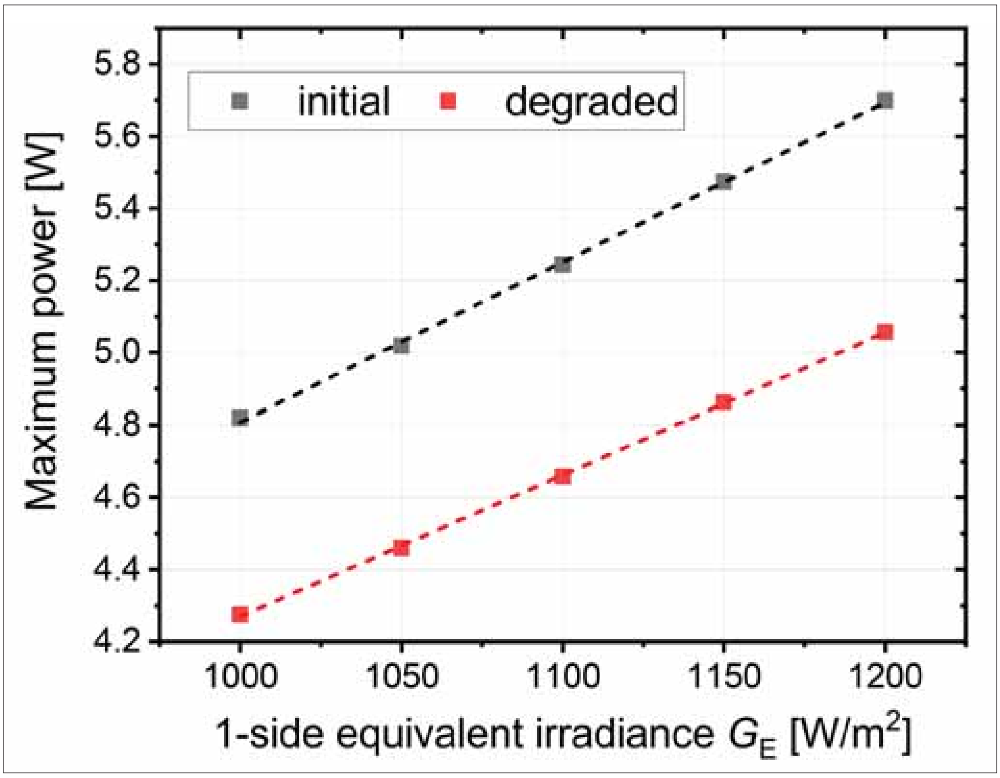

Figure 1. Power (P_{max}) of a mini-module as a function of the one-side equivalent irradiance G_E

The second currently known PID effect is due to corrosion of the Si below the passivating AlO_x and SiN_y layers. By analysing just the *I–V* curves, it is not possible to distinguish whether the high potential causes just a depolarization or an irreversible corrosion. This differentiation can be accomplished by using spatially resolved methods: microscopic regions of up to 2µm in size showing corrosion can be detected by means of laser beam induced current (LBIC) or electron beam induced current (EBIC) methods [14].

Another fundamental difference between PID-p and PID-c can be related to the recovery behaviour of degraded cells or modules under light exposure. Alternatively, the high-voltage stress test can be performed under simultaneous illumination. If the degradation is caused by corrosion (PID-c), the performance of the stressed sample cannot be recovered by illumination. However, in the case of PID-p a complete healing can be achieved [17,18]. More importantly, if the PID test is performed under simultaneous illumination, PID-p can even be suppressed. This implies that for a PV park, polarisation-type degradation (PID-p) is probably not critical, assuming that a rear-side light intensity exceeding 10W/m² is sufficient to suppress PID-p [17]. This is not the case, however, for corrosion-type degradation (PID-c), which causes damage to the cells in field conditions.

In the light of these findings, an accelerated PID test is proposed for the rear side, whereby illumination together with the high-voltage stress is simultaneously applied in the test set-up. Furthermore, to test for PID at the rear side a new standard ought to be developed which includes these combined test conditions. On the basis of the results obtained at Fraunhofer CSP, the authors propose that the standard should feature a high-voltage stress of 1,500V at elevated temperatures around 85°C, combined with an illumination of 1–5% of normal test intensity.

As an example, Fig. 1 shows the power of a mini-module as a function of the one-side equivalent irradiance G_E. The measurements were carried out before and after a PID test. In the test configuration, a voltage of 1kV was applied across the full-area metallic electrode on the back of the module opposite the grounded solar cell. The front of the module was also connected to the ground. In this special configuration, a single-side PID assessment is possible in such a way that shunting-type PID (PID-s) of the front side is avoided. Power losses of around 11% under standard test conditions are thus caused by rear-side PID as a result of the degradation of the rear side only.

Classification and quantification of different types of PID

The major impact of all types of PID in an advanced stage is the reduced power of the solar cells and modules. During quality assurance tests or product development, the power under standard test conditions is typically determined using solar simulators. As the cells within a single module are usually not affected equally by PID – visible, for example, as a checkerboard pattern in luminescence imaging – it is essential that the light field from the solar simulators used is of high lateral uniformity for a reliable power analysis. Reliability can be ensured, for example, by the use of the Fraunhofer CSP uniformity test sensor, which is made of identical materials to those of the modules under consideration, but with all cells individually connected to an integrated measurement electronics. This allows a simple, fast and accurate assessment of the lateral properties of the solar simulator light field.

Nevertheless, while conventional measurement systems reliably yield the power losses after a stress test, it is not possible to identify the specific type of PID. In particular, for a failure identification and optimisation of the production process, it is of critical importance whether the front side or the rear side of the solar cell is affected.

It has been shown that the two types of PID, PID-p and PID-c, exhibit a distinct characteristic change in the spectral response of the cell (see Fig. 2). A spectrally resolved external quantum efficiency (EQE) analysis was carried out for the one-cell module, both in the initial state and after the PID stress test. In the degraded state, an increase in carrier recombination is observed for wavelengths above 700nm when measured with the sunny side up. This is reflected in a reduced EQE signal at larger wavelengths. While the absorption of the incident light depends on the wavelength, electron hole pairs are still created throughout the entire depth of the cell, including the degraded rear surface of the cell.

With the module flipped over, i.e. the rear side is now the sunny side during the EQE measurement, PID-related carrier recombination dominates the near-surface regions and thus leads to a characteristic and severe drop at wavelengths below 900nm. A peak in the rear-side EQE in the 900 to 1,100nm wavelength range indicates that an increase in bulk recombination due to rear-side PID is negligible. These spectral features are characteristic for rear-side degradation and thus serve as a criterion for distinguishing rear-side PID from front-side PID.

Using a recently developed rapid quantum efficiency test based on LED solar simulators [19], this classification and distinction of the PID type can easily be combined with the power test under standard test conditions. Furthermore, the spectral information provided by a more advanced test set-up using

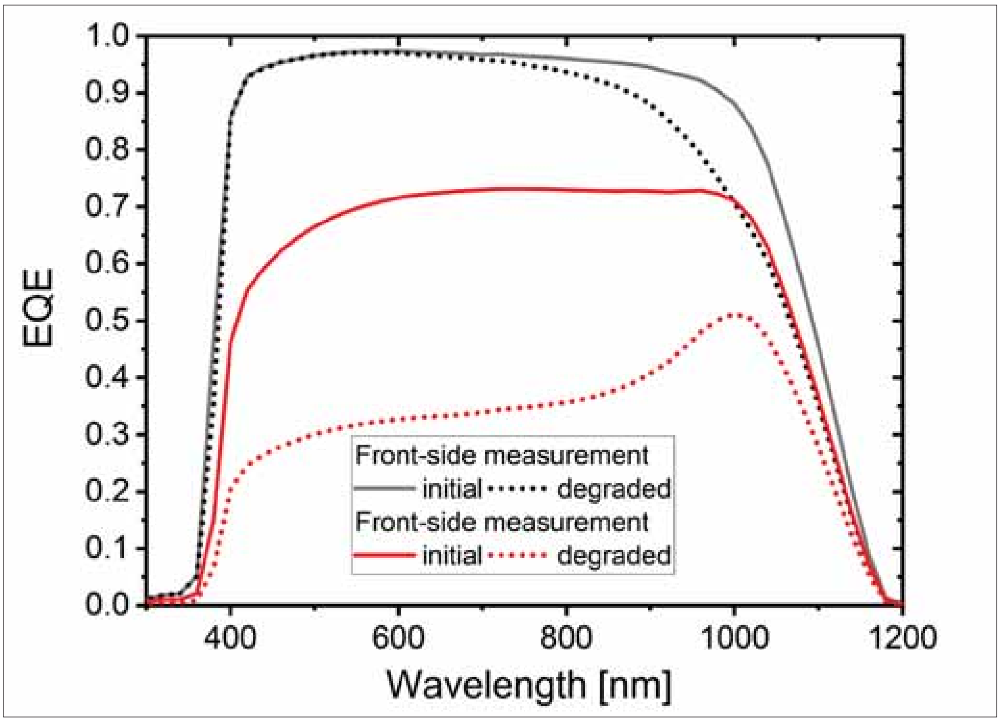

Figure 2. External quantum efficiency (EQE) of a bifacial PERC one-cell module. Compared with the initial state (solid lines), the measurements in the degraded state (dotted lines) have reduced EQE signals in certain wavelength ranges as a result of PID

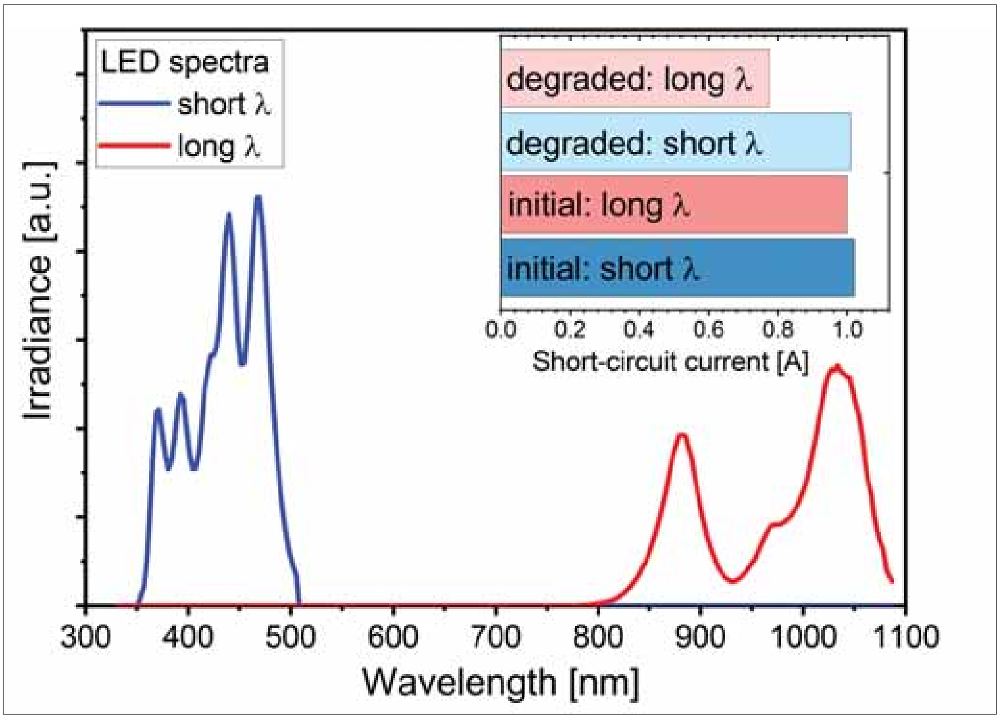

Figure 3. Two spectra of an LED solar simulator for rapid rear-side PID testing, representing the short-wavelength range (blue line) and the long-wavelength range (red line). The inlay shows the resulting short-circuit current of a bifacial one-cell module for the two indicated spectra in the initial and degraded states. While there is almost no change in the current for the short-wavelength spectrum, the long-wavelength spectrum clearly shows the rear-side degradation

Figure 4. LED-based solar simulator at the Fraunhofer CSP bifacial PV park. Using different coloured LEDs, an initial diagnosis of the type of PID can be made

LED solar simulators results in far more reliable estimation of yield than a single measurement as described in the test norm for measurements under standard test conditions.

In a simplified version, the usage of LED solar simulators allows the illumination to be controlled using either short or long wavelengths only. As can be seen from the inlay in Fig. 3, the short-circuit current I_{sc} of a module is significantly reduced by about 20% for long-wavelength illumination; on the other hand, the I_{sc} is not reduced when using short wavelengths. Thus, this simplified version of a spectral measurement can clearly reflect the increase in carrier recombination at the rear surface of the solar cell due to rear-side PID.

The indoor-testing schemes applicable to quality assurance or to R&D can also be transferred to a quick outdoor assessment. As the first outdoor LED solar simulators are now commercially available, similar measurement approaches can be implemented in a field inspection of PV modules, resulting in a more defined failure classification and in the ability to distinguish between rear-side PID and front-side PID (see Fig. 4).

Conclusions

With bifacial PERC, or PERC+, technologies, new degradation mechanisms related to high-voltage stress of the cell rear side can occur. There are two PID effects which can affect the rear side of a bifacial solar cell and reduce a PV module's power in a significant way. The first of these, polarisation-type PID (PID-p), is reversible and can be suppressed by illuminating the solar cells; thus, the implications for field operation are less significant. The second, corrosive-type PID (PID-c), leads to permanent structural damage of the passivation layer of the solar cell; it is not reversible and also occurs under illumination. The new types of PID associated with PERC+ solar cells need to be tested using an adapted new test standard which includes the simultaneous application of illumination and high-voltage stress.

All three PID types – PID-s, PID-p and PID-c – result in a power loss of the cell. In order to distinguish between the various types, spectral measurements are necessary, which – in a simplified version – can even be performed using LED solar simulators. As PERC+ technology becomes more widespread, it is essential that new test schemes are established, i.e. high voltage combined with illumination, new test devices, and adapted characterisation tools and procedures, in order to classify and quantify the PID effects. ■

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References

[1] Mori, H. 1966, "Radiation energy transducing device", U.S. Patent 3.278.811.

[2] Dullweber, T. et al. 2016, "PERC+: industrial PERC solar cells with rear Al grid enabling bifaciality and reduced Al paste consumption", *Prog. Photovolt: Res. Appl.*, Vol. 24, No. 12, pp. 1487–1498.

[3] ITRPV 2019, "International technology roadmap for photovoltaic (ITRPV): Results 2018", 10th edn (Mar.) [https://itrpv.vdma.org/en/].

[4] Dullweber, T. et al. 2016, "Industrial silicon solar cells applying the passivated emitter and rear cell (PERC) concept – A review", *IEEE J. Photovolt.*, Vol. 6, No. 5, pp. 1366–1381.

[5] Osterwald, C. et al. 2003, "Electrochemical corrosion of SnO_2:F transparent conducting layers in thin-film photovoltaic modules", *Sol. Energy Mater. Sol. Cells*, Vol. 79, No. 1, p. 21.

