At the heart of floating solar: Singapore

Floating PV | Singapore operates the world's largest testbed for floating PV, comparatively testing and evaluating 10 different floating PV installations from around the world, and held the first floating solar conference globally in October 2017. Writing exclusively for *PV Tech Power*, Thomas Reindl of the Solar Energy Research Institute of Singapore (SERIS) reports on a form of solar power whose huge potential is starting to be realised

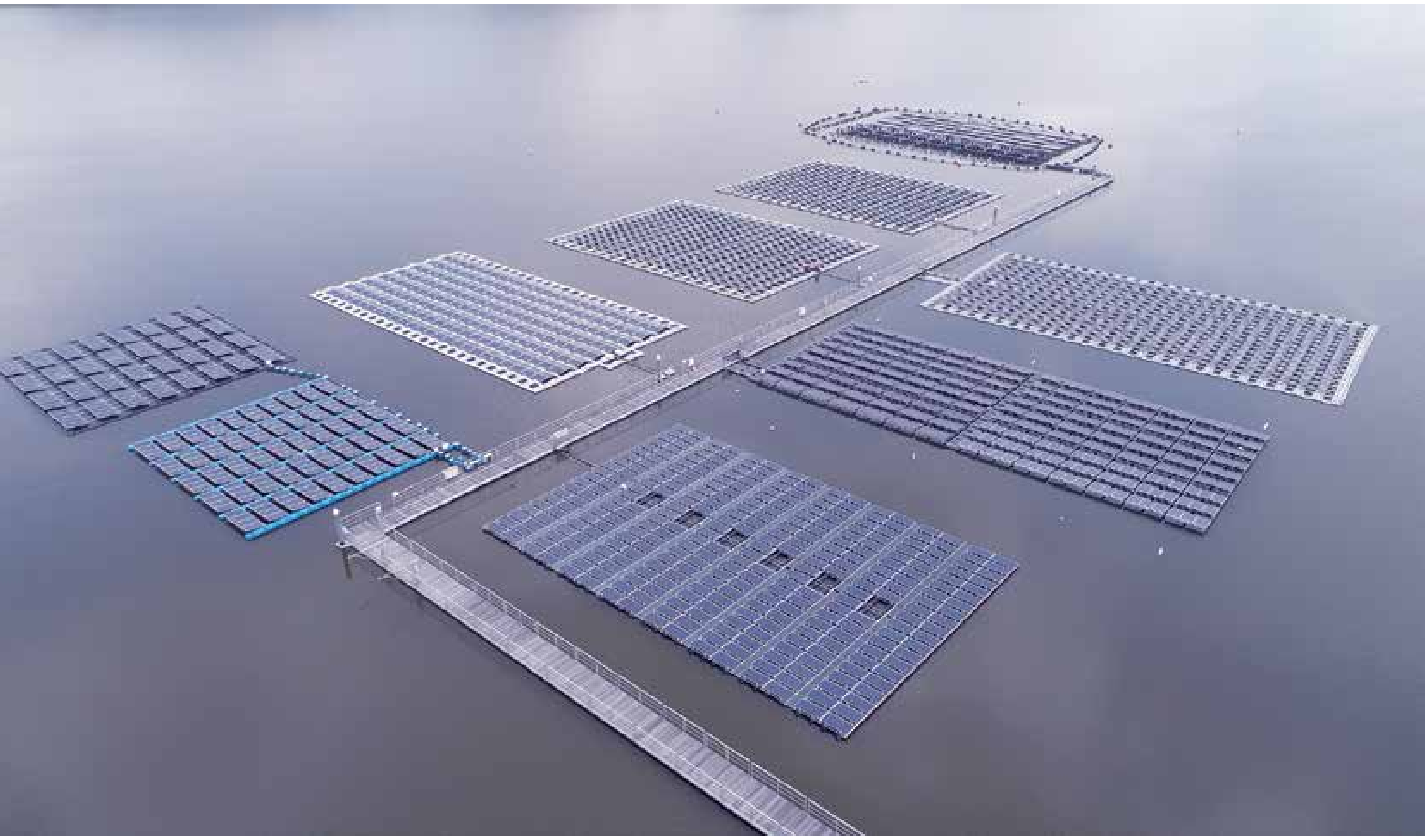

Figure 1. Singapore testbed of 10 different floating solar technologies on Tengeh reservoir

The interest in floating solar has grown rapidly in recent years. In many established and emerging markets, such as Japan, South Korea, UK, China and India, floating solar is already considered an attractive and viable option for PV deployment. In October 2016, Singapore launched the world's largest floating PV testbed, with a total installed capacity of around 1MWp. This testbed aims to study the economic and technical feasibility, as well as the environmental impacts of deploying large-scale floating PV systems on water reservoirs. The testbed consists of 10 sub-systems with different types of PV modules, inverters and floating structures. The field experience of operating these systems, and a comparison of their performance and reliability, offers highly valuable learning points for the floating PV community.

Floating solar refers to the installation of PV on water bodies, such as lakes, reservoirs and other often under-utilised water bodies, with PV panels usually mounted upon a pontoon-based floating structure. Floating PV is considered an attractive option due to the following advantages:

- No or reduced land usage. This is important for regions where land resources are scarce or undesirable for PV installations (e.g. when considered competing with agricultural use), but sufficient water bodies are available;

- The evaporative cooling effect from the water (thus lower operating module temperatures) likely increases the annual energy yield of the PV modules. Improvements from 10% to even 25% as compared to land-based PV systems have been reported for some early floating PV projects [1, 2];
- Floating PV is less prone to shading due to the open and flat environment;
- Great potential for complementary operation of floating PV with hydro-power stations due to (i) existing electricity connections, (ii) synchronised operation during day/night time and times with high PV variability (effectively using the reservoir as a "big battery") and (iii) complementary generation patterns in areas with high seasonality, especially with dry and wet seasons;
- Possible reduction in water evaporation losses from the reservoirs, which is of particular interest for reservoirs for fresh water supply and irrigation;
- Expected reduction in algae growth because of less sunlight intake into the water body;
- Potential integration with aquaculture and fish farming.


Figure 2. BBR/Solaris testbed system


Figure 3. REC/Takiron testbed system


Figure 4. Upsolar/Koine testbed system


Figure 5. Sunseap/C&T dual-pitch testbed system


Figure 6. Phoenix Solar/C&T testbed system


Figure 7. Sharp/Sumitomo testbed system


Figure 8. SolarGy/4C+NRG testbed system


Figure 9. Sunseap/C&T testbed system with active cooling

About the Singapore floating PV testbed

The Singapore floating PV test bed (see Figure 1) is a collaborative initiative by the Singapore Economic Development Board (EDB) and PUB, Singapore's National Water Agency. The Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS) is acting as project manager who took complete ownership of design, construction, testing, commissioning and the scientific evaluations of the project.