[6] Swanson, R. et al. 2005, "The surface polarization effect in high-efficiency silicon solar cells", *Tech. Digest 15th Int. PVSEC*, Shanghai, China.

[7] Hacke, P. et al. 2011, "Characterization of multicrystalline silicon modules with system bias voltage applied in damp heat", Report No. NREL/CP-5200-49344, National Renewable Energy Lab (NREL), Golden, Colorado, USA.

[8] Pingel, S. et al. 2010, "Potential induced degradation of solar cells and panels", *Proc. 35th IEEE PVSC*, Honolulu, Hawaii, USA.

[9] Berghold, J. et al. 2010, "Potential induced degradation of solar cells and panels", *Proc. 25th EU PVSEC*, Valencia, Spain, pp. 3753–3759.

[10] Naumann, V. et al. 2014, "Explanation of potential-induced degradation of the shunting type by Na decoration of stacking faults in Si solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 120, pp. 383–389.

[11] Freiberg Instruments, PIDcon testing tool [https://www.pidcon.com/en/pid-testgeaete.html].

[12] Pingel, S. et al. 2012, "Recovery methods for modules affected by potential induced degradation (PID)", *Proc. 27th EU PVSEC*, Frankfurt, Germany.

[13] Luo, W. et al. 2018, "Elucidating potential-induced degradation in bifacial PERC silicon photovoltaic modules", *Prog. Photovolt: Res. Appl.*, Vol. 26, No. 10, pp. 859–867.

[14] Sporleder, K. et al. 2019, "Local corrosion of silicon as root cause for potential-induced degradation at the rear side of bifacial PERC solar cells", *physica status solidi (RRL)*, Vol. 13, No. 9, 1900163.

[15] Carolus, J. et al. 2019, "Physics of potential-induced degradation in bifacial p-PERC solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 200, 109950.

[16] Sporleder, K. et al. 2019, "Root cause analysis on corrosive potential-induced degradation effects at the rear side of bifacial silicon PERC solar cells", *Sol. Energy Mater. Sol. Cells*, Vol. 201. 110062.

[17] Luo, W. et al. 2018, "Investigation of the impact of illumination on the polarization-type potential-induced degradation of crystalline silicon photovoltaic modules", *IEEE J. Photovolt.*, Vol. 8, No. 5, pp. 1168–1173.

[18] Sporleder, K. et al. 2019, "Potential-induced degradation of bifacial PERC solar cells under illumination", *IEEE J. Photovolt.*, Vol. 9, No. 6, pp. 1522–1525.

[19] Turek, M. et al. 2019, "Spectral characterization of solar cells and modules using LED-based solar simulators", *Sol. Energy Mater. Sol. Cells*, Vol. 194, pp. 142–147.

Post-subsidy solar: the reality on the ground

Design | The era of subsidy-free solar is well underway in a growing number of markets, with Europe leading the way. As Solarcentury's Peer Piske explains, the greater sensitivities around modelling zero-subsidy projects mean new approaches to design and planning are required by developers

Credit: Solarcentury

The reality of subsidy-free solar brings fresh challenges as well as opportunities for developers

The solar industry stands on the cusp of a genuine step-change, as the long-awaited era of subsidy-free solar becomes the new reality. Solarcentury is developing subsidy-free solar projects in Spain, Italy and the UK and evaluating projects in Greece and Germany. In Spain, we are constructing 500MWp of subsidy-free solar (across two sites) and across Europe we have a further 1.5GWp pipeline in subsidy-free markets.

Subsidy-free solar has long been the predicted gateway for mass deployment, but it has a major impact on the approach to development of projects. New economic realities change both the risk profile for investors and the selection and design of projects, with large utility-scale solar farms becoming the new norm.

In the UK this transition is only just getting started, but in other markets such as Spain, subsidy-free solar has already become a reality. The 300MWp and 200MWp developments which Solarcentury is building in Spain serve as a model for how a new focus on markets less reliant on government subsidies has fundamentally changed our approach to development.

First, the financial risk profile for investors is completely different. The last couple of years has seen many debt and equity providers on a rapid learning curve to determine what risk they will and won't accept in this new model.

For example, investors need to determine their approach to managing the risk of increasingly more solar coming onto the grid over the years and the effect this substantial increase in kWh will have on spot pricing (solar profile risk).

Equity investors are now fully up to speed and the banks have determined their risk appetites; which often varies from bank to bank and country to country. We see in all countries an increasing appetite for merchant risks. For example, in Spain we already have several banks financing fully merchant projects.

It's important to talk up front to all parties with a financial interest to ensure a complete overview of the route to market, debt and IRR expectations.

Second, the selection and design of projects is changing and impacting the way developers assess opportunities. Without the buffer of a government-backed income stream the model becomes more sensitive, and projects need to be managed significantly more carefully in terms of capex and opex.

> "The selection and design of projects is changing and impacting the way developers assess opportunities. Without the buffer of a government-backed income stream the model becomes more sensitive, and projects need to be managed significantly more carefully in terms of capex and opex"

Size is everything to achieve the necessary economies of scale, and ongoing costs such as rental for the land, O&M and taxes could severely damage the IRR if not managed precisely. This impacts decision-making, and as a result Solarcentury now excludes many more projects from development than in previous years.

To achieve the accuracy required to model and predict the systems and be on budget and programme requires the collective expertise of all disciplines from the very start of a project. The engineers, procurement team, project managers, asset managers and the data management team all provide considerable input into the planning, and without such a multi-disciplinary approach it's hard to imagine how a

Credit: Solarcentury

pure-play developer could achieve the level of precision required to model and plan developments with such tight parameters.

As an example of how this collaboration has paid dividends, two years ago Solarcentury's procurement team started working with our supply chain on their roadmap of products, determining which products we should be building with in 2019/20. As a result of this, our engineering team designed the Talayuela and Cabrera solar farms using products that didn't exist at the time of designing – increasing efficiency and providing a highly accurate view of how the systems will perform. This is essential for long-term investment planning.

We are also finding that to make these projects bankable, we have benefitted from changing the order in which we do things. For example, we have blurred the line between the development and EPC phases. For example, at Talayuela and Cabrera we built the grid connections at our own risk during the development phase. This is normally part of the EPC scope. However, the projects only became bankable because we were able to sign the PPA knowing that the grid connection was 'in the bag'. Completing these steps in this order significantly de-risked the projects.

Our control over every aspect of the asset (development, construction, ownership and operation) gives us hands-on control over the inputs to our long-term modelling when it comes to costs and performance. The variable is electricity pricing (currently impacted by the oil-price crash and COVID-19). Once prices have recovered from the current shock, the consensus is that power prices will go down over time, but in large part this is driven by the increase in availability of renewables which are already cheaper than fossil fuels in most markets – and the continuing trajectory of cost down in solar and wind. So lower pricing is not a threat for renewables, it's driven by them. The threat is to fossil fuel businesses. And underpinning this is the political will of governments committed to climate change pledges and therefore the growth of renewables.

The fine margins in subsidy-free projects mean new approaches in design and modelling are required to ensure bankability

The other key stakeholder in subsidy-free solar is the off-taker, or power purchaser. In this arena the market is also changing rapidly with both utilities and corporates showing an interest in participating in PPAs and with a high degree of engagement and sophistication. Utility PPAs are more popular in Iberia whereas in northern Europe, where there is more industrialisation, corporate PPAs are the more common route. And a big driver for more corporate PPAs is the power-hungry data centres of the big tech groups.

Talayuela Solar is perhaps the most complex PPA we have signed to date; the power from the plant will be sold on the open market. The PPA that has been signed is actually a swap – a financial instrument which hedges the off-take price for approximately 75% of the volume of production, ensuring both a secured stable income for the first 10 years of operation and the bankability of the project.

The PPA is based on industry standard documentation published by the International Swaps and Derivatives Association (ISDA), more commonly used to hedge financial interest rate or currency risks and has been tailored to the Talayuela Solar project. The PPA is structured as a hedge of Talayuela Solar's capture price rather than base load price, thus providing an optimal hedge for the Talayuela project revenues.

In countries like Spain, PPAs have a big discount on market pricing. This is driving investors to take more merchant risk and choose different routes to market.

Much is made of the potential future issue of cannibalisation. But when considering this, we must remember the climate imperative for electrification and the major role batteries are going to play. First, the amount of renewable power to feed a world powered by electricity rather than relying on fossil fuels is staggering as is solar's role within that. In Europe alone, trade body SolarPower Europe has released a report showing that the demand for solar could grow to over 10,000TWh by 2040. The same report shows we could also achieve as much as 2,000TWh of battery storage in the same timeframe. The demand for renewables is set to grow exponentially, which creates a more volatile market. However, the co-location of battery storage will enable investors to capitalise on the volatility, allowing a higher energy price to be captured, while reducing market risk and improving returns. In this regard, we have some way to go as a fair amount of market design is still required to incentivise battery storage for renewables and governments are aware of this and working on solutions.

In summary, the new approach we have developed in Spain is paying dividends and provides a roadmap for subsidy-free solar development in the next key markets: UK, Italy and Germany. We've learned, and continue to learn, how to operate in this new world where the key to our success is up-front engagement; with investors, off-takers and with the end-to-end team at Solarcentury.

Turn to pages 66 and 71 for further insights into post-subsidy project finance and price cannibalisation

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Price cannibalisation and future solar PV deployment

Economics | The growing volumes of variable solar and wind generation on the grid raise the risk of depressed wholesale prices, particularly at times of high generation and low demand. James Brabben of Cornwall Insight explores the phenomenon of so-called price cannibalisation and how its most serious potential impacts on the renewables industry can be avoided

Credit: Vattenfall

As we move towards the Net Zero 2050 target set by government, a key question for investors, developers and policy makers alike is what business models can be utilised to incentivise the rapid expansion of new renewables assets.

Looking at the Climate Change Committee's (CCC) Net Zero report (Net Zero – The UK's contribution to stopping global warming 2019) assessing the UK's long-term emissions targets, it is estimated that between 9GW and 12GW of new-build capacity per annum is needed on top of the current ~110GW market to generate approximately 600TWh of electricity a year by 2050, doubling the levels of today's market (~300TWh).

The opportunity is apparent, investment is being signposted towards low carbon renewable generation assets, with the majority focused on the mature and economically viable wind and solar PV technologies.

We at Cornwall Insight build our own long-term market models, looking at power price assessments, technology deployment and the carbon intensity of the grid out to 2050 to meet these targets. In our latest range of scenarios, we forecast that between 10GW and 28GW of solar PV could be built between now and 2050 to meet Net Zero. Supported by further falls in levelised costs of energy (LCOE), the trajectory of solar PV development may seem clear.

However, one key aspect we factor into our assessments for long-term power prices is a view on the "captured price" of solar PV and the degree to which price cannibalisation impacts PV and other renewable technology revenues. Currently, this is having a profound impact on how developers and investors configure their views on project revenues and expected returns, causing doubts among many in the community.

The growing volumes of solar and wind on the grid bring greater price risks

What is price cannibalisation?

So, what is price cannibalisation? Price cannibalisation describes the depressive effect on wholesale prices where large volumes of 'must-run' power plant continue to operate during periods of oversupply from generation and/or low demand. The effect is most marked during periods where there is a predominance of output from subsidised, intermittent renewable generation, such as solar PV or wind.

As these technologies have no fuel costs and low operating costs, they have comparatively low short run marginal costs (SRMC) and can out-compete fuelled plant. This results in high-cost, inefficient thermal plant being squeezed to the margins, with cheaper more efficient thermal plant setting the price, or possibly all thermal plant being pushed out of merit. The results can be dramatic, causing very low or even negative prices at times of high intermittent renewable generation.

The renewable subsidy schemes operating in the GB market – for solar PV, namely the Renewables Obligation (RO) and the feed-in tariff (FiT) scheme – provide generators with revenue based on volume of electricity produced, providing a simple prerogative to maximise output. No subsidy is paid when the generator is not producing, hence there is an opportunity cost for not generating.

The incentive is therefore to continue to produce when the market is otherwise oversupplied and the wholesale price falls. The incentive is even to continue to do so if prices turn negative, up until the point this negative value reaches subsidy revenue. The strength of this incentive, and the wholesale price ranges in which it applies, depends on the value of the subsidy received and the scheme under which it is paid.

Typically for solar PV, this will either be a 1.2ROC/MWh, 1.4ROC/MWh or 1.6ROC/MWh of RO subsidy or the more lucrative FiT scheme for sub 5MW projects. Of the total ~13GW of solar PV capacity in GB, 6GW is accredited under the RO scheme while a further 5GW is under the FiT scheme. A small proportion of capacity is under the contracts for difference (CfD) scheme at 40MW, while the remainder of capacity is subsidy free.

The signal to generate even in times of low or negative prices can be robust for this existing solar PV fleet. For a solar plant receiving 1.6ROCs/MWh, RO subsidy is currently worth over £85/MWh, while under the FiT scheme early ground-mounted projects built before 2012 can receive generation tariffs well in excess of £300/MWh. Under the CfD scheme, negative price provisions are in place to limit the incentives, but these only kick in for existing projects after six consecutive hours of negative day-ahead hourly prices, an event yet to happen in the GB market.

What is the impact now?

With incentives in place to continue running even at times of surplus electricity, as renewables capacity has grown in the last decade, especially for solar PV and wind, the degree of price cannibalisation has increased. What has surprised many in the market is the degree to which it is already a key feature impacting project returns.

We have been tracking the impact of pricing cannibalisation in our market research since 2015 and have noted an increasing disparity between the baseload electricity price and captured value of wind and solar PV.

Figure 1 details these trends, with a key aspect being the more pronounced decrease in solar PV capture prices over the period from a positive annual average in 2015, meaning a value captured typically above baseload power prices, to averaging around 2% below the captured price by the end of last year.

The reason, as noted above, is simply due to high solar PV deployment across 2015, 2016 and 2017 following a rush to build new sites to beat RO and FiT scheme closure and banding change dates.

The cannibalisation effect for solar projects is less profound than for wind currently, but still significant. Solar power benefits from delivering most of its output during the peak periods (Monday-Friday, 07:00 to 19:00) when demand is high, and therefore tracks closer to

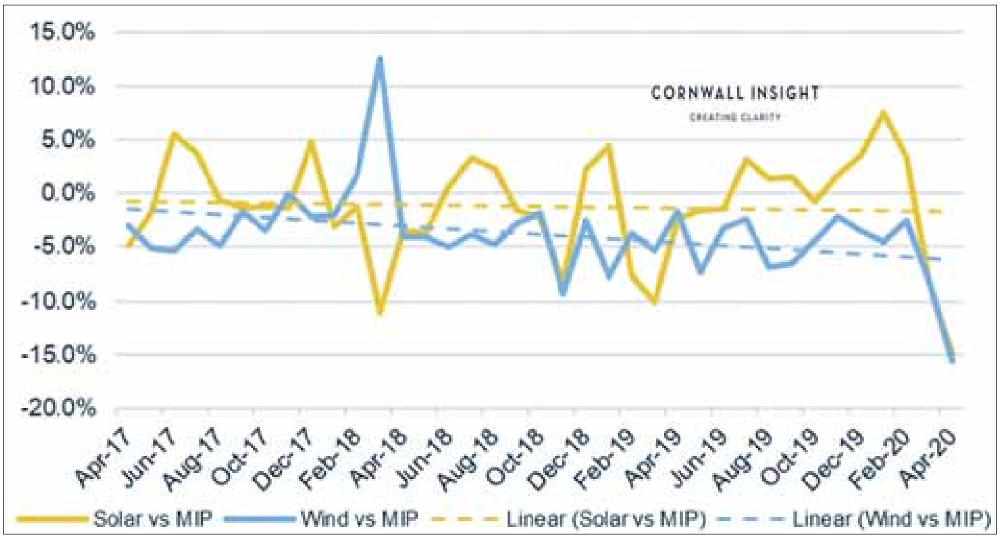


Figure 1. Historical captured prices for solar and wind versus the market index price (MIP)

baseload power prices as a result of a less dramatic merit order impact than wind. The cannibalisation effect for solar and the propensity for zero or negative pricing is greatest at weekends (and bank holidays), and from May to October, when demand is lower and solar output is at its highest.

Everyday operational impacts

We at Cornwall Insight are not alone in factoring this into our assessment of value. Through our Power Purchase Agreement (PPA) market research it is clear that suppliers and off-takers trading the power from solar PV assets are factoring current price cannibalisation into their PPA price offerings in the form of higher discounts against baseload prices. Many solar PV generators already take the decision to fix prices in their PPAs for 12-36 months in order to mitigate the impacts of this discount and the price cannibalisation.

There is also an appreciation of cannibalisation in government, with the Department for Business, Energy and Industrial Strategy (BEIS) incorporating a different and lower "intermittent wholesale power value" compared to the baseload view in its assessment of future wholesale prices in the last round CfD Allocation Round.

For generators in the market who are not fixing prices in their PPAs, the impact of COVID-19 has also laid bare how differences in selling strategy can have a material impact on asset returns. Those who may have fixed value in late 2019 or early 2020 are now reaping the benefits of the protection afforded to them, whilst those on market-linked contracts are subject to periods of extremely low wholesale prices.

The cannibalisation effect has dramatically increased since lockdown measures were introduced in March and for the first time in GB, we have seen consecutive periods of negative day-ahead hourly price periods. This correlated almost exactly with high solar PV output periods across the middle of the day. For those on market-linked contracts with exposure to market prices, COVID-19 impacts have had a material impact on returns.

What the recent trends with COVID-19 have shown is the degree to which high renewables penetration from wind and solar PV can impact on wholesale price formation. With renewables penetration rising suddenly with the ~20% fall in demand driven by lockdown measures, the current market provides a glimpse into the potential future when renewables consistently account for 50% or more of generation.

The coming years for price capture

Back in 2018 we undertook our first long-term assessment of price cannibalisation out to 2030 to understand what this future may look like. At the time, we calculated that price cannibalisation could see solar price capture fall below 95% by 2030, with wind capture below 80%. This was based on a view of market developments at the time, well before more stretching legislation was passed on Net Zero emissions targets, pledges for 40GW of offshore generation were launched and further falls in LCOE were taken account of.

Since this time, we have updated our assessments to incorporate these views and our latest assessment in March 2020 provides a starker picture. The need for higher build out of zero marginal cost solar PV and wind to meet Net Zero targets is likely over time to reduce wholesale power prices and expected capture rates. A higher proportion of generation from variable sources will also increase price volatility. Compared to our 2018 assessment our latest analysis shows that solar PV capture rates could drop on an annual basis below 90% by 2025. Taking a more granular look, monthly capture rates could range from over 100% to below 87%. As expected, solar PV may see less of an impact than wind, where the acceleration of offshore wind growth has knock-on impacts for the onshore fleet.

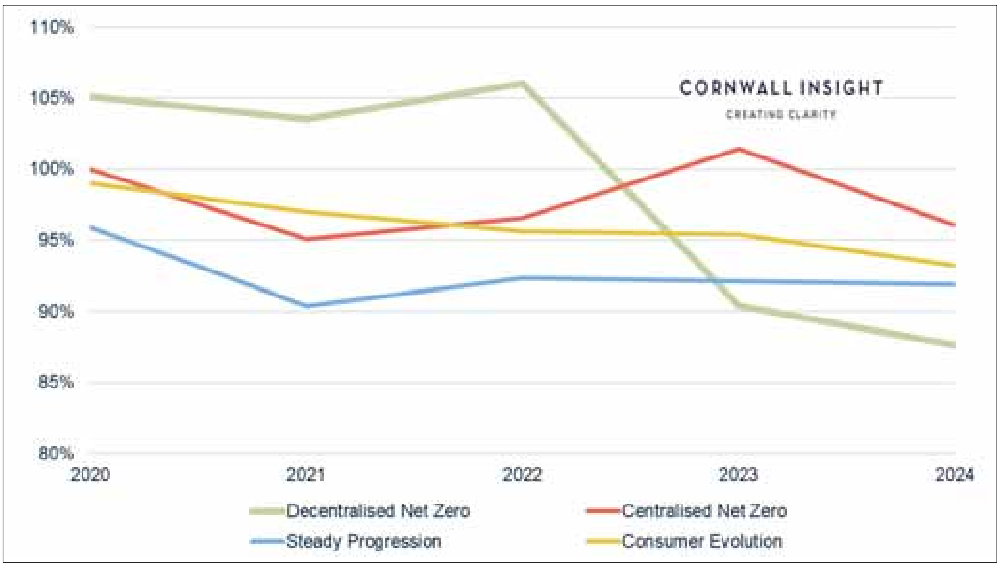


Figure 2. Solar PV captures rates under different Cornwall Insight scenarios – 2020-2024

Should they develop, unsubsidised solar PV projects would need to turn off once prices drop below their operating costs and may have to do so more often than previously expected and when compared to their peers under RO, FiT and CfD schemes.

The impact on future developments could therefore be profound and propose material questions for industry and policy makers alike about the ambitions to deliver the maximum capacity of low carbon generation at the lowest possible cost:

- In a low or low capture wholesale price environment will intermittent renewables be financially viable without subsidy?
- If subsidies or substituting revenues are not available how will these projects be financed? The established project finance model relies on a combination of fixed or floor prices and subsidy to ensure debt can be covered. A volatile market with falling capture rates will likely reduce the level of floor prices. Investing against lower floor prices or increasing reliance on wholesale power revenues would see costs of capital increase
- What will be the effects on the wholesale market and trading behaviours of participants? Our analysis shows a wholesale market with increasing price volatility as the sources of dominant supply switch between 'must-run' subsidised generation and flexible, short-run marginal price-based generation. This creates a high-risk environment with significant implications not just for generators, but for all parties including off-takers, suppliers and end-users and the system operator
- What does the projected level of volatility mean for the point at which different sources of flexibility, particularly battery storage, become economically viable? And in the case of battery storage at what stage can it viably play a role in mitigating cannibalisation effects for intermittent renewable generators, especially solar PV?

Solutions and market response

Fortunately, a number of new business models aiming to provide solutions to these questions have matured over the last two years.

To de-risk against volatile wholesale revenues, many generators have turned towards corporate PPAs (CPPAs), either for grid-connected assets or in direct private wire arrangements. When agreed at the correct price level, these models can provide long-term fixed-price arrangements, which suit the debt-raising project finance model that assets are used to. CPPAs have been signed recently by NextEnergy and Lightsource BP with credit-worthy counterparties such as Anglian Water and ABinBEV for their GB operations. We note through our research that many more CPPAs are in the pipeline.

However, the "queue" of generators is far longer than that of corporates, with our forecasts showing the onshore wind and solar PV pipeline measured in potential GWh is at a 3:1 ratio against credit-worthy corporate volumes that may require a CPPA. Recent and dramatic falls in wholesale prices, driven by the COVID-19 lockdown, have also tempered corporate appetite for a deal where prices are typically over £40/

MWh. Added to this, private wire and behind-the-meter models are having to reconfigure their assessments of revenues in light of large-scale changes to network charging under Ofgem's two Significant Code Reviews, the Targeted Charging Review (TCR) and the Network Access and Forward Looking Charges Review (NAFLC).

As a result, developers have also turned to large off-takers to try and negotiate purely merchant "utility PPAs". With the long-term off-take market in GB as competitive as it has ever been in our latest PPA market research, many developers are seeking to structure long-term floor and fixed-price arrangements to try and de-risk financing of new projects. However, as already noted off-takers are acutely aware of the price cannibalisation risk and heavy discounts or low floor prices are still the norm.

Some developers are going further, trying to make projects more attractive to off-takers and the wider market by reducing cannibalisation risks through co-location. Incorporating volatility into the revenue stack can support projects; perhaps the most striking example is the proposed Cleve Hill Solar Park in Kent, a mammoth 350MW solar park with large-scale battery capacity attached. The aim of this and similar models is to mitigate the risk of cannibalisation through storing excess power in batteries to be exported at times of higher or peak pricing. Added to this are additional revenue opportunities in markets such as the Capacity Market, Balancing Mechanism and Balancing Services contracts.

Hybrid or "power-park" sites for solar PV are also being proposed, typically looking at solar, battery and gas peaking configurations. These again look to access upside in market volatility, and also optimise grid connections to ensure the site's network capacity can be fully utilised. Other developers are using more techno-economic solutions to the problem, such as tracking or bifacial panel technology, which can increase yields and smooth the shape of asset production.

For these examples however, we note that "stacking" all of these revenues together into a bankable model can be difficult with balancing revenues typically very short-term in nature and markets for batteries such as frequency response currently heavily oversubscribed. Technical solutions also have to ensure that cannibalisation protection and greater production rates outweigh additional panel costs.

Finally, and only an option put back on the table recently by BEIS, is the possible re-integration of solar PV and other 'Pot 1' technologies including onshore wind and energy from waste into Allocation Round 4 (AR4) of the CfD scheme. Whilst budget parameters and strike price caps are still yet to be confirmed by BEIS, as is the confidence that procurement will go beyond the AR4 auction proposed for 2021, the opportunity for subsidy-based support may be back on the table for solar PV.

The benefits of the scheme in protecting against price cannibalisation are clear with the 15-year inflation-linked contract and guaranteed price obviously likely to prove attractive to the pipeline of solar PV projects. We note from our pipeline research of planning data that over 1.8GW of solar PV could be eligible and able to bid for a 2021 auction.

A question for bidders would be the strike prices achieved in the auction, with the history of the CfD scheme showing just how low prices can go. Low prices may even deter solar PV bidders, especially against competition from onshore wind, and attention could turn instead towards how other routes to market could offer protection against cannibalisation.

Silver linings

If any solar PV is successful in the next CfD round, the result would highlight the degree of difference in price cannibalisation exposure between the "haves" of those with a CfD and the "have nots" of those without.

Unless government budgets are loosened then there will be a large swathe of renewables development that does not access the CfD. These assets will have to protect against the impact of cannibalisation knowing full well that further deployment of all technologies through the CfD would add to the cannibalisation issue and make the impacts more pronounced for those exposed to the market.

But there could well be a silver lining in the form of electrification of transport and heat in the coming decade. Whilst our modelling shows a downward trend in capture rates out to 2025, under more aggressive scenarios that meet Net Zero an uptick in demand is expected from the middle of the decade as the penetration of electric vehicles (EVs) rises and the electrification of heating grows. The additional volumes and potential flexibility these sources of demand offer could provide an uplift to solar PV assets as technologies such as smart charging and vehicle-to-grid (V2G) charging shift large elements of EV demand from periods of high price to lower price periods. The delivery of Net Zero targets through transport and heat should have positive implications in raising demand, and thus the need for new generation, and in providing greater flexibility on the demand side than currently seen.

The question for solar PV developers building subsidy free will be: when will this trend emerge and how certain can we be that it will create the opportunities, or help mitigate the cannibalisation risks, to support projects. Investment certainty cannot be guaranteed, and relying on smart charging or heating solutions to support renewables generation is certainly a less secure business model than traditional subsidy models.

As the volume of assets, notably offshore wind, under the CfD scheme increases through this decade, we believe wider questions will emerge as to whether the current wholesale market design is fit to support new-build subsidy-free renewables such as solar PV. ■

Author

James Brabben leads Cornwall Insight's wholesale team, which provides research subscription services across renewables, flexibility and commodities markets. He is also active in consulting and research areas covering his specialist knowledge areas of PPAs, renewables policy and green certificates, and regularly speaks on these at industry events. Cornwall Insight provides research, analysis, consulting and training to businesses and stakeholders in the Great British, Irish and Australian energy markets, leveraging a combination of analytical capability, a detailed appreciation of regulation codes and policy frameworks, and a practical understanding of how markets function.

Turn to p.71 for a banker's view on the future of unsubsidised solar post-COVID-19

Post-COVID merchant solar: The financier view of Banco Sabadell

Project finance | José Rojo speaks to Roger Font of Banco Sabadell for his take on the financing landscape for unsubsidised PV projects following the COVID-19 outbreak

For European solar, the onset of the COVID-19 crisis has come to disrupt one particular segment that had dominated some of the most recent industry spotlight.

In conferences and one-on-one interviews last year, the talk was of the success story of subsidy-free solar; the triumph of PPA- and merchant-based developments precisely in those countries – Spain, Italy – where deployment had been brought to a halt by swings of subsidy policies.

Fast forward to spring 2020, and the picture has muddled. The nosediving of power prices brought about by quarantining measures has crippled the business case of merchant solar ventures. Spanish solar operators have come forward to warn that the funding taps will dry, as banks tighten their terms and conditions before they support a solar venture relying on direct sales to market.

Will the headwinds derail Europe's merchant solar shift or will it prove a temporary pause? *PV Tech Power* put the question to Roger Font, Banco Sabadell's global head of project finance, asset and specialised lending. Recently interviewed, he walked this publication through Sabadell's approach with solar lending so far and plans around merchant deals this year.

PV Tech Power: Could you explain to our readers Banco Sabadell's vetting process and rationale when it comes to granting loans to renewable projects?

Roger Font: As a bank, our advantage is we've got a very structured financing framework. Based on the project type, the framework applies different criteria to the loan terms, the ratios, the structuring, the leverage level and so forth, so it's all very clear. The other difference is we've got solid knowledge of the market in Spain and abroad, which means we can go for smaller but also bigger projects. There'll be ventures of 30MW but also 400MW, where we'll go alongside other banks.

Thanks to this knowledge, when a sponsor comes forward, we either already know them or we can review them like any other firm: the shareholders, the management team and so forth. Then there is technical due diligence into aspects such as generation parameters, EPC costs and others. When we insert these parameters into our framework it soon becomes very clear what we can and can't provide and, based on that, we can make our offer.