Inauguration of the world's largest floating PV test bed at Singapore's Tengeh Reservoir was announced on 25 October 2016 by Mr Masagos Zulkifli, Singapore's minister for environment and water resources, at the Joint Opening Ceremony of the 3rd Asia Clean Energy Summit (ACES) and the 26th Photovoltaic Science and Engineering Conference (PVSEC-26).

Floating PV testbed participants

Leading PV system integration companies (SolarGy, Phoenix, Sunseap, BBR, Upsolar, REC and Sharp) are participating in the testbed, using a number of tier-one PV module manufacturers (Trina Solar, REC, JA Solar, Upsolar, Sharp, Yingli etc.) to study their performance on water bodies. Floating system products from Ciel & Terre, 4C Solar, NRG Energia, Solaris, Koine, Takiron and Sumitomo Mitsui have been deployed at the testbed. The systems use on-grid solar inverters from SMA, ABB, Huawei and Sungrow. The testbed also features one of the largest floating PV systems with active water cooling.

Figures 2 to 9 show some of the installed Floating PV testbed installations.

Research activities at the world's largest floating PV testbed

The testbed aims to study the technical, economic and environmental feasibility of deploying large-scale floating PV systems on inland water surfaces. The study particularly includes a wide number of testing activities and studies on the performance of PV systems on water bodies, especially by benchmarking the various floating PV systems against each other and against a rooftop PV reference system.


Figure 10. Meteorological station at the rooftop


Figure 11. Meteorological station on the floating pontoon


Figure 12. Module temperature probes


Figure 13. Albedo measurements on water

SERIS has deployed numerous sensors across the test site, including two meteorological stations (one near the floats, one near the rooftop reference system). There are more than 500 parameters measured in real time and transmitted to SERIS' central monitoring system at the NUS campus. Figures 10 to 13 show some of the installed sensors. Others include DC, AC string monitoring and six-degree freedom movement trackers on each floating test system.

Initial results of the research activities

The analyses of the collected data show that the evaporative cooling effect depends on the type of floating structure used. From measured ambient air temperature, wind speed, in-plane solar irradiance level and module temperature, the so-called "heat loss coefficient" of each PV system type is determined, which indicates the effectiveness of module cooling by the environment. The comparison clearly shows a dependence on the way the PV panels are mounted. Higher values of the heat loss coefficient correspond to better cooling, and thus lower module temperatures, leading to a better electrical performance. The floating structures in the testbed are roughly categorised into "free-standing" types (with PV panels open to the water surface), and the "pontoon" types differentiated by the extent of water surface coverage beneath the modules (from "small footprint" to "large footprint").

The module temperatures for the free-standing systems are found to be much lower than those in the rooftop reference system. The heat loss coefficients for those systems are generally in the range of 40 to 50W/m²K, which is about 30 to 60% higher than the typical values of 30 W/m²K for a well-ventilated rooftop system. This is primarily due to lower ambient air temperature and higher wind speed on the water. For floating structures that have PV panels mounted close to the water surface, the cooling effect is dependent on the water footprint as well as module arrangement, as can be seen from Figure 14. Please note that "well ventilated" refers to a rooftop installation that has good ventilation, while an "insulated" system would refer to one with little exchange of heat with its environment (e.g. compact dual-pitch design).

In terms of performance, the performance ratio (PR) of the eight best floating PV systems as well as the rooftop reference system for the past few months of steady operation were measured. The majority of the floating systems reached PR values of well above 80% (see Figure 15), which is not easily achieved in Singapore's hot climate conditions. System G and the reference system use the same modules, showing that there is a slight performance gain for the floating system, despite the installation close to the water surface in this case. It is noted that the rooftop reference system is installed about 1.5 metres above the roof and close to the seaside (next to the reservoir), hence is much better ventilated than a typical rooftop PV system in Singapore's urban environment, and its bifaciality gives it an extra performance boest

One interesting finding is about the albedo and the benefits of using bifacial modules. The albedo from the water surface was found to be much lower than on the rooftop due to low water reflectivity at high incidence angles as well as the light absorption properties of water. Therefore, the bifacial modules generated less power on water than on the rooftop.

With a longer duration of monitoring, SERIS will also assess whether there are accelerated degradation effects for the floating PV modules and systems.

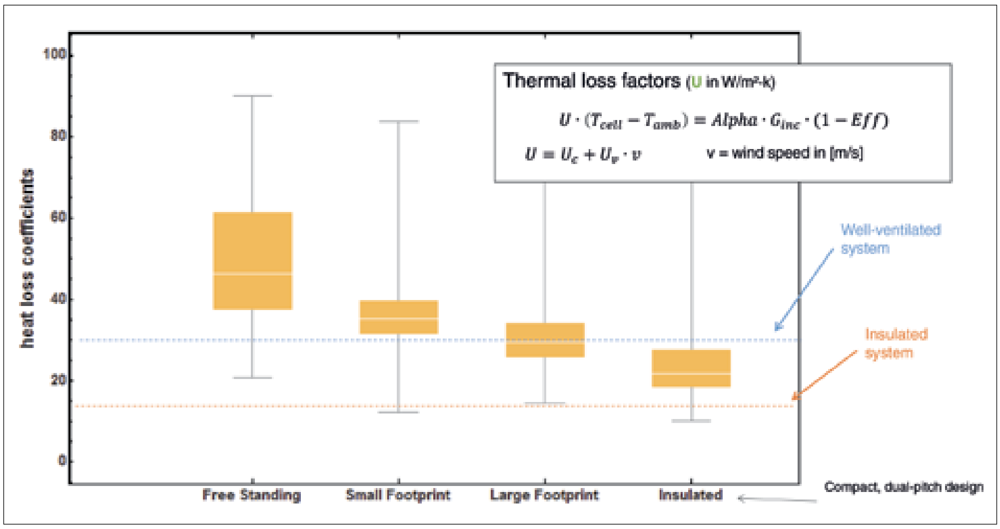

Figure 14. Measured heat loss coefficients in (W/m2K) for different types of floating PV systems. Common values for comparative standard systems are also indicated as dashed lines