How many renewable deals did you finance in 2019 and do you expect the flow to slow down following this year's COVID-19 outbreak?

Last year we financed 2.3GW across 32 renewable transactions, split between 23 greenfield projects and nine brownfield projects. Of the 23 greenfield projects, nine were auction-backed renewables – five with PPA, four without – and 13 went down the merchant route. Of the 2.3GW total we financed last year, 60% was solar capacity and 37% wind power.

COVID-19 has muddied the waters for subsidy-free solar projects such as Iberdrola's 500MW Núñez de Balboa in Spain

All in all, last year we provided more than €800 million through these 32 renewable transactions. Given that some were syndicated, these deals represented a higher €1.8 billion. As for 2020, the number of overall projects we fund will likely not be the same given COVID-19 but the financing model we're striving for will be largely similar. Regarding categories, only 300MW of the 2.3GW last year were pure merchant. The merchant volumes we finance in 2020 are obviously going to be higher than last year's 300MW but as for the exact share – it's tricky to say at this point.

Even before the pandemic, some in Europe feared a cannibalisation bubble could be forming. Now that power prices have plunged, what are merchant's solar prospects?

[At Banco Sabadell] our belief is that the sponsors who are carrying out merchant renewable projects have a very high level of sophistication and market knowledge, they have access to all the different information sources so we feel quite reassured on that front. Regarding the talk of a bubble, we don't think in those terms. I see many projects are currently underway, either merchant- or PPA-based, and the present drop in power prices is the specific result of low oil prices and the drop in demand that will eventually bounce back.

What are Banco Sabadell's expectations in terms of European power prices, both currently and the upcoming recovery?

In our case and the other banks more generally, we are working under scenario assumptions that there won't be a return to power prices of €50/MWh, in part because of the installed renewable capacity that we see today. Instead, we think we'll be looking at prices of around €40/MWh in the medium to long term. Next year, we're not thinking of €50/MWh but €45/MWh prices.

However, it's important to understand the role of sponsors versus the role of banks. Their play is an equity play whereas what we seek are returns through the supplying of debt. We're not

pretending to have a forecasting vision or to know more than market consultants – the prices I mentioned are the base we're working under and with which we feel comfortable.

Some of the analysts we talked to say that if power prices do not recover, merchant projects might have to be shelved in the near term. Will activity freeze in places like Spain?
We're not that worried about the long term. I think there are going to be several merchant deals in Spain this year, and when I say several, I don't mean just two or three. Again – the sponsors we see in the merchant segment are among the most sophisticated we see in the global scene and they have a high equity capacity, which is necessary as merchant players tend to get less debt. If you tick those two boxes, then you realise these sponsors are first rate.

> "Good merchant projects, featuring the right amount of financing and the appropriate structures, will continue to be funded"

Some on the developer side have warned banks could be closing the merchant solar funding taps. Are financing terms becoming tighter as power prices fall?
I can't say we are seeing [this talk of] taps being closed. Good merchant projects, featuring the right amount of financing and the appropriate structures, will continue to be funded. In general terms, the structuring choices of loans haven't changed. Obviously, any alterations to the price curve that forms the base of our assumptions will impact on the volume of debt being supplied. And it's also true that there have been increases to the banks' own funding rates, whose cost is affected by the risk premium of Spain itself.

What is happening, and this is my personal opinion, is that what we do see is many sponsors who were perhaps considering a PPA play – they either turn to merchant or they opt to delay because of the uncertainty around the falling PPA prices. They're likely waiting to see how PPA prices reposition themselves when the market stabilises again.

Might shorter-term PPAs be the answer for solar developers looking to underpin revenues for just a few years, while the economic shock subsides?
In terms of financing share, a very short-term PPA does not result in more debt being provided to a project than under a merchant model. You do see a difference with, say, a 10-year PPA – that's where you would grant the solar project more debt. The numbers are what they are – the longer the better. We have seen some developers seeking PPA cover for two or three years but they are very few. With the projects we're currently studying, we're beginning to note some are going for five-year PPAs, but again it's not that frequent.

Since the COVID-19 pandemic emerged, has Banco Sabadell been approached by merchant renewable developers seeking funding?
Several have, yes. We actually signed three renewable funding deals in the post-pandemic weeks, a brownfield transaction and two merchant transactions. There's been some delay on the licensing front but we're continuing to work on it and we hope to sign these deals and others still. I'm hoping to conclude several transactions before the summer, with and without PPA.

Are there any differences in the profile of the merchant solar projects currently coming forward with financing requests?
There haven't been any changes with COVID-19. I think all sponsors that had secured authorisation for certain megawatts are pressing on, they have tried to speed up as much as possible with the capacity they had requested. What I'm hearing as well is that [Spain's] administration has not shut down, they're still working on licensing, which is very positive. It's true there has been a bit of a standstill given the volume of delays with licensing, but these projects are now in a position where they're about to be financed. We do see larger projects than last year, but it's similar in general terms.

Whether the pandemic ends up disrupting merchant solar in a meaningful way, the segment's reliance on power price forecasts will stay in place. How reliable is the data banks access?
In January, [Banco Sabadell] carried out a review of the various analysts. We spoke to some and examined the power price curves offered by each. The picture was different across each data provider – some prioritised supply and put much stock on the role of new generation, while others also thought it important to factor in the demand, the possible increases from new technologies such as electric vehicles, hydrogen and the electrification of power-intensive infrastructure such as data centres. With these different versions, what a bank can do is to look at the trends, if not at the exact numbers. And if you look at the various consultancies, it is possible to draw some trends across all the different reports. What we do as banks is to end up in a position where we're comfortable around these trends and form our own opinion around the base case and the power price curve. ■

Presented to you by:

STORAGE & SMART POWER

Introduction

Welcome to another edition of 'Storage & Smart Power', brought to you by Energy-Storage.news.

The previous volume of the journal was published just in time for it to become clear the COVID-19 pandemic was unlike anything most of us had faced in our lives before. We usually talk about disruption in our industry in a positive light, but the disruption the virus has caused has been anything but that for most people, whether through its impact on their own or loved ones' health, or as a result of the worsening economic situation.

Despite this, the energy transition continues. It's a sign that energy storage has really 'arrived' that battery projects have been ruled to be essential and critical infrastructure, and work carries on. In Germany and Italy as the lockdown begins to end, battery and energy storage system manufacturing has been allowed to re-start. And there are signs that the EU, Australia and even the US are starting to see support for renewable and cleaner energy industries enabling the green shoots of recovery.

Perhaps we should leave the last word on this to one of this quarter's guest writers, Power Ledger's executive chairman and co-founder, Dr Jemma Green:

"The great pause that has affected all of our lives has shown us what is important – the health of our families, our communities and the environment we live in. After the First World War, the old power structures of the world shifted as women entered the workforce, class differences became blurred and new technologies like radio, mass flight and industrial chemistry utterly transformed the world's economies and culture.

"In many ways, COVID-19 presents us with a similar set of circumstances. We will look to become more interconnected with our local communities and embrace technology that helps the environment. My hope is that the challenges faced by the renewables sector in the coming years will not be how to grow, but how to keep up with the demand for growth."

In the following pages, you can read about how Power Ledger is taking the technology of blockchain to the distributed energy space, enabling peer-to-peer trading of solar energy and power stored in batteries among communities and across the grid. That article is a double-bill feature along with another explaining the growing and vital role of artificial intelligence in the solar-plus-storage space, from distributed energy platform provider AutoGrid's Rahul Kar.

We're also really excited to bring you the second part of a deep dive into flow batteries, from the CENELEST joint international research centre formed by Fraunhofer Institute for Chemical Technology (ICT) and the University of New South Wales (UNSW). Authors including UNSW's Maria Skyllas-Kazacos – who actually invented the vanadium redox flow battery (VRFB) – talk us through the potential of VRFBs in the energy transition.

Finally, let's not leave out the lithium! I've spoken in-depth with senior representatives of two energy storage system manufacturer/integrators: Powin Energy and the Sungrow-Samsung SDI joint venture. Responsible for hundreds of megawatts and megawatt-hours of deployed lithium-ion battery energy storage between them, we were lucky to get some deep insight into what makes the systems tick, not just on a technical level but in terms of customers' demands.

We thank all of you for your continued support as you face today's challenges head-on, whatever they may be.

Andy Colthorpe
Solar Media

Hydrogen electrolysis using renewable energy begins at 10MW Fukushima plant

What is thought to be the world's largest 'single-stack' green hydrogen electrolyser, a 10MW project in Fukushima, Japan, began operations on schedule in April.

The demonstration project has been put into action by the Japanese government's New Energy and Industrial Technology Development Organisation (NEDO) as well as industrial gases company Iwatani Corporation and Tohoku Electric Power, one of Japan's 10 main regional utility companies. Toshiba Energy Systems & Solutions Corporation (Toshiba ESS) hired Asahi Kasei to deliver the electrolysed system.

The new 10MW system uses surplus renewable power from solar and wind power plants to drive a process called chlor-alkali electrolysis, commonly used in production of industrial chemicals including chlorine, to make so-called 'green' hydrogen.

Credit: Asahi Kasei

Alkaline-water electrolysis system by Asahi Kasei at the FH2R project in Fukushima, Japan

Italy grid operator TERNA to pilot 230MW grid-balancing opportunity

TERNA, operator of Italy's electricity transmission system, is to launch a pilot scheme in which up to 230MW of aggregated nominal capacity including energy storage could supply frequency and voltage services to the grid.

The grid operator opened a consultation period for stakeholders on the roll-out of up to 230MW of Fast Reserve Unit (FRU) pilot projects. The stakeholder comment period closed on 24 January.

Traditionally, thermal generation plants have provided all-important grid-balancing services such as reduction of regulating power needed to keep frequency and voltage "within defined security limits", TERNA said.

The growth in variable renewable energy sources on the grid means that the need for these services increases, while reducing the number of mostly fossil fuel-powered generators that have provided them in the past. Italy's National Energy and Climate Plan (NECP) foresees an increase of renewable energy capacity on the grid to 40GW by 2030.

CATL batteries energise Powin's new 'long duration, long life' Li-Ion systems

Powin Energy has launched a set of three battery storage system products using CATL's large form factor lithium-ion cells, including a system solution capable of 4+ hour duration and backed by a 20-year warranty.

The new products, branded Stack 225, Stack 230 and Stack 230P are system manufacturer Powin's first to utilise Contemporary Amperex Technology Limited – to give China-headquartered CATL its full monicker – battery cells combined with Powin's battery management and controls software, StackOS.

Powin said that the three products perform a wide variety of applications for the main industry segments of front-of-meter, behind-the-meter and micro- or off-grid energy storage. CATL is one of the few large vendors in the world to manufacture large volumes of lithium iron phosphate (LFP) battery cells.

Q CELLS promises households '100% eco-friendly electricity'

Q CELLS has officially launched a home solution that promises a "100% sustainable power supply," through combining solar and battery storage to meet the majority of demand and a digital cloud solution to cover the rest.

Now available in Germany and expected to be "shortly" rolled out into other markets, the Q CELLS Q.HOME Cloud can either be added to new solar PV systems or retrofitted to existing systems. Customers can use the Cloud to connect to renewable energy generation in Germany and Austria and use it to source the remaining portion of energy that their solar-plus-battery system is unable to provide.

The company says it adjusts the available and expected quota of energy to meet the size and location installation of each solar system and storage unit, claiming in a release sent today that "every customer receives a tailor-made, transparent and fair cloud solution".

California utility awards 770MW of battery contracts to help replace ageing natural gas plants

Contracts have been awarded to 770MW of battery energy storage project proposals by Southern California Edison (SCE), one of the US state of California's three major investor-owned utilities (IOUs).

The projects will help solve reliability issues anticipated to impact on the California grid when a number of ageing natural gas power plants reach their retirement, as well as helping to integrate larger shares of renewable energy that in turn will help replace those gas plants.

The projects, which came through a competitive bidding process, still require approval by the California Public Utilities Commission. The largest is the 230MW McCoy project for developer NextEra Energy Resources, the smallest the 50MW Sanborn project by TerraGen Power.

BloombergNEF: 'Already cheaper to install new-build battery storage than peaking plants'

The levelised cost of electricity (LCOE) that can be achieved today for battery energy storage means that "new-build batteries can be competitive on cost with gas peaker plants," according to BloombergNEF.

New-build utility-scale solar and onshore wind are the cheapest options in much of the world, putting existing coal and gas power plants at risk, with BloombergNEF assessing 25 different technologies and 7,000 projects in 47 countries.

The LCOE of battery storage systems meanwhile has halved in just two years, to a benchmark of US$150 per MWh for four-hour duration projects. In an interview, BloombergNEF analyst Tifenn Brandily, the report's lead author, told Energy-Storage.news that below two-hours duration, batteries are already cheaper for peak shaving than open cycle gas turbines (OCGT), traditionally the go-to technology for that purpose.

Understanding vanadium redox flow batteries

Battery technology | In the second of a two-part series for this journal, Jens Noack, Nataliya Roznyatovskaya, Chris Menictas and Maria Skyllas-Kazacos from CENELEST, a joint research venture between the Fraunhofer Institute for Chemical Technology and the University of New South Wales, examine the potential of vanadium redox flow batteries in the future energy system

With the increasing amount of renewable energies in an electrical grid, the need for compensation requirements increases in order to avoid shortfalls in coverage. Amongst the possible technologies available are electrochemical energy storage systems such as batteries, redox flow batteries (RFBs) and combinations of fuel cells and electrolysers [1]. RFBs differ from the other two technologies in that the energy is stored in liquid media and offer the possibility of charging and discharging in the same cell. This allows energy conversion and storage to be scaled separately and flexibly, adapted to the respective application, which in turn creates potential economic advantages over other technologies. Like all other electrochemical energy storage devices, RFBs can be realised in a wide range of size classes. Typical sizes range from a few hundred watts and watt hours of power and energy respectively, to systems with several megawatts and megawatt hours as large storage devices for grid tasks.

In principle, RFBs can be used for all stationary energy storage tasks, although storage times of several hours cause the lowest normalised energy storage costs [2,3]. To date, an almost unmanageable number of different types of RFB have been investigated [4,5]. However, the best-known representative is the vanadium redox flow battery (VRFB). VRFBs have potentially extremely high cycle lifetimes and are constructed with simple and inexpensive materials. This results in potentially low storage costs when used as safe and sustainable stationary energy storage devices in grids with renewable energy sources.

Compared to other storage technologies VRFBs have many advantages:

- High safety (non-flammable and no thermal runaway)

Figure 1. Kilowatt-class vanadium oxygen fuel cell system

- Long service life and cycle life
- Separate scalability of power and energy
- Modular design
- No use of materials from politically unstable areas
- Easy recyclability

Today's classical VRFB was developed in the 1980s at the University of New South Wales in Australia by Professor Maria Skyllas-Kazacos and her group and has been continuously improved until today [6]. Often several generations can be distinguished, whereby the energy density in particular, but also many other characteristics, differ from each other:

- Gen1: V/V-RFB (30 watt hours per litre)
- Gen2: V/Br-RFB (50-70 Wh/L)
- Gen3: V/V-RFB with mixed acids (~47 Wh/L)
- Gen4: V/O2- RFB or Vanadium/Oxygen fuel cell VOFC (~150 Wh/L)

Due to the relative simplicity of construction and operation, low cost and high safety, the VRFB (Gen1) is still the most studied and installed type of redox flow battery.

General principles of operation of VRFBs

The most important components of VRFBs are the energy converter, i.e. an electrochemical cell or cell stack formed from multiple cells, the energy storage medium (often referred to as the electrolyte), the fluidic system, the heat management and control system and the regulation technology for the interaction of all components. In the classical VRFB, the electrolyte consists of dissolved vanadium sulfates in sulfuric acid and a small amount of phosphoric acid that is used to increase the thermal stability of the charged positive half-cell electrolyte [7].

During operation, the two half-cell electrolytes are continuously pumped through the electrochemical cell, whereby the actual energy conversion reactions take place at the electrodes as oxidation and reduction reactions of the vanadium ions. The electrode is the phase boundary between the electronic and ionic conductor. At the positive electrode, tetravalent vanadium ions (V^{4+}) are oxidised to pentavalent vanadium ions (V^{5+}) during the charging process [8] [1]. During this process, an electron at the positive electrode is moved from a tetravalent vanadium ion via an electronic conductor to the negative

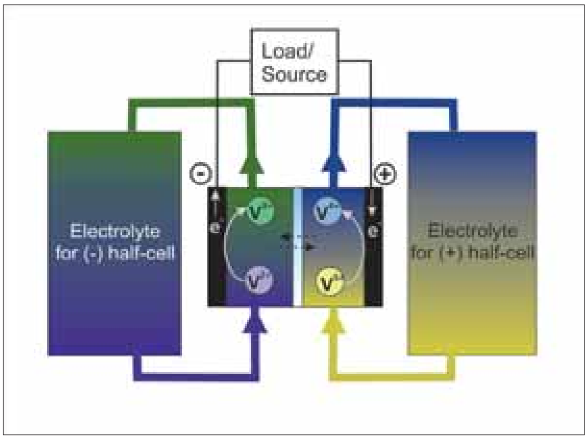


Figure 2. Schematics of vanadium redox flow batteries

electrode, using energy, and a trivalent vanadium ion (V^{3+}) is reduced by the electron to a divalent vanadium ion (V^{2+}):

Positive electrode:

$$V^{4+} \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} V^{5+} + e^-$$

$$\varphi^{0,+}_{VO_2^+/VO^{2+}} = +0.999V$$

Negative electrode:

$$V^{3+} + e^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} V^{2+}$$

$$\varphi^{0,-} = -0.255V$$

Cell reaction:

$$V^{4+} + V^{3+} \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} V^{5+} + V^{2+}$$

$$U^0 = \Delta\varphi^0 = 1.254V$$

The discharging process is reversed accordingly under energy release. The achievable voltage of a cell is determined by the potentials (φ) of the reactions of the half cells of the positive and negative electrodes. Basically, the open circuit voltage of a cell is the difference between the positive and negative half-cell potentials plus a membrane potential:

$$U_{cell} = \varphi^+ - \varphi^- + \varphi_{membrane}$$

The potentials depend on various factors such as concentration (correlated with the state of charge – SOC), temperature, type of redox pair (standard potential) and, in the case of current flow, the speed of the reactions. The cell voltage during operation can be described in a simplified way as the open circuit voltage minus (discharging) or plus (charging) further voltage losses due to ohmic losses, speed of the reactions and mass transport losses:

$$U_{cell} = U_{OCV} \pm U_{losses}$$
$$= \varphi^+(c,T) - \varphi^-(c,T) + \varphi_{membrane}(c,T) \pm [IR_{ohmic}(T) + IR_{reaction}(c,T) + IR_{mass\ transfer}(c,T)]$$

All factors are at least dependent on the concentration of the substances involved in the reaction, resulting in the typical non-linear charge and discharge curves of batteries. For VRFBs, this means that the open circuit voltage of a fully charged cell is approximately 1.6 V and 0.8 V in the discharged state. The speed of the charging and discharging process depends directly on the current. However, there are always limits for batteries, which for various reasons must not be exceeded. With VRFBs, as with all batteries based on aqueous electrolytes, the charging voltage is limited by the electrochemical stability of water. Depending on the electrode material and the pH value, water decomposes into hydrogen and oxygen at certain potentials. At platinum electrodes (standard potentials) the difference between the potentials is 1.23 V. Apart from the costs, it would therefore not be possible to charge a VRFB with such electrodes even half full with a reasonable efficiency, since more and more hydrogen and oxygen would be produced during the charging process. Unfortunately, other metals have similar properties or even react, so that the electrodes of VRFBs are made of carbon-based materials. This increases the stability range of water, called the voltage window, to about 1.7-1.9 V and results in an upper voltage limit of approximately 1.65 V for VRFBs. Exceeding this limit, e.g. by excessive electric current, first leads to an intercalation of ions in the electrode material of the positive electrode and finally to the formation of highly reactive oxygen, which in turn reacts with the carbon electrode material to form carbon dioxide. Both effects lead to an irreversible increase of the internal resistance and thus to a loss of performance due to this ageing effect. At the negative electrode, however, an additional hydrogen formation takes place. As at the positive electrode, the speed of this side reaction depends exponentially on the magnitude of the voltage. At high charging rates, the voltage of a fully charged VRFB is very close to this limit, so the state of charge of commercial systems is usually limited to approximately 80% of the theoretical maximum capacity to reduce gassing side reactions and increase the lifetime of the VRFB. Higher states of charge can however be attained by utilising constant current – constant voltage charging profiles as used in other types of batteries.

As mentioned above, the VRFB requires some kind of membrane or separator to prevent the mixing of the two half-cell electrolytes [9,10]. If this would not be the case, V^{5+} would chemically react directly with V^{2+} to form V^{4+} and V^{3+}, releasing heat. The membrane provides a physical barrier to prevent mixing, but it must allow ions to migrate and complete the circuit. Since electrons migrate from one half cell to the other via the external circuit during charging and discharging, the resulting charge imbalances must be compen-

Figure 3. Vanadium redox flow laboratory test cell setup

<?> The tetra- and pentavalent vanadium ions are actually more complex compounds. Often they are given as vanadyl (VO^{2+}) or divanadyl cations (VO_2^+), but this again is a simplification of reality and the actual conditions are much more complex and the subject of research. For better comprehensibility V^{4+} and V^{5+} are used here.

sated for by ion migration through the separator to maintain electroneutrality. This balance is usually achieved by the migration of positively charged protons H^+ (actually hydronium ions - H_3O^+) in the acid electrolyte through the separator. The separator must have the highest possible conductivity for the balancing ions and a high barrier effect (high selectivity) for all other ions and molecules (water). The conduction of ions through the separator can become a speed-determining factor. In practice, however, it is usually a cost factor, since the separators used can be relatively expensive. In principle, all known types of separators can be used, including ion exchange membranes, microporous separators and solid ceramic ion conductors. For research purposes, mostly ion exchange membranes are used which have a high selectivity and relatively high costs. Microporous separators are porous polymer films which are much cheaper but have a low selectivity. Microporous separators are standard for lithium-ion batteries, but their use in the VRFB is complicated by the flowing and much lower viscosity electrolyte. Although coulombic efficiencies as high as 99% have been reported for VRFBs employing several types of ion exchange membranes, for other separators, the low viscosity leads to a higher diffusion of all substances, thus to a lower selectivity and to losses due to direct reaction of V^{5+} and V^{2+}, which results in higher efficiency losses as well as higher self-discharge.

Pressure differences of the flowing media can also lead to a direct transfer of electrolyte across the separator, causing further energy efficiency losses. Another important effect regarding the use of membranes and separators that must be considered is a continuous change in the volume of the two electrolyte solutions with cycle number. In the case of cation exchange membranes, the bulk electrolyte transfer is from negative to positive, while for anion exchange membranes, the net transfer is from positive to negative. This increases the volume of one electrolyte by reducing the other. There are several factors that affect this transfer, including osmotic pressure effects resulting from the different ionic strength of the two half-cell solutions. Another reason is that water molecules are transported across the membrane around the equalising hydrogen ions (hydrate shell) which is asymmetrical. If no countermeasures are taken, this effect will result in a continuous loss of capacity. In the case of the VRFBs however, this can readily be reversed by volume compensation. In practice, the volume of the two electrolytes is rebalanced by pumping electrolyte solution from one tank to the other by the battery management system (BMS) [11]. This is only possible because the same elements are used in both half-cells of the VRFB. This would not be possible if different elements were used.

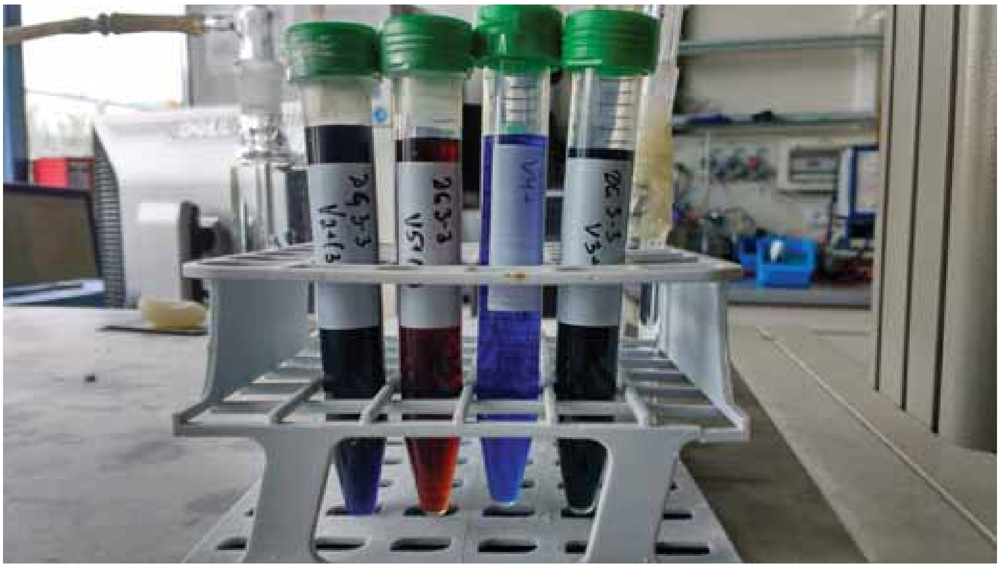


Figure 4. Vanadium electrolyte samples

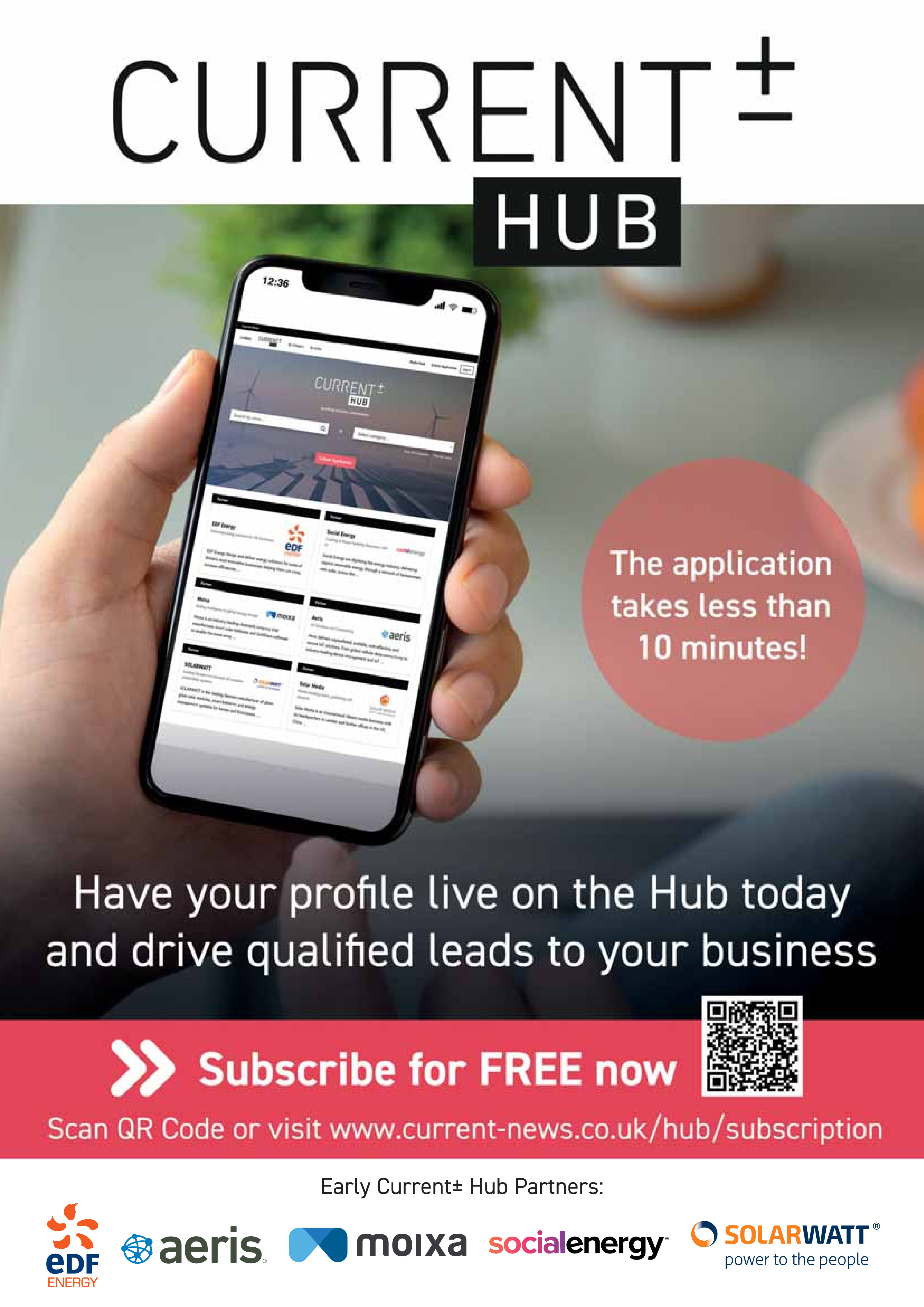
Despite their poor performance to date, non-ionic separators continue to be investigated in an effort to reduce the costs of VRFBs. Suitable separators must be chemically stable, highly conductive to protons and with low permeability to the four vanadium ions. In parallel however, continuing cost reduction is being achieved in the production of highly stable ion exchange membranes. This is being made possible by the increased production volumes that are being achieved with the recent installation of MW-scale VRFB systems around the world.