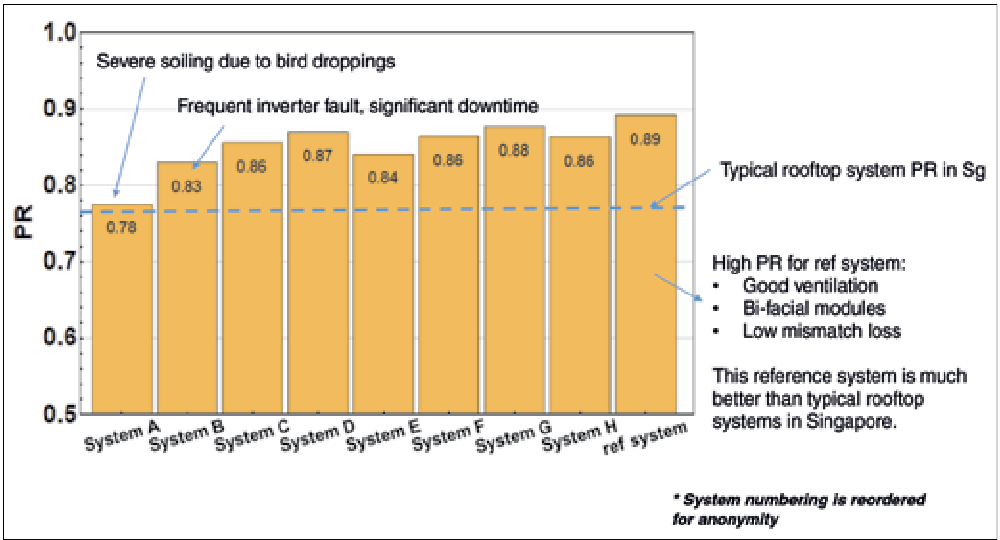

Figure 15. Overall performance ratio (PR) for various floating PV systems and the rooftop reference system. Typical PR for rooftop systems in Singapore is marked as red dashed line. PR values are corrected for DC cabling losses

Other current topics of interest are: electrical ground faults (observed multiple times), loose electrical connections (despite sufficient slack provided), soiling from bird droppings (which can be quite severe at times) and rupture of anchoring lines (occurring at selected systems).

Building a global community - the world's first floating solar conference

The inaugural "International Floating Solar Symposium" (IFSS) was held during October 24-26, 2017 at the Marina Bay Sands Convention Centre, Singapore, under the motto: "Building the global community". IFSS is an integral part of the annual Singapore International Energy Week (SIEW) and the Asia Clean Energy Summit (ACES).

Floating solar is taking the solar industry by storm. Globally, it unlocks 400,000 km2 of potential deployment space on man-made freshwater reservoirs alone, and thereby a new TW-scale opportunity for photovoltaics. It addresses the water-energy nexus through evaporation reduction and opens paths to ultra-low balance of system (BOS) costs.

The fascination with scalability and market potential is palpable: new form factors are being discussed and field tested, and the young industry is charting its way through the options for electrical architectures and unfamiliar environmental considerations. This made it the right time to bring industry players, innovators, developers and other stakeholders together for the very first time.

Jointly chaired by your author and Philipp Schmaelzle (X, formerly Google X, USA), over 100 experts from industry, governments, financing and academia gathered and shared experience in all related fields, such as the latest floating solar technologies, deployment strategies, environmental impact of floating structures, hybrid operation of hydropower with PV and bankability perspectives. The most important learnings and key take-aways from this first floating solar conference ever are highlighted below.

Setting the stage

IFSS 2017 shared the Grand Opening as well as the Solarising Singapore and Asia sessions with the Asia Clean Energy Summit (ACES), before it continued its own track on global market opportunities.

Oliver Knight from the World Bank Group (WBG) highlighted the benefits of floating solar and its great potential globally. He also shared the various funding opportunities for such projects and underlined the interest in lending for WGB, which includes both the World Bank itself and the International Finance Corporation (IFC). Moving on to the leading floating solar market, China, Frank Haugwitz of AECEA highlighted the enormous plans for floating applications there. He cautioned a bit that in China the term literally calls for "solar over water", which also includes installations on piles, such as the 200MWp installation on a fish farm in Zhejiang province. Floating solar solves a number of problems of large-scale solar farms: long transmission lines from Western China to the load centres in the East are expensive, which also leads to severe grid curtailments in certain areas, whereas there are plenty of water bodies in eastern China, which are often not utilised and don't require major permissions. The prime area for floating PV at the moment is Anhui province where water bodies on top of abandoned coal mines are earmarked for installations beyond 1GWp. The largest installations under deployment are in the range of 150MWp. In the meantime, floating PV has also been added to the so-called "Top Runner" programme, with cumulative goals of up to 4.5GWp over the next few years.

India, in contrast, has not really kicked off yet on Floating Solar, although it hides a huge market potential, as Rahul Jain from Renew Power pointed out; this even more so when taking the side benefit of reduced water evaporation into account, especially for irrigation canals and freshwater reservoirs. Similarly, the ASEAN member countries are still at an early stage, but with large opportunities when it comes to the combined hybrid operation of floating PV with existing hydropower stations, such as in Thailand, Cambodia, Laos or Indonesia, according to Badariah Yosiyana from the ASEAN Centre for Energy (ACE).

Keynotes

The IFSS 2017 keynotes were delivered by four highly recognised experts in floating solar. Professor Eicke Weber from UC Berkeley and BEARS (Singapore) made the point that floating PV clearly has the potential to become the third pillar of the PV industry, after ground-mounted and rooftop – this in particular when comparing the sheer areas of all rooftops in the world and the available reservoir surfaces: while covering all rooftops would lead to ~20TWp of PV installations, the reservoirs area could house ~50TWp.

Weber also highlighted the great benefits when combining hydropower with floating solar. If not run-of-river, hydropower stations have a reservoir attached anyway, which is typically not much utilised. In addition, there is naturally an electricity grid connection, which typically also has some spare capacity. The most striking fact he presented, however, was that "more water evaporates from reservoirs than is consumed by humans". If floating solar can reduce the evaporation losses, it

Figure 16. IFSS 2017 was chaired by the author (right) and Philipp Schmaelzle (X, USA)

would have a substantial double benefit for humankind.

It was a great honour to have one of the pioneers of floating solar speaking at IFSS 2017: Bernard Prouvost, the founder and chairman of Ciel & Terre. He shared his impressive journey, but also the pains of being a pioneer. C&T has installed more than 100 floating solar farms, including the largest in operation at 70MWp. The company had enormous growth and manufactures now in 10 countries at a capacity of ~800MWp per annum. C&T's Hydrelio has become a quasi-standard design for floats around the world, although obviously not all of them are manufactured by C&T. Prouvost called for a voluntary charter for "good practices in floating PV", which the chairpersons returned to later.