Electrolyte raw material

Two electrolyte solutions are required for the operation of VRFBs: an acidic electrolyte solution containing the V(IV)/V(V) couple in the positive half cell and an acidic V(II)/V(III) electrolyte in the negative half cell. Both electrolytes are continuously pumped through their own half cells during charging and discharging. However, only a single electrolyte comprising a 50:50 mixture of V(III) and V(IV) is used as the starting solution in both half-cells, which in the classic VRFB contains a total vanadium concentration of approximately 1.6 M, 4 M total sulphate and additionally approximately 0.05 M phosphoric acid [12].

Vanadium oxide is used as a raw material and is dissolved in sulphuric acid supporting electrolyte to produce an equimolar amount of 0.8 M V^{3+} and 0.8 M V^{4+} as sulfate salts, although total vanadium concentrations up to 2 M are also used in special situations. The electrolyte solution containing the equimolar mixture of V^{3+} and V^{4+} is usually called $V^{3.5+}$ solution. An equal amount of this $V^{3.5+}$ electrolyte is used in both half cells at the beginning of the first charging process. In the first charging process, V^{3+} reacts first to V^{4+} on the positive electrode and V^{4+} to V^{3+} on the negative electrode. This produces a state of charge SOC=0 at a voltage of approx. 0.8 V. A second charging step converts V^{4+} to V^{5+} in the positive half-cell electrolyte and V^{3+} to V^{2+} in the negative. It is also important to note that due to the extremely slow reaction from V^{3+} to V^{4+}, a VRFB can only be electrically discharged up to a state of charge of SOC=0. Even a short circuit does not cause further discharge and a battery system would always be under high voltages, similar to lithium-ion batteries (maintenance problem). With VRFB, however, this problem can be bypassed simply

Figure 5. Discharged non-flow vanadium redox flow battery laboratory cell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by mixing both electrolyte solutions. The cell voltage drops quickly to 0 V and allows safe work on VRFB components.

Cells and stack

The electrochemical cell is the core component of a VRFB system. A cell has a voltage range of 0.8-1.6 V depending on the SOC as described above. To increase the voltage, multiple cells are connected electrically in series and hydraulically in parallel in a cell stack [14,15]. Typical voltages of stacks are approximately 24-70 V, although larger 100-cell stacks with much higher voltages have been produced. A high voltage is desirable due to lower power electronics costs, but the number of cells in a stack is limited by unwanted shunt currents.

The cells of VRFBs are symmetrically designed and consist of two half cells separated by a separator. Due to the similar reactions, the same materials can be used in both half cells. There are two fundamentally different cell design concepts: porous felt electrode based half cells and cells with structured bipolar plates [16]. The typical design is based on felt electrodes. Cells with structured bipolar plates are much more complex and can be designed as flow-by or flow-through design, as in fuel cells. Cells with structured bipolar plates incorporate very thin carbon paper electrode materials and a so-called "zero-gap' configuration that allows significantly higher power densities, but may have higher costs. In the classic felt-based flow-through design, both electrolytes flow through carbon-based graphite felts several millimeters (typically 2-4 mm) thick, which serve as the electrodes. The graphite felt is embedded in a flow-through frame which in turn distributes the electrolyte within the cell and stack. Graphite-based plates (bipolar plates) are used to hydraulically seal the individual cells tightly while simultaneously providing electrical conductivity between adjacent cells. Typical operating current densities of a cell cover a wide range and can reach average values between 50-150 mA/cm^2, although the maximum current can be considerably higher in the case of high-power density cell designs. A stack with an electrode area of 1,000 cm^2 per half cell and 25 cells can thus achieve a power output of between 1.25-3.75 kW at an average cell voltage of 1.0 V during discharge in conventional cell designs. Power densities of 5 kW/m^2 have however been reported for high power density cell designs [14].

Figure 6. Control room of a 2 MW/20 MWh vanadium redox flow battery at Fraunhofer ICT

System

The special features of VRFBs require a process technology similar to that of fuel cells for safe and long-term operation, but much less complex. In a VRFB system at least one or more stacks are first electrically connected in parallel and/or serially to achieve the voltage and current values required for the power electronics. As with the stacks themselves, however, there are voltage limits due to shunt currents [17]. The shunt currents are also created here by the parallel hydraulic paths through the individual stacks fed from common electrolyte tanks. In practice, the influence of shunt currents can be minimised simply by using multiple tanks and pumps and as many inverters as possible. Ideally, each individual stack should have its own tanks and inverter, but this may not be cost effective.

The amount of electrolyte solution determines the amount of energy in the battery. One litre of a 1.6 M vanadium electrolyte solution has a theoretical maximum capacity of 21.6 Ah. At an open circuit voltage of 1.4 V, this results in a maximum energy content of 30 Wh/L. It should be noted, however, that this quantity corresponds to 0.5 L electrolyte for both negative and positive half cell. In reality, the dischargeable energy content is lower due to the factors mentioned previously. These include, in particular, the current density dependent efficiency of the discharge process, the temperature and the limitation of the charge state range.

Figure 7. Two kilowatt-class vanadium redox flow battery test systems

The two electrolytes are stored in tanks and are pumped in parallel through each individual cell of the system. The energy loss due to pumping the electrolyte is about 5% and can be optimised by modularisation. This can be achieved by building the entire system with a number of identical modules and using different numbers depending on the power requirements. Another possibility is the sole modularisation of pumps to operate the pumps at maximum efficiency at partial load. A further necessity is the regulation of the volume flow with the change of current and state of charge. During discharge at high SOC the flow rate requirement is lowest and increases exponentially with decreasing SOC due to decreasing concentration of the active species in solution and the mass transport requirements at the electrode. Considerable work is currently being carried out on intelligent flow controllers that continually adjust the flow rate to minimise the parasitic pumping energy losses and maximum overall energy efficiencies of flow batteries.

Due to the corrosive nature of the acidic V(V) electrolyte in the positive half-cell and possible side reactions, all parts of a VRFB system in contact with the medium must be designed free of metal. For this reason, polymers such as polypropylene (PP) or polyvinyl chloride (PVC) are used as materials for cell frames, pipelines, tanks and all other parts in contact with the medium. The two electrolytes must be protected against oxidation by atmospheric oxygen. V^{2+} ions in particular react strongly with the oxygen in the air, resulting in a loss of capacity. The negative electrolyte tank is usually sealed from the atmosphere and is often de-oxigenated and covered with protective nitrogen gas layer over the electrolytes in the tanks. The use of a protective layer comprising an inert oil such as paraffin has also been proposed as a blanket to prevent air oxidation in the negative half-cell electrolyte tank.

Air oxidation is one process that leads to an imbalance in the half-cell SOCs that causes capacity loss, so this needs to be avoided. There are processes that allow electrolytes oxidised by atmospheric oxygen to be regenerated and thus restore the original capacity however. For example, the reaction can be reversed electrochemically using electric current and oxygen is released again [18]. Chemical regeneration can also be used to restore capacity losses caused by these side reactions.

Figure 8. Piping and stacks of a 2 MW/20 MWh vanadium redox flow battery at Fraunhofer ICT

As with all large-scale processes a good battery management system also requires a certain number of sensors and actuators for efficient monitoring and operation. These include flow and pressure sensors, temperature sensors and an open circuit voltage sensor. The open circuit voltage sensor is a special feature for RFB systems (not for hybrid systems!) that allows the SOC to be determined at any time and especially with current flow. The open circuit voltage sensor is often a separate single and smaller cell as used in stacks. The flow sensors are necessary for the regulation of the pumps and thus for the increase of the efficiency of the VRFB system. Pressure sensors can be installed for safety reasons to detect possible pressure overruns. However, passive fuses can also be installed as a form of pressure relief.

The temperature sensors are necessary to detect temperature minima and maxima and where necessary to perform active thermal management. The vanadium solution used in VRFBs is highly concentrated to achieve the highest possible energy content and the vanadium salts are at the limit of solubility at the supplier specified maximum and minimum operating temperatures. The thermal stability of V^{5+} determines the upper temperature limit of VRFBs by a reaction which leads to an irreversible precipitation of solid vanadium oxide depending on V^{5+} concentration, temperature and time. For this reason, the maximum temperature in the electrolyte is limited to 40°C for a 1.6 M vanadium electrolyte. Thus, only a range at high states of charge at high temperatures becomes critical, which is why the storage of partially discharged or discharged batteries at high ambient temperatures is no problem. Normally the heat generated from the electrolyte is dissipated by electrolyte-air heat exchangers.

Safety

VRFBs are a relatively safe technology. Due to the use of aqueous electrolytes, the fire risk of VRFB systems is much lower than with other technologies. Overcharging the battery does not lead to fire but to a reduction in battery performance and ageing of the stacks. Thermal runaway as with lithium-ion batteries is excluded. Precisely because of ageing, the voltage is continuously monitored as with all other battery systems. A deep discharge is possible, and this even increases safety by the resulting cell voltage of 0 V.

In addition to its corrosive character, vanadium electrolyte solution is classified as toxic and hazardous to ground water. However, it should be noted that the electrolyte is used in a closed system and vanadium can escape solely through electrolyte leaks. For this reason, VRFBs have a secondary containment to prevent the escape of vanadium solution into the environment.

In spite of the measures described above, there will always be a small amount of hydrogen produced during charging at high states of charge, which is a safety risk due to the possible explosive reaction with atmospheric oxygen. The amount is extremely small, but must be taken into account when installing the battery. For this purpose, the gas is discharged from the negative tank into the environment through a simple pipe and the battery room or container is well ventilated and flushed with fresh air to prevent any build-up of hydrogen gas.

Recycling

Unlike other compact battery types such as lithium-ion batteries, VRFBs are relatively easy to recycle by common methods. The battery system components can be divided into electronics, fluid technology, stacks and electrolyte, with the last two components being the only ones that require analysis. Stacks ultimately consist solely of steel, copper, plastics and carbon. Stacks can be disassembled into their individual components and almost all components can be returned to the material cycle. For membranes and gaskets as well as carbon-based materials such as electrodes and bipolar plates, thermal recycling is necessary, but is energetically positive. Recycling of electrolyte can take place in two ways: as starting material for metallurgy or as recycled electrolyte for VRFBs. Used vanadium electrolyte ultimately represents a highly concentrated source of vanadium. The vanadium price has a low of approximately US$10/kg today at the beginning of 2020. Nevertheless, because of the high concentration, the material value of the electrolyte is still high after the battery has reached the end of its life. As with lead-acid batteries, the material value of vanadium can be taken into account in the running costs. Leasing models for vanadium electrolyte already exist.

Costs

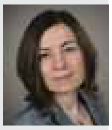
In general, the comparison of battery systems should not be based on investment costs, but rather on the energy-specific lifetime costs for the respective application (levelised cost of storage – LCOS). LCOS takes into account the physical and economic characteristics of battery systems, which makes clear differences between different technologies. Even better, however, is the consideration of the levelised cost of energy (LCOE) for the entire energy grid in which the battery is to be integrated. Depending on the application and the amount of renewable sources, the entire grid must be adapted to the requirements of the consumers and the potential for generation. Therefore, simulation programs must be used for the design in order to achieve the lowest possible LCOE. This leads, for example, to such constellations in which a grid with a low-efficiency energy storage system achieves lower LCOE than a battery with a high efficiency. The cost of efficiency losses can be compensated by a higher share of low-cost PV generation if the storage system also offers other advantages. Turnkey VRFBs today have an investment cost of less than US$700/kWh for a 20-year life.

Summary

VRFBs have progressed beyond the prototype and demonstration stage in recent years. Due to the extremely high vanadium price in 2018, commercialisation efforts of VRFBs were severely curbed but are currently experiencing a renewed upswing. Today, more and more systems in the megawatt hour range are being installed worldwide, as are smaller container-based VRFBs. The largest system with 200 MW and 800 MWh is currently under construction in China. In Australia, several plants with a total of over 200 MWh are being planned. Alongside lithium-ion batteries, they are now one of the most important stationary energy storage technologies, especially for grids with renewable energies and with average storage times of a few hours. The costs for VRFBs have fallen significantly in recent years and a further reduction in costs with a simultaneous increase in service life can be expected in the next few years as alternative production technologies are used and economies of scale gain influence. ■

Authors

Jens Noack is a chemical engineer and scientist at the Fraunhofer Institute for Chemical Technology. He is project leader and coordinator of several national and multi-national projects regarding redox flow batteries. His research interest is focussed on redox flow batteries and other technologies for renewable energy storage.



Nataliya Roznyatovskaya studied chemistry at the Moscow State Lomonosov University and completed her PhD in 2005 on the mechanisms of the electrochemical reduction of binuclear metal–ligand complexes. After postdoctoral research at the University of Regensburg, she became scientific Associate in the Department of Applied Electrochemistry at the Fraunhofer ICT. Her research focuses on the electrochemical investigation of electrolytes for electrochemical storage and conversion.

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Maria Skyllas-Kazacos AM is an emeritus professor in chemical engineering at UNSW Sydney Australia. She is one of the original inventors of the all-vanadium redox flow battery and holds more than 30 patents relating to the technology. She is a fellow of the Australian Academy of Technological Sciences and Engineering and has received several awards including Member of the Order of Australia, the CHEMECA Medal and the Castner Medal.

References

[1] Dunn, B.; Kamath, H.; Tarascon, J.-M. Electrical Energy Storage for the Grid: A Battery of Choices. *Science* **2011**, *334*, 928-935, doi:10.1126/science.1212741.

[2] Viswanathan, V.; Crawford, A.; Stephenson, D.; Kim, S.; Wang, W.; Li, B.; Coffey, G.; Thomsen, E.; Graff, G.; Balducci, P.; et al. Cost and performance model for redox flow batteries. *Journal of Power Sources* **2014**, *247*, 1040-1051, doi:10.1016/j.jpowsour.2012.12.023.

[3] Noack, J.; Wietschel, L.; Roznyatovskaya, N.; Pinkwart, K.; Tübke, J. Techno-Economic Modeling and Analysis of Redox Flow Battery Systems. *Energies* **2016**, *9*, 627, doi:10.3390/en9080627.

[4] Noack, J.; Roznyatovskaya, N.; Herr, T.; Fischer, P. The Chemistry of Redox-Flow Batteries. *Angew. Chem. Int. Ed.* **2015**, *54*, 9776-9809, doi:10.1002/anie.201410823.

[5] Winsberg, J.; Hagemann, T.; Janoschka, T.; Hager, M.D.; Schubert, U.S. Redox-Flow Batteries: From Metals to Organic Redox-Active Materials. *Angew. Chem. Int. Ed Engl.* **2017**, *56*, 686-711, doi:10.1002/anie.201604925.

[6] Parasuraman, A.; Lim, T.M.; Menictas, C.; Skyllas-Kazacos, M. Review of material research and development for vanadium redox flow battery applications. *Electrochimica Acta* **2013**, *101*, 27-40, doi:10.1016/j.electacta.2012.09.067.