Torgeir Ulset shared his view from a leading PV manufacturer, REC Solar, which is an early mover in floating solar. The company had already extensively tested PV modules in water bodies a few years ago, both in freshwater, but also in seawater and found no evidence of higher degradation or lower reliability from the presumably harsher environments in floating PV installations. Therefore REC is very committed to the market and extends its warranties to such systems without any reservations.

Co-chair Philipp Schmaelzle gave an overall market opportunity and highlighted the opportunities beyond the current system design, which is largely based on pontoons with conventional solar panels mounted on top. He shared more detailed information on the approach, which X had pursued later in Session 1 (see below).

Session 1 (Architectures for Floating PV Systems and Modules)

The first session saw a great number of presentations about how PV modules can be deployed on water bodies. Veyis Neo Toprak from LG CNS gave a great overview about the various types of installations, but also about the materials, mooring systems and deployment methods. He also highlighted the importance of environmental impact assessments (EIA), which is often neglected amidst the current hype in the industry.

Dr Zhao Lu of SERIS then introduced the world's largest testbed for floating solar and shared first results from it (see details above). Philipp Schmaelzle then showed the work X had done in this area, in particular the development of a novel flexible, self-buoyant floating macro-module that could be manufactured in lengths of up to 100m. This would eventually save all the pontoons and metal structures and hence dramatically reduce the cost of floating PV, once mass-produced. In a similar approach, Tobias Haarburger of Continental proposed the use of rubber-based membranes for floating solar applications. Those membranes are used to cover large-scale reservoirs in areas where evaporation losses are substantial, such as desert areas in Israel.

Moving over to offshore floating systems, Raymond Hudson introduced the SUNdy structure by DNV GL. Although still in the concept stage, he encouraged participants to further develop the technology, especially since the module prices and cost for floating structures have significantly come down since it was first presented in 2011. Børge Bjørneklett from Ocean Sun demonstrated the results from his company's novel floating solar platform, which is based on large fish farming floats, which have been used in Norway for decades. The initial results are very promising and larger testbeds are under preparation. Already commercialised is the offshore floating PV system from Swimsol, as Dominik Schmitz pointed out. It is mostly applied in eco-resorts such as in the Maldives.

Closing the session was Wu Weiwu from Sungrow in China. The company has expanded from an originally pure inverter manufacturer towards a full green energy company, including turnkey provision of floating solar farms. He explained the details about Sungrow's standard 2MWp floating solar blocks, which also include a floating inverter and transformer station. The system is deployed, amongst others, in a 40MWp installation in Anhui province, China.

Session 2 (Enabling Components and Reliability for Floating PV)

The session was opened by Marco Rosa-Clot of Koine Multimedia who wrote the first book on floating solar. He gave an overview of the history and types of floating solar structures, including various tracking and concentrating versions. He also highlighted the importance of wind-loading tests and shared some of his latest developments that are undergoing tests at the moment. Leo Casey from X then gave a more detailed view of the electrical concept of the self-buoyant structure, with a specific focus on the electrical safety of the macro-module. It was not trivial to guarantee highest electrical performance, while maintaining proper grounding and ensuring that the macro-module and its components remain "touch safe" at all times.

Oakland Fu from DuPont then moved on to highlight the importance of suitable component selection when it comes to the packaging materials for solar modules to be deployed in harsh environments such as nearby water bodies. This includes preventive measures for potential-induced degradation (PID). Duncan Harwood of D2 Solar added to that discussion that floating PV installations rank higher in risks with respect to moisture, mechanical stresses and hot spots (e.g. from soiling or bird droppings). He described accelerated stress tests for those three mechanisms that have been applied on the self-buoyant macro-module which X had developed. He presented results of typical failure modes and suitable mitigation strategies.

Adding the views from a certification body, Keith Punzalan from VDE Germany, highlighted that there is an urgent need to develop standards for floating PV modules and systems, against which the certification bodies can then test and certify. At present, there are no such standards and he invited the industry to work with VDE and other certification bodies, probably starting with the testbed in Singapore where multiple floating systems are deployed next to each other.

Session 3 (Operational, Environmental and Financial Aspects of Floating Solar)

This session touched upon issues which are often "left aside", but are increasingly gaining awareness amongst stakeholders, in particular what the impact of floating solar is on the environment and the water body itself.

Jenny Johnson from Ascent Solar gave a great overview of what needs to be taken into account when looking at the environmental impacts of floating PV on water bodies. She differentiated by industrial water bodies (e.g. treatment plants, mines, cooling water) and reservoirs (e.g. for irrigation and flood control, municipal water or hydropower). She then walked the audience through the process of a proper "anti-degradation" strategy.

Geoff Schladow from UC Davis followed on by explaining the potential impact on the water body, introducing the hydrodynamic mechanisms that occur in any lake or reservoir. He presented the results from simulation studies at a hypothetical lake in Freson, CA, concluding that for a mat-like coverage (like the self-buoyant macro-module from X) there is a projected impact on the surface temperature of the lake and the temperature gradient from the water surface. Also the wind boundary layers are affected. All in all, a 10% coverage of a reservoir could theoretically lead to a 4-6% reduction in evaporation. It could also affect the lake circulation pattern, which may have some effect on the environment. More modelling work is required to come to conclusive results, especially since every reservoir is somewhat different.

Moving over to the financial aspects, Monika Bieri from SERIS presented insights from a detailed financial modelling of floating Solar, using today's component prices. Based on a turnkey system cost of US$1.14/Wp, the resulting levelised cost of energy (LCOE) is around 10.4 US$-cents per kWh, but with a wide range from 7.5 to 15 US$-cents/kWh – depending on the assumptions and financial parameters. The LCOE is particularly a function of the country risk and the conditions for debt financing, but in general floating solar is competitive with other LCOEs, also benefitting from the higher energy yield due to the evaporative cooling effect. Similarly, Jan Napiorkowski of ArielRe had no reservations that floating PV farms are commercially viable and, in principle, do not represent a higher risk for their unique PV system output guarantee, which acts as yield insurance for the project lifetime.