[7] Choi, C.; Kim, S.; Kim, R.; Choi, Y.; Kim, S.; Jung, H.-y.; Yang, J.H.; Kim, H.-T. A review of vanadium electrolytes for vanadium redox flow batteries. *Renewable and Sustainable Energy Reviews* **2017**, *69*, 263-274, doi:10.1016/j.rser.2016.11.188.

[8] The tetra- and pentavalent vanadium ions are actually more complex compounds. Often they are given as vanadyl (VO^{2+}) or divanadyl cations (VO_2^{+}), but this again is a simplification of reality and the actual conditions are much more complex and the subject of research. For better comprehensibility V^{4+} and V^{5+} are used here.

[9] Gubler, L. Membranes and separators for redox flow batteries. *Current Opinion in Electrochemistry* **2019**, *18*, 31-36, doi:10.1016/j.coelec.2019.08.007.

[10] Prifti, H.; Parasuraman, A.; Winardi, S.; Lim, T.M.; Skyllas-Kazacos, M. Membranes for redox flow battery applications. *Membranes (Basel)* **2012**, *2*, 275-306, doi:10.3390/membranes2020275.

[11] Yuan, X.-Z.; Song, C.; Platt, A.; Zhao, N.; Wang, H.; Li, H.; Fatih, K.; Jang, D. A review of all-vanadium redox flow battery durability: Degradation mechanisms and mitigation strategies. *International Journal of Energy Research* **2019**, *50*, 88, doi:10.1002/er.4607.

[12] Skyllas-Kazacos, M.; Cao, L.; Kazacos, M.; Kausar, N.; Mousa, A. Vanadium Electrolyte Studies for the Vanadium Redox Battery-A Review. *ChemSusChem* **2016**, *9*, 1521-1543, doi:10.1002/cssc.201600102.

[13] USGS National Minerals Information Center. Vanadium 2018 **2019**.

[14] Skyllas-Kazacos, M.; Kasherman, D.; Hong, D.R.; Kazacos, M. Characteristics and performance of 1 kW UNSW vanadium redox battery. *Journal of Power Sources* **1991**, *35*, 399-404, doi:10.1016/0378-7753(91)80058-6.

[15] Ping Zhao, Huamin Zhang, Hantao Zhou, Jian Chen, Sujun Gao, Baolian Yi. Characteristics and performance of 10 kW class all-vanadium redox-flow battery stack. *Journal of Power Sources, 162, 1416-1420* **2006**.

[16] Aaron, D.S.; Liu, Q.; Tang, Z.; Grim, G.M.; Papandrew, A.B.; Turhan, A.; Zawodzinski, T.A.; Mench, M.M. Dramatic performance gains in vanadium redox flow batteries through modified cell architecture. *Journal of Power Sources* **2012**, *206*, 450-453, doi:10.1016/j.jpowsour.2011.12.026.

[17] Tang, A.; Bao, J.; Skyllas-Kazacos, M. Studies on pressure losses andw flow rate optimization in vanadium redox flow battery. *Journal of Power Sources* **2014**, *248*, 154-162, doi:10.1016/j.jpowsour.2013.09.071.

[18] Noack, J.; Roznyatovskaya, N.; Pinkwart, K.; Tübke, J. Vanadium proton exchange membrane water electrolyser. *Journal of Power Sources* **2017**, *349*, 144-151, doi:10.1016/j.jpowsour.2017.03.039.

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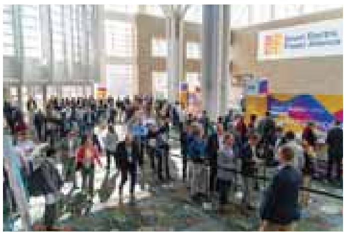

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Building battery storage systems to meet changing market requirements

Storage systems | Battery system integrators must navigate a broad array of technologies and varying market drivers when putting systems together. Andy Colthorpe speaks to Powin Energy and Sungrow about the engineering challenges involved in building lithium-ion battery storage systems at scale

In the previous edition of *PV Tech Power,* we spoke to four leading developers of solar-plus-storage and standalone energy storage projects based in North America about what it takes to get projects over the line, their experiences in the field – and what sort of technologies are making their efforts possible.

This time around, we've spoken in depth with two of the system integrator/manufacturers that supply that segment of the energy storage market as well as projects in other key markets including the UK, mainland Europe and Australia.

Danny Lu, vice president at Oregon, USA-headquartered Powin Energy and Dr Zhuang Cai, R&D director at Hefei, China-headquartered Sungrow, share their insights on what it means to build lithium-ion battery storage systems at scale.

Credit: Sungrow

Sungrow 9MW/3.836MWh solar-plus-storage project in Jacksonville, Florida, US.

A 21st Century industry

Powin Energy is a pure-play battery energy storage system (BESS) manufacturer and system integrator, having pivoted away from its role as a developer in 2017, while Sungrow will be better known to readers as one of the world's biggest solar inverter makers.

"Sungrow has focused on power electronics for more than 20 years. Our president (Can Renxian) was a university professor and saw a large potential for renewable energy," Cai says.

Sungrow has to date supplied more than 100GW of PV inverters. Since first announcing a joint venture (JV) with South Korean battery maker Samsung SDI to create and supply energy storage systems in China with an investment of around US$20 million, the storage JV has accelerated its activities rapidly. By 2016, when it went global, investment in the JV stood at a reported US$170 million. According to Sungrow the JV has already installed more than 900 battery systems, at various scales and for varying applications.

The company's background in solar was instrumental in allowing for the move into energy storage, Cai says.

"From a technical perspective, we utilised the same platform: we started with PV inverters, [in energy storage], we focus on power conversion technology (PCS). The PCS equipment evolved by the same platform as the inverters," Cai says, with solar project work providing a strong level of understanding of how to go from "inverter to converter technology".

The biggest difference, of course, is that solar inverters only convert in one step, from DC to AC, whereas energy storage is bi-directional, drawing power from the grid as well as injecting electrons into it. While this "very specific characteristic" allows for energy storage to perform various roles in providing flexibility to the electricity network, it presents fresh engineering challenges.

"A PV inverter [works in] a single direction and the PCS is bi-directional. So, because the PCS is bi-directional, energy storage can be an 'energy buffer'. It's not a generation unit, it is also not load consumption: it can play different roles in different applications. This is the reason we achieve a lot of applications such as frequency regulation, price arbitrage, peak shaving, and PV-plus-storage scenarios," Cai says.

"Different applications will also have different control strategies, so we have to design the dispatch strategy into the PV part and also the storage part to combine the two parts together to achieve different functions."

For Powin Energy too, its connections with the solar industry and resulting partnerships with international big names have helped put the company on the energy storage map. Formerly Powin Corporation, Powin began its R&D into large-scale storage in 2011 and then netted investment from the owners of PV company Suntech, Shun Feng Clean Energy (SFCE) in 2013 and 2014.

"The SFCE was really kind of our Series A funding," Powin Energy VP Danny Lu says. "They were one of our first strategic shareholders and they provided us with growth capital, working capital, in a time when we were trying to finish up the R&D of our battery management system (BMS). So we really utilised those funds to commercialise our product and to get it to a point where we could deliver on utility-scale projects."

From there, Powin made an early stage project win, after the infamous 2015 Aliso Canyon gas leak in California led to the expedited awarding of energy storage contracts to help utility Southern California Edison meet capacity needs. Danny Lu says SFCE's funding meant Powin Energy was able to secure and build its awarded 2MW/9MWh facility in Irvine, California.

Although it wasn't the largest project among those awards, Lu says the whole timeframe for executing the Irvine project, from starting the development to interconnection, was about six months. To date, Powin Energy has now delivered or installed around 250MWh of BESS and expects to exceed 1GWh of installations and deliveries by 2021, according to projections from earlier this year.

Partnerships and adaptation of technology

The building of partnerships across international lines remains key for Powin's strategy. While SFCE retains a stake, it has taken a backseat and Lu says Powin also has a deal with GCL, agreed in November 2019, to expand sales reach into the utility-scale markets of Southeast Asia, South Korea and Australia.

There's also Powin Energy's tie-in with one of the world's biggest lithium-ion battery producers, Contemporary Amperex Technology Limited (CATL). Powin and CATL have a 1.85GW master supply agreement over three years. Lu says that has given Powin both locked-in pricing of cells and locked-in availability up to 2022.

Powin has just launched a new range of stacks including long-duration (four-plus hours of storage) products with a 20-year lifetime, based on prismatic large-format lithium-ion cells supplied by CATL. Powin

Credit: Powin Energy

Powin Energy's recently launched product line features CATL's 'made-for-stationary-storage' LFP battery cells

Energy claims it has around 600MWh of contracted orders for the new Stack225, Stack230 and Stack230P products during 2020 and 2021.

Part of that is to do with CATL's design of 280 amp-hour battery cells specifically for stationary storage systems, while another is the manufacturer's selection of lithium iron phosphate battery chemistry. Much has been written about the pros and cons of lithium iron phosphate (LFP) versus nickel manganese cobalt (NMC) for use in energy storage systems.

While there is a perception that LFP is 'safer' than NMC, having a higher tolerance for thermal runaway, Sungrow-Samsung SDI nonetheless use Samsung SDI battery cells that have passed the stringent UL9540 test certification for the safe installation of stationary energy storage systems – the Korean manufacturer was the first in the industry to pass the test, in fact. Sungrow "has invested a lot already" to ensure system safety, according to the R&D chief.

"For example, we have the DC combiner between the batteries and also the PCS. So, inside the combiner we have the breakers and fuses inside, in case of short circuit [of the] current," Cai says, adding that "other specific designs were made" for the Sungrow-Samsung SDI systems to also pass the UL9540 tests.

"We have to test the ground impedance from different points in the equipment and also design thermal management. Also, we design our own software: for example, if you have some communication failing, it doesn't matter, because we can reduce the rated power of the PCS automatically, in order to avoid charging and discharging with very high rates."

In terms of strategy, Cai says that the company is flexible to working with different battery chemistries and has in the past done projects using lead acid and redox flow batteries too. Both LFP and NMC are likely to take big shares of the energy storage market going forward, Cai says.

Sungrow recently worked with both Samsung SDI and CATL as cell suppliers on one of its own 'milestone' system integration projects: the 100MW/100MWh Minety project in Britain, which is split across two 50MW sites in close proximity to one another. The project got underway in late 2019 and could be expanded by another 50MW. According to Cai, the level of complexity behind such projects is deep. Work on it required engagement with several stakeholders including transmission operator National Grid and distribution operator Eclipse Power Networks, and it's been invested in by China Huaneng Group, and Chinese government-backed fund CNIC.

BMS and EMS

There is a lot more to consider than the choice of battery chemistry when it comes to building large-scale energy storage. Sungrow's Cai says that in utility-scale energy storage, there are many challenges in getting the dispatch and control of the assets to meet customer expectations. Sungrow sources energy management systems (EMS) from third parties and in order to do so needs to negotiate with grid operators what the specific requirements will be for each application, such as the required response time.

Asset operators, meanwhile, will "have their own dispatch strategies in order to achieve very stable revenue streams", Cai says, which can present "a lot of challenges", and for this reason Sungrow prefers to design customised containers according to the customers' requirements. "We don't have a very standardised, container solution with 3MWh or 4MWh [for example]," he explains.

Powin Energy as a system manufacturer, meanwhile, has its own battery management system (BMS). Lu says that chief technology officer Virgil Beaston has been very focused on designing a BMS scalable to utility-scale projects that are growing to be hundreds of megawatt-hours or even in the gigawatt-hour range for a single system. Beaston's BMS design includes "all of the standard safety features, alarms and shut-offs", Lu says, as well as cell-level controls and cell-level monitoring.

"We utilise a balancing circuit that utilises auxiliary power from the grid to be able to charge energy into a single cell, to balance that battery up. When you are performing a full 100% discharge, if your lowest cell is a slightly lower voltage than all your other cells, when that one cell reaches its bottom threshold, it will stop the whole system from discharging further," Lu explains.

"What that delta is between your low-charge cell and your other cells will be the amount of capacity that is stranded within your system that you can't discharge further, without damaging other battery cells within the system. During these discharge events we try to pump grid power into the system. We pinpoint the individual cells through our monitoring system that might have a slightly lower voltage ... then we utilise that grid power to pinpoint those individual cells, pump auxiliary AC power that we transfer to DC into the individual cells to keep them online longer, before they drop the whole system offline."

Powin Energy's BMS allows the company to be flexible on which cells go into its systems, Lu says. "Right now we're pretty settled on LFP but if there's another chemistry that comes out in the next few years that has better performance, lower costing, longer life than LFP we can easily change the layout in dimensions of our battery module to accommodate a new cell and tweak the range of our BMS to accommodate those cells' characteristics".

Geographies and applications

Of course, what you want your system to do and how you size it depend on which market the battery storage is going to be deployed in. Different geographies have different regulatory regimes, different levels of solar penetration on the grid and so these different markets have greatly different asks. As an overall trend, it's certainly true that as costs come down and solar and wind penetration go up, longer duration systems are being deployed, but it would be a generalisation to say that this is the case everywhere. Dr Zhuang Cai of Sungrow says that he believes that longer duration "will be popular in the near future", owing to the dynamics described, but there's still a significant appetite for shorter duration storage too.

"Batteries are [still] a very expensive thing. If you want to do frequency regulation, you have to calculate the business models to check if you can earn money or not. Because of the higher cost of the batteries, sometimes investors don't want to invest a lot of money for long periods of payback, so this brings an opportunity for shorter duration batteries. Last year we achieved one project in Germany for frequency regulation with half an hour duration of storage."

Meanwhile, for Sungrow, in general terms the different applications and therefore types of system asked for by customers can be divided into different regions. There is rising demand for solar-plus-storage from North American customers, ordering a lot of DC-coupled systems at present. In Europe, the market is more focused on AC-coupled, short-duration battery systems. The growing Southeast Asia market in countries such as Thailand and the Philippines on the other hand, is more about micro-grid solutions.

Although Powin has made some forays into Europe and started up its partnerships in Australia and in Asia, Lu says around 90% of its business is in North America. As alluded to earlier, this began with the California boom of 2016 and 2017. Lu says that Ontario's commercial and industrial (C&I) market, where behind-the-meter systems that more closely resemble utility-scale projects in terms of size are frequently deployed for peak shaving, has been important too. Ontario got kick-started by the independent system operator procuring front-of-meter storage for its system reliability needs, but latterly has focused on C&I projects of over 1MW.

"The Ontario market has developed into more of a C&I market – but very large C&I projects for the Global Adjustment Charge (GAC), which is the demand charge that all industrial power users of over 1MW get charged every year... all the industrial energy users get charged a very significant per-megawatt demand charge.

"It's actually a very low cycle use case but it offers big savings to the customer if you time it right and you hit the right states at the right times. We've deployed over 100MW of projects in the GAC market, and we have a significant pipeline of about 70MWh of projects that we'll be deploying this year to that market."