At the end of this session, two great presentations were given on the hybrid operation of hydropower with solar PV. Pang Xiulan from SPIC/Huanghe Hydropower Development Corporation showed details of the joint operation of a 1.3GW hydropower plant (consisting of four turbines) with an 850MWp solar farm – which happens to be the largest solar system in the world. The solar farm is ground-mounted (hence not "floating" in nature), but the intriguing issue here is the fact that the control centre operates the solar farm "as if" it was a fifth hydropower turbine. It can even buffer the variability from solar power within minutes and hence can provide a steady and stable output to the power grid. The Natural Heritage Institute (NHI) is applying this concept in a large-scale feasibility study in Cambodia where it proposes to shelve the plans for a potentially devastating hydropower dam across the Mekong River and rather deploy floating PV on a newly built hydropower station in one of the tributaries of the Mekong River. This would not only help save one of the most productive fishery systems in the world, but also, by installing the solar system in stages as demand grows, make the capacity addition more market-compliant and with fewer financial risks.

The day ended with a dinner event under the motto "Building the Global Community", which was also the occasion of the birth of the IFSS – the International Floating Solar Society. More on this to come…

The final day of IFSS 2017 saw workshops on "Electrical and Grounding Architectures for Safety, Reliability and Yield in Floating PV" (by Leo Casey, X) and "Hydro Power Basics & Colocation and Hybrid Operation of PV with Hydro" (by David Wright and Øystein Holm, Multiconsult), as well as the long-awaited site visit to the Floating Solar Testbed.

IFSS 2018 will be held October 31st to November 2nd, 2018 in Singapore as part of SIEW and ACES. It is anticipated that IFSS would also travel to other locations or continents in the future, if the demand arises.

Conclusions

Floating solar is on the best way to become a third pillar of the solar industry. The deployment growth is breathtaking, but certain issues need to be addressed, such as electrical standards and environmental impacts. Singapore has positioned itself as knowledge and know-how hub for floating PV and will continue to drive R&D efforts and work with the industry to develop innovative solutions and suitable standards. ■

The author would like to thank Liu Haohui, research fellow, PV system technology at SERIS, and Zhao Lu, head of PV system technology at SERIS, for their contributions to this article.

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Author

Dr Thomas Reindl is the deputy CEO of SERIS and principal research fellow at NUS. He started with PV in 1992 at the SIEMENS Corporate R&D Labs. After holding several management positions at SIEMENS and running one of the leading German PV systems integration companies as chief operating officer, he joined SERIS in 2010 and became director of the Solar Energy Systems cluster. During his time at SERIS, he has won public research grants in excess of SGD20 million, founded two spin-off companies and authored strategic scientific papers such as the "PV roadmap for Singapore". His research interests are high-performing PV and embedded systems, including BIPV and floating PV, techno-economic road mapping and the reliable integration of renewable energies into power systems".

Turn to the following page for our in-depth case studies exploring how floating PV is already being deployed around the world.

Credit: Seaflex

Monsoon rising: An anchor for India's floating PV dreams

Projects | The huge potential offered by floating PV technology is already being realised in a variety of regions. In a series of case studies, Tom Kenning and Liam Stoker explore some of the trailblazer projects and the challenges they faced in execution

India is in the midst of a frantic large-scale solar tender bonanza that seeks to emulate China's colossal PV deployment. Doubters say the plans are ill-timed given the Indian sector's stuttering at the hands of various trade disputes and additional taxes, but the hunger for new capacity could be satiated through a promising new outlet. A 10GW consultation exclusively for floating PV has been issued by the Solar Energy Corporation of India (SECI) and it is conceivable that no such plans would be on cards had it not been for the completion of a humbly sized but strategically significant project in the southern state of Kerala. Given its size and potential, India was a relative latecomer to the multi-gigawatt solar markets of the world stage and its module procurement remains stuck at the low end of product ranges on offer. However, floating solar, the up-and-coming saviour of PV's traditional land constrictions, could turn out to be a technology on which India is amongst the early adopters on a grand scale.

With plenty of hydroelectric reservoirs in certain states and a vast number of manmade ponds used by thermal power plants, there is no shortage of water bodies to keep India's floating pioneers busy. But first, the industry needed proof that such projects could work in India, which is a market seen by many as somewhat tricky.

No doubt under the watchful eye of the central government in 2015, one state utility, Kerala State electricity Board Limited (KSEBL) went about tendering for a 500kW system at the Banasura Sagar reservoir in Wayanad, which now stands as the largest floating PV plant in India following grid connection in late 2017. Local firm Adtech Systems, based in Trivandrum, won the tender and proceeded using modules assembled by Telangana-based manufacturer Radiant Solar and 32kW string inverters made by ABB, a firm that is well established in India and has service support locations in the city of Bangalore, not far from the project location. Two other major contributing firms were Floatels India and Regen Power, which is based in Western Australia.

KSEBL was not primarily looking for payback, says Raveendran T. Nair, vice president, projects, Adtech, because the aim of the floating plant was more to act as a technology demonstrator. As the utility of Kerala, a green and tropical state with plentiful rainfall, KSEBL was also looking to make the most of its many reservoirs. Moreover, as one of India's most densely populated states, Kerala has expensive land, which gave added impetus to the search for viable alternatives to land-based projects. Likewise, Nair believes the utility had no worries about the long-term outlook for floating PV tariffs once the technology becomes widespread in India, given the extreme drops seen in utility-scale ground-mount prices across India in recent years. With this confidence, the stakeholders in the Wayanad project chose to focus on using highest quality materials and components to make it a successful proof-of-concept undertaking. Total project cost was INR92.5 million (~US$1.46 million).

While the surrounding area was scarcely populated before the government procured the land and built a dam to support the Kakkayam hydroelectric power project in 1979, many locals were displaced when the dam project was started. It remains the largest earth dam in India and the second largest in Asia. Regular dams are made of concrete, whereas this is made of an earth embankment that is nearly 100 kilometres in length, adds Nair. Now the site attracts tourists drawn by many surrounding waterfalls and smaller lakes and adventure sports.

To test project viability in this location, a scaled down 10kW version of the system was installed in the same reservoir by Vaatsa Energy, a young start-up company with technical support from Floatels, says M.R. Narayanan, chairman of Adtech Systems and managing director of Floatels India.

Bar a few minor cuts, the next 500kW was completed without accident although Nair says the main challenge was constructing the floating platforms due to a lack of suitable facilities on site. Progress slowed down for this period due to the site's lengthy distance from any main industrial base. As a comparatively new reservoir, the soil around it was soft, meaning that mechanised equipment could not be taken near to the shoreline. Such difficulties would be less likely in other locations around industrial or thermal power plants, adds Nair.