The customer is always right

Looking ahead, both Sungrow and Powin Energy see opportunities all over the world. For Powin, there have been around 100MWh of recent projects for solar-plus-storage and wind-plus-storage, while the next major US opportunity is in Texas where the company has already deployed over 100MWh of projects

"There's a lot of developers targeting the fast response frequency regulation market in Texas," Lu says, as well as "humungous requests for proposals (RFPs) ranging from one to two-hour systems all over Texas".

The big shift for Powin, Lu says, is that Texas and other nascent markets present almost purely merchant opportunities. Cai meanwhile says that Sungrow has already seen a lot of business potential for energy storage and believes it can "achieve a huge amount of projects in the 2020s".

"Recently we are also focusing on North America, Europe and Australia. Maybe the next booming market will be Australia. We have a lot of operations with engineering, procurement and construction (EPC) companies, even from the domestic market from China. We see a lot of potential in energy storage systems and we believe the energy storage business will be booming in the next two years." ■

Credit: Andy Colthorpe/Solar Media

China's CATL, one of the biggest makers of lithium iron phosphate cells in the world, has worked with both Powin and Sungrow recently

Optimising DERs: Artificial intelligence and the modern grid

AI | The optimal integration of distributed energy resources such as solar, battery storage and smart thermostats becomes an ever-more complex and pressing question. Rahul Kar, general manager and VP for New Energy at AutoGrid Systems looks at the role artificial intelligence can play in smarter energy networks

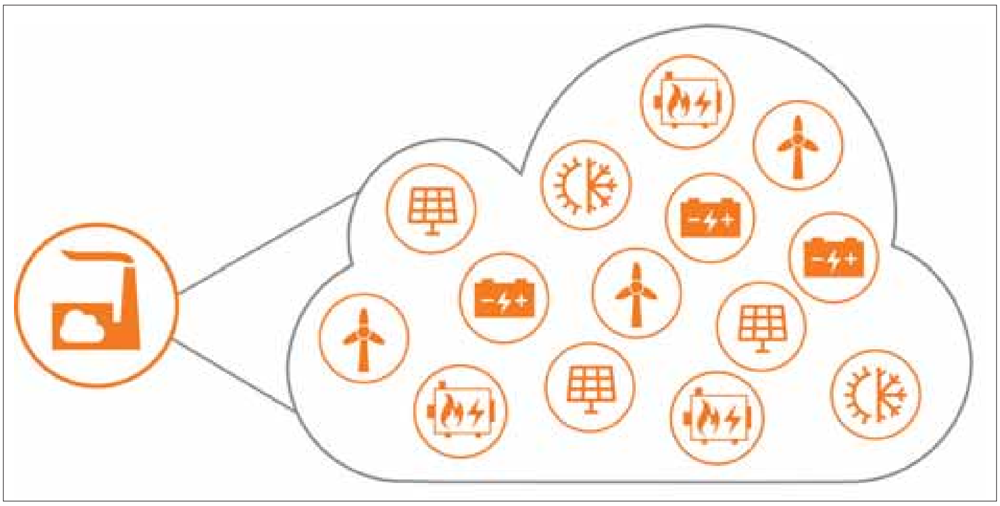
The modern electric grid is an engineering marvel and millions depend on it for reliable and on-demand power supply. The grid is becoming greener with the growing retirement of fossil fuel generation and the penetration of renewable energy, energy storage, electric vehicles (EVs), and a variety of other networked distributed energy resources (DERs). Such growth of DERs will continue at a rapid pace in the near future with rapidly reducing costs, favourable policies and increased customer adoption.

Integrating these DERs optimally — while maintaining grid reliability, delivering value, and maintaining customer preferences — is not an easy problem to solve. Especially considering that conventional methods have failed, simply because of the complexity involved and the need for scale.

Where utilities, grid and energy market operators once had to coordinate 9,000 power plants (and used supercomputers!) in the United States to match demand with supply, in the not-too-distant future, almost every rooftop will have a generating PV system coupled with storage. Coordinating across millions of such distributed systems will be impossible to solve using traditional computational systems.

Enter artificial intelligence (AI) for the modern grid, which uses a combination of three key technical elements to solve this problem: 1. machine learning for recognising patterns to forecast supply and demand; 2. high performance computing for optimisation; and 3. a modern Internet of Things (IoT) infrastructure to monitor and control the connected DERs.

With the right approach, the AI can aggregate all the DERs into a virtual power plant (VPP), that in essence is able to displace conventional sources of generation — thus mitigating harmful emissions and climate change consequences. And with cloud computing, which enables distributing and parallelising computations for forecasting and optimisation, these AI-based systems are cost effective as well.



Credit: AutoGrid

Many distributed assets are orchestrated to run the grid where once a limited number of centralised, large generators would have done.

The power behind trillions of data points

Connected assets — from household thermostats to large grid-connected solar farms — produce data every second on how much energy they consume or generate. There is immense value to the grid if this data is intelligently collected, aggregated, analysed, and enables decision-making by grid operators.

For example, using machine learning algorithms, one can forecast if a transformer will get overloaded or if there will be congestion in a certain part of the grid. Not only is this helpful for long-term grid planning, but it also offers real-time situational visibility alongside control of other DERs to mitigate any power quality issues.

Forecasts typically serve as critical inputs to downstream control and optimisation modules used by utilities and energy companies to drive enhanced grid operations. Examples of this include leveraging software applications to schedule customer demand response, reserve battery state of charge, or to guide operations of combined heat and power facilities to improve grid performance.

What is optimal?

Take a typical city street as a simplistic example, where you might find a house

Credit: AutoGrid

Flexibility is the name of the game

with a solar photovoltaic (PV) system and an energy storage asset, a large office building, and a hospital with a backup generation system. Let's say they are all enrolled in a utility demand response programme. Each building on the street has its own unique energy needs, ranging from the everyday to the critical, different rate tariffs, and varying abilities to moderate energy consumption. Given the capability to predict and control the consumption patterns of each building, would you choose to save on the energy bill for the end consumer or participate in demand response events for the utility and get paid? How about doing both? What is the optimal strategy?

"There is tremendous potential to create enough grid flexibility with control of on-site DERs... AI unlocks the flexibility of the assets and combines them in such a way that they become a reliable and dispatchable source of capacity for grid use — a virtual power plant"

This is not a straightforward problem to solve because the economic optimal control is often not intuitive and rule-based approaches typically fail to scale. Imagine doing this, not just on one street, but for every utility feeder or substation, where many also have DERs like solar contributing to the grid energy mix.

This is where AI is able to handle the complexity and drive scale — load and generation forecasts feed into optimisers that provide outputs on the best way to operate. For example, for the battery in your home, the optimisation ensures that you can not only save on your bill but also make money from demand response incentives.

In the real world, scalability is essential for a comprehensive AI energy application. The modern grid, with an ever-changing pattern of generation and consumption, needs control strategies that account for the specific constraints of each site (for example, not turning off critical backup in a hospital).

At the same time, there is tremendous potential to create enough grid flexibility with control of on-site DERs. In other words, AI unlocks the flexibility of the assets and combines them in such a way that they become a reliable and dispatchable source of capacity for grid use — a virtual power plant (VPP)!

Grid operators can then utilise the aggregated DER portfolio to make decisions — either to delay building expensive infrastructure (non-wires alternatives) or reduce system peak to avoid turning on fossil-fuel based reserves. Complex solutions like wholesale market trading, ancillary services and increasing hosting capacity for renewables may also address this issue.

Intelligent use of AI

Ultimately, the success of any AI solution depends on combining industry subject matter expertise with data intuition and ingenuity. Co-locating energy experts with software engineers and data scientists leads to better training, testing, validation, and deployment of AI models. Discipline around data ingestion, quality, scalable software architecture and massive real-time processing capabilities are key in any energy AI application.

Going forward, the energy industry's need for AI solutions will intensify, as the grid becomes more distributed, with a growing number and types of DERs being deployed every year. Sustainability goals driven by compelling economics are already challenging the 'art of the possible' when it comes to energy infrastructure. Managing a growing machine as complex as the grid requires AI solutions that are scalable, robust, and DER-agnostic. That way we make the smart grid even smarter. ■

Turn to p.92 for the second part of this #SmartSolarStorage2020 double-bill feature exploring the cutting-edge technologies enabling greater integration of solar on to the grid

Author

Rahul Kar is responsible for revenue growth, product development, solutions design and delivery of the New Energy business unit at AutoGrid, which has developed a platform for integrating all distributed energy resources using cutting-edge analytics and in-depth energy data science. He has over 15 years of experience developing and successfully delivering innovative energy solutions for industries, utilities and the government.

Digitising the solar revolution

Blockchain | Our ability to generate renewable energy is scaling up fast, and solutions to integrate that energy will rely on technologies like blockchain to help keep new solutions on track. Power Ledger's executive chairman and co-founder, Dr Jemma Green, looks at the role blockchain plays within her company's platform to integrate and automate solar energy trading and balancing

Credit: Power Ledger

Power Ledger's blockchain platform has been used since 2018 to track renewable energy trading between 18 households in Fremantle, Western Australia

With the COVID-19 lockdown still in effect, our team has been working from home more frequently. This has given me pause to observe the solar panels on roofs in my neighbourhood.

It's inspiring to see so many people embracing a renewable energy source, but I'm reminded that no matter how good its products are, the success of any business is largely determined by economic conditions.

That's an insight I saw played out many times during my career with J.P. Morgan in London. And it's influenced my work in environmental sustainability to help create Power Ledger – an energy trading platform that uses blockchain technology to record and track renewable energy transactions.

Power Ledger's mission is to deliver clean, low-cost and resilient distributed energy markets by providing a market mechanism for energy trading and fostering the economic conditions for its long-term success.

Because despite the best intentions of environmentalists, simply swapping grid power for solar panels or replacing coal-fired power stations with wind farms creates grid instability. Unless the right economic conditions are created and sustained, renewable energy may cause as many problems as it solves.

And digital solutions like Power Ledger's blockchain-facilitated energy trading platform, which can dispatch battery-sourced energy in the peak, and stabilise the grid, seem to be in the right place at the right time.

So, while the socially distant view of my neighbours' renewables reminds me of the green energy sector's many challenges, I'm also fired with the belief that our sector finally has an enormous opportunity in its grasp.

Solar panels and algorithms

Over many years the global energy sector has been transitioning from a centralised system with a small number of very large power plants, to a distributed cleaner electricity grid. On a macro scale, we are seeing wind, solar and even wave-based renewable technologies supplementing and replacing coal and gas fired power stations. And on the micro level, solar panels, smart meters and battery storage are alleviating demand on the fossil fuel-powered grid.

The opportunity Power Ledger has identified is to link the macro of green energy production to the micro through a trading platform that businesses and everyday consumers can use to trade energy peer-to-peer and to the market to stabilise the system. There are many possible configurations.

A household with solar panels can sell excess power to a neighbour. A household with a battery can sell services to the grid to keep it stable. Another household using the Power Ledger platform can choose to source its power from an external renewable source. Businesses can do the same, either selling their excess renewable power or using the platform to tap into a green source.

Even those without solar panels can

still access renewables from sellers in the Power Ledger network and its partner retailers.

All of this is made secure and convenient through the Power Ledger platform's use of blockchain technology to record and track energy transactions. This allows for greater transparency, increased automation and reduced possibility of human error.

For energy retailers, the blockchain-enabled platform improves efficiencies by enabling peer-to-peer (P2P) transactions, virtual power plants (VPP) from small batteries combining, renewable energy certificate trading, as well as energy provenance tracking.

The apex of all of this is to create an economically viable market for renewable energy, driven by secure peer-to-peer trading that fosters true demand.

Power Ledger in action

Blockchain technology can create a decentralised market for VPPs and P2P energy trading as it can handle transactions and payments on both sides of the meter, in real time, at a lower cost to all involved. Using a blockchain can facilitate cross-retailer trading and settlement too, fostering network market effects such as greater liquidity and efficiency in the market.

An example of our technology's potential is Power Ledger's partnership with green energy retailer ekWateur in France using our blockchain-enabled product Vision, which certifies the origin and source of renewable energy and allows customers to choose their own mix.

More than 220,000 electricity meters across France are gaining access, so that households can choose their power sources, including renewables like wind farms and neighbouring solar panels. Every transaction is securely traced and tracked and the whole process is made as simple as possible for users.

Whilst the ekWateur partnership is just one example of the power of sharing energy, it also demonstrates the new products and services being built on top of the grid.

Generating virtual power plants

Grid stabilisation services have historically come from traditional energy sources like coal and gas-fired power plants. But as there are fewer of these and more solar the grid is becoming unstable.

Batteries, coupled with the Power Ledger platform's VPP feature, allows

A rooftop solar installation in Bangkok, Thailand, where the Power Ledger technology has been introduced

Credit: Power Ledger

energy stored to be dispatched to stabilise the grid. This arrangement encourages more people to use blockchain-enabled trading technology, creating a larger network of users that bolsters the economic viability of renewables and provides a low-cost and stable energy system.

This is more than simply placing solar panels on a roof or installing a smart meter – this is an entirely new marketplace of energy trading that can be activated with the flick of a switch.

The benefits of using blockchain

The reason Power Ledger has based its trading platform on blockchain technology is twofold: firstly, it's secure and fast and secondly, it creates new efficient markets.

Through blockchain, users can trace and verify that they are receiving energy from renewable sources and have confidence that their financial transactions are being securely recorded and enabled.

More crucially, blockchain connects smaller buyers and sellers together in a low-cost fashion and allows for faster settlement compared to longer settlement periods with the current energy market. With blockchain, settlement can be achieved in real-time.

The advantage of simplicity, speed and security is that consumers can embrace the technology quickly and become part of a growing global network, creating more demand and opportunities for fulfilment.

This allows the marketplace to grow and provide a viable and reliable economic base for the renewable energy sector.

Creating green economies of scale

To build the operating system of the new energy marketplace, we need to ensure the existing infrastructure has the required supporting technologies.

With Power Ledger's energy trading platform now in use in Australia and nations such as France and Thailand, the technology is helping to redefine how energy is distributed, managed, traded, used and governed.

Blockchain technology has the potential to transform the energy sector as it improves transaction efficiency, enables price setting and allows for energy to be traded easily peer-to-peer.

The next challenge is that of scale – to deploy blockchain enabled trading of energy across as many networks and sectors of the market as possible.

Whilst Power Ledger is seeing successful take up of its technology offering, I believe the time is ripe for more rapid shifts in energy systems and markets.

My hope is that the challenges faced by the renewables sector in the coming years will not be how to grow, but how to keep up with the demand for growth. ■

Author

Dr Jemma Green is the executive chairman & co-founder of Power Ledger, a blockchain technology company focused on revolutionising green energy generation and distribution. With a background in investment banking and sustainability, Dr Green was a 40under40 winner in 2016 and in 2018 received the EY Fintech Entrepreneur of the Year award.

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next issue

Overcoming grid challenges

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