The solar plant will not affect the quality of the water in any way, Nair assures, claiming that there are no effluents from the equipment and even forecasting that the structure might improve fishing figures by providing a section of water that is shaded and therefore of a lower temperature than the rest of the reservoir. The environmental effects of floating solar are certainly a concern in the industry and it is not just water quality that causes concern. The impact of a sudden lack of sunlight on biodiversity in these water bodies is often raised as a potential problem, but has not yet been well-studied in the context of floating solar as far as *PV Tech Power* is aware.

The system

The project involves fibre-steel-based floats that were designed with ferrocement, which involves applying reinforced mortar or plaster over layers of metal to create a hollow structure, making the project very stable, says Narayanan. "Our company has been specialised in making

Credit: Seaflex

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ferrocement platforms and floating structures for the last 20 years," he adds. "They are guaranteed for a 50-year life."

Unlike similar materials, the ferrocement uses either welded mesh or expanded metal to make the metal to mortar ratio higher, so that if taking a cross-section, the metal content will be higher than in regular concrete. Nair is surprised that it has not become a more popular material since it is thin, lasts well beyond 50 years and requires little maintenance.

"With steel it tends to rust – you have to scrape and bend it and all that, whereas this needs no such maintenance," he adds.

Each floating platform has one string inverter. The 415V from these inverters is fed to the ELT 415V switchboard, which is then transformed to 11kV. An 11kV XLP underwater cable, from major Indian cable supplier APAR, has been laid along the bed of the reservoir to the shore. Many other floating solar designs have the cables above water, but in this case the reservoir attracts many tourists for boating so underwater cabling was required to prevent any hindrance to those activities. Adtech also felt that it was more aesthetically pleasing to have the cables hidden.

Generation benefits

Being located on top of a hydro plant means the solar generation can support daytime peak load and more hydro power can be reserved for the evening peak, says Nair. It's a major opportunity, particularly in Kerala, given that almost all of the state's locally generated power comes from hydro already. The state relies on energy imports from other states for a significant portion of the rest of its power mix.

"The water available in these generating stations in the reservoir is not sufficient for running these hydro generators for 24 hours, 365 days so they have to stop the generators over substantial periods," adds Nair. "So instead of that they can run the hydro plants during night and you can utilise the solar generation during daytime."

The hydro plants also guarantee that transmission infrastructure is already available in close proximity to any co-located floating PV plant. Nair describes this as a "win-win" situation.

From a logisitics perspective, while the Banasura Sagar reservoir is remote, it was still relatively accessible by lorry, being located just 20 kilometres from the Calicut-Mysore-Bangalore road.

O&M

Adtech was awarded the EPC contract for the project by KSEBL as it put in the lowest price bid, and under this contract it must perform O&M services on the plant for a two-year period; subsequently it has to maintain the equipment in case of any faults for another four years.

Cleaning the plant is easy given regular rainfall on location for nearly six months of the year, which naturally washes the panels. Dust, which can cause soiling of the panels, is also minimal at the location. Of course there will still be occasional build ups of sediment on the panels and the two-man team uses long handheld mops to clean them. They brush using rainwater as it falls or pump water onto the panels from the reservoir itself. An ABB remote monitoring system keeps tabs on each string feeding the inverters and can record energy generation statistics.

Tenders

With the successful completion of the project, the government is now scanning the rest of India to see where the opportunities lie and how much appetite there is. Besides hydro dams, industrial units and thermal power ponds are the most obvious targets for now and Nair says they are a multi-gigawatt prospect.

Since the project was completed, Adtech has received enquiries for dozens more megawatts of projects, Narayanan adds, which demonstrates a desire to try out this technology already at this early stage.

To drive the technology further, Nair suspects that KSBEL will now go down the tender route to procure more floating PV, although he expects there to be strict prequalification requirements. ■

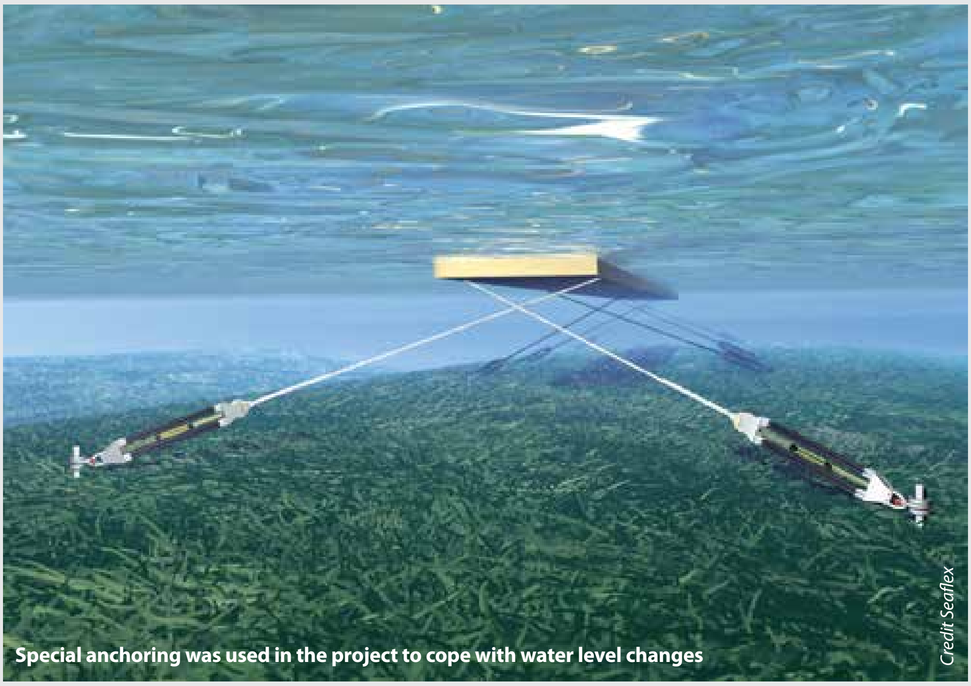
Anchors and huge water level variations

The main challenge for the project was a water level variation of up to 25 metres between summer and monsoon seasons, says M.R. Narayanan, chairman of Adtech Systems, so the firm had to procure and design special anchoring systems to ride the variations as well as high-speed wind conditions while lasting 25 years.

Swedish specialist in mooring and anchorage systems, Seaflex AB, supplied the Wayanad project. Company CEO Lars Brandt says that harbours and marinas from around the world have done business with Seaflex to make use of its floating marine structures. A Seaflex representative visited the Indian project in March 2017 to survey the site and surrounding area. Based on these details Seaflex designed the anchoring system and Adtech installed it.

Withstanding the huge water level variations was a key challenge. For this, the anchoring system uses a patented polypropylene rope assembly where the ropes, tied to the floating structure on the surface of the water above and to the anchors on the bed of the reservoir below, can stretch to roughly 70% of their initial length. A total of eight anchors were used to allow the floats to withstand wind from several directions and the slight stretching of the elastomer rope can alleviate the wind forces.

The depth of the reservoir at the plant location is around 35 metres when full. As the water levels rise and fall with seasonal rains, the ropes can stretch or contract as necessary. The stretching rope means that once assembled, installed, tested and put in place it operates automatically without requiring any external forces.



Credit Seaflex

Special anchoring was used in the project to cope with water level changes

Malaysia's first grid-connected floating PV project: a matter of national security

A reservoir supplying drinking water to the people of the Malay Peninsula was the chosen site for the country's first grid-connected floating solar plant under the feed-in tariff programme. The prestigious location meant that the developer not only had to take the risk of using a relatively young technology, but also had to take care not to disrupt a site of national security.

Local firm Cypark Renewable Energy (CRB), a subsidiary of Cypark Resources, built the 270kW floating PV project at the Ulu Sepri Dam using equipment supplied by specialist French firm Ciel & Terre (C&T), which to date has dominated the floating solar space globally. C&T offered its Hydrelio support, taking charge of engineering the 'solar island' and anchoring system design. The bottom anchoring was designed to meet a maximum depth of 45.6 metres and a seasonal level variation of 17.5 metres.

A total of 900 solar panels were used to cover around 1.5% of the roughly 18-hectare water surface. Bin Ibrahim says Cyparks's in-house research team conducted tests on several module brands and from those it studied performance and several other factors before selecting components. These parts have to last 21 years as CRB signed a 21-year power purchase agreement (PPA) with TNB, the national utility.

"Our company uses equipment from tier-one suppliers," says Achmat Nadhrain Bin Ibrahim, general manager at Cypark, remarking on the chosen 300W modules from China's Bluesun for the project. "We emphasise quality performance and reliability; we also look into the company's position in the market – whether they are financially sound or stable."

This is not the first floating project located on a reservoir used for drinking water. Indeed, UK developer Lightsource's project on the Queen Elizabeth reservoir just south of Heathrow, London, is also above a major drinking water source. However, the Malaysian project is located upstream at the first reservoir which collects all the water before it goes on to a feeding reservoir.

The Malaysian project took close to three years to obtain a permit because of the stringent compliance rules at what is a national security location. To assess environmental impact, Bin Ibrahim says the company did its homework and had to produce plenty of data to comply with the wishes of the authorities.

Inverters from Germany-based supplier SMA were chosen for the project, says Bin Ibrahim, and they were placed on land rather than on the floats given the relatively short distance between the solar island and the shoreline. Moreover, the company felt that managing risk as well as managing O&M of the inverters would be easier on land.

Cypark's other floaters

Cypark had already been a frontrunner in the Malaysian large-scale PV market, having secured EPC contracts in the first Large-Scale Solar (LSS) auction and bagged more floating PV contracts in the second, most recent LSS round. From this second tender, the firm is developing a 30MW(AC) floating project at the Terip Dam and has been awarded an

EPC contract by Cove Suria for another 30MW(AC) floating PV project at the Kelinchi Dam in Negeri Sembilan, which is also on the Peninsula of Malaysia.

Cypark also built what was at one time the largest solar project in the country standing at 13MW under the feed-in tariff (FiT) programme. The firm looks forward to participating in many more solar tenders, which it believes the government will be rolling out on a regular basis to meet its renewable energy targets. As well as being a fully fledged turnkey EPC contractor and project developer, Cypark offers financing for developers so they do not have to come up with securities or conventional finance tools themselves.

The Ulu Sepri floating project did pose some unique challenges compared to CRB's previous ground-mount endeavours. Logistically, getting equipment to the site was straightforward but launching the floats onto the lake was troublesome since the launching site was particularly small, says Bin Ibrahim.

"It's very similar to floating solar projects around the world," he explains. "The challenge is the same, but every site poses a unique challenge or concern. In this case, the launching site was small, so we had to adapt to what land was available to construct the plant."

Even so, Bin Ibrahim believes that the company's experience with land-based solar still helped it execute the floating project with great efficiency.

Malaysia-wide

The overall opportunity for floating PV in Malaysia is significant, says Bin Ibrahim, with plenty of dams, hydroelectric projects and recreational lakes available, but getting approval is hindered by the fact that different locations have different authorities and there are no standard requirements for this technology.

"That's expected because nobody has done this before," he adds.

Nonetheless, CRB found advantages in using the technology. For example, the module efficiency gains recorded by C&T in a water-cooled environment were also confirmed by Cypark's own research and the project's performance to date has been in line with such expectations.

Bin Ibrahim also speculates that the floating structure of the Ulu Sepri project could be used to rear fish in the future, citing companies in Scandinavia that have managed to combine similar floating structures with raising salmon.

It's not the first time Cypark has considered dual-use for a solar project. Indeed, it was a pioneer in agricultural solar when it built a 1MW solar system across 2 hectares of land also used to grow various crops including rock melons and chillies. There were challenges in securing the land, says Bin Ibrahim, and this drove Cypark to go down the unconventional route of applying to use the land for both energy generation and farming.

Cypark has clearly been an innovator in Malaysia, but the LSS auctions have attracted plenty of international attention.

"We worked hard to get this position," adds Bin Ibrahim. "But when you are leader, where you are ahead of the train, there's a big lorry with a bigger carriage following behind you." ■

Europe's floating PV pathfinder

Lightsource and Ennoviga Solar partnered to install more than 23,000 panels on floating pontoons, covering the Queen Elizabeth II reservoir near Walton-on-Thames. At the time of completion it was not only Europe's largest floating solar project, but also the world's first to be installed on a deep water reservoir. The system has a capacity of 6.3MWp, covering 9% of the reservoir.

The array was several years in the planning before it was connected in 2016. Formal plans first surfaced in 2013, with Thames Water – the benefactor and off-taker – successfully claiming it to fall under permitted development rights. This quirk in UK planning law means the system did not require formal planning and, by extension, a full environmental impact assessment.

The system was made achievable by the two developers bringing in Ciel et Terre International. The French floating PV pioneer supplied the floating pontoons for the project in what was the company's largest outside of Japan at the time of completion in 2016. Lightsource managed the installation of the project with Ennoviga, Thames Water's frequent solar EPC.

A total of 23,046 panels are kept afloat by a platform consisting 61,000 floats, held in position by 177 anchors which were secured during its installation by professional divers.

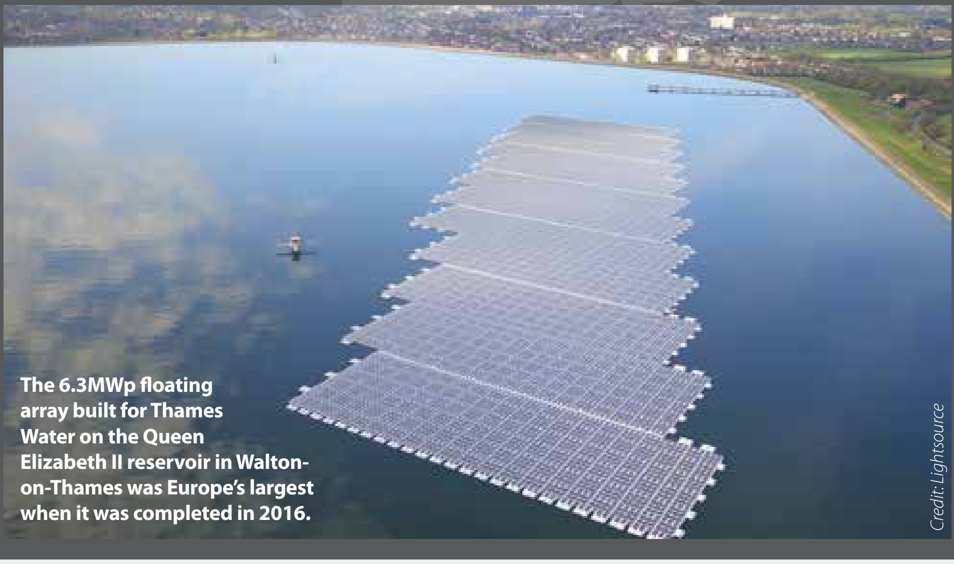
The project was borne from Thames Water's ambition to generate one-third of its own renewable energy by 2020, a significant increase from the 12.5% it achieved in 2014/15. While the water utility currently has solar on 41 of its sites across its operating area, the QEII floating solar array represented the largest single PV installation Thames Water had invested in to date.

Power generated by the site is supplied directly to Thames Water's private network under a power purchase agreement entered into with Lightsource, meeting roughly 20% of the water treatment facility's total energy demand throughout the year. Thames Water noted that water utilities are amongst the UK's most energy intensive industries, accounting for 2% of overall energy consumption each year.

In its first year of operation, the array was generated roughly 5.8MWh of electricity.

But maintaining the site has required new skillsets, techniques and procedures which Mark Turner, managing director at Lightsource's O&M division, says had been developed for the "challenging environment".

"Even on inland, fresh water floating solar can present a range of challenges for O&M providers such as access, soiling, corrosion and stress from continual flexing. These challenges should first be addressed during the design, specification and construction phase," he adds.



The 6.3MWp floating array built for Thames Water on the Queen Elizabeth II reservoir in Walton-on-Thames was Europe's largest when it was completed in 2016.

Credit: Lightsource

One floating PV installation – double the benefits

Credit: SolarEdge

When the De Krim Resort on Texel Island in the Netherlands decided to become more energy independent, its main requirements were the generation of green energy and an installation that would not be visible from street level.

The tender was awarded to Texel4trading because of its proposal to place floating PV modules on the rainwater reservoir used to irrigate the resort's golf course. This novel approach resulted in a number of benefits for the resort, and the installation also qualified for an incentive programme from the Dutch government (SDE+). The resort outputs the solar power it generates to its local public grid provider.

Floating installation – cost-effectiveness and increased yield

The placement of PV modules on the reservoir means revenue is generated from a property asset that would otherwise have had no financial yield. By repurposing the reservoir for the PV installation, the resort eliminated the need to allocate any other costly land and maintained the beauty of the surrounding environment. And, because the PV modules cover most of the surface of the reservoir, they reduce the amount of direct sunlight hitting the water, bringing an added environmental and financial benefit.

When fresh water is protected from direct sunlight, there is a two-fold effect. First, there is a reduction in the plant and algae growth on the water surface, which, if untreated, can cause costly damage to the pumps in an irrigation system. And second, there is a reduction in water surface evaporation, resulting in a preservation of valuable fresh water. As a consequence of this effect, the resort expects to reduce fresh water losses by up to 30%.

Based on a predicted PVsyst performance ratio of 0.9, the installation is expected to generate 700MWh per year; however, placing the modules on the reservoir produces a natural water cooling effect which should improve PV system performance.

Texel4trading manager Nicol Schermer explains: "This cooling effect has been shown to produce greater energy generation and, based on results from previous installations, Texel4trading expects that the floating solar installation will generate between 770MWh and 800MWh per year, some 10-15% more energy compared to a similar ground-mounted installation. This will offset the additional costs of installing a floating installation. We are seeing growing interest in installing floating solar parks to conserve fresh water, including at hydroelectric plants and especially in arid countries."

Meeting the challenges of a 'floatovoltaic' installation

Floating PV installations come with a great deal of benefits, but also have unique design and maintenance considerations. Modules and components require planning for attaching on to concrete pontoons or plastic floats. The fact that the modules are located on water makes on-site monitoring and maintenance of the installation, and the safety of maintenance personnel, potentially more challenging due to location and access issues. SolarEdge power optimisers monitor the performance of modules and communicate performance data to the web-based SolarEdge monitoring platform, reducing the number of actual site visits needed and the time spent on-site in each visit.

Design flexibility and reliability

When working with SolarEdge inverters, SolarEdge power optimisers maintain a fixed string voltage, allowing installers even greater flexibility with longer strings and strings of different lengths in order to design optimal PV systems. Modules positioned at different tilts and orientations cause energy losses when connected in a single string to traditional inverters. With the SolarEdge solution, energy yield from each module is optimised independently, eliminating these energy losses.

As the De Krim Resort is located in close proximity to the sea, protection of the PV installation from the effects of the salt mist corrosion and other harsh environmental conditions was an important consideration when p lanning the installation. To this end, SolarEdge optimisers and inverters were installed together with modules resistant to salt-mist and humidity mounted on saline-resistant frames on concrete pontoons in the reservoir. Having long warranties, SolarEdge inverters and power optimisers are designed to respectively meet IP65 and IP68 ratings for water and humidity resistance and are suitable for saline environments. ■

Credit: SolarEdge