

# Floating solar PV on dam reservoirs: The opportunities and the challenges

It is well acknowledged among policy makers and professionals in the renewable energy sector that floating PV installations on dam reservoirs, and other solar-hybrid systems, have a strong and promising future role to play, and that a vast potential can be exploited, especially in developing countries. However, this emerging technology is not without its complications. Thus, the SOLAR-HYDRO 2021 on-line conference in July served to bring together safety experts, economists, environmental scientists and others within the hydropower, dam engineering and solar PV sectors, for two days of practical discussions and sharing of experience.

The great value of experts from the solar sector and the dam engineering profession coming together to exchange experience on floating solar PV on reservoirs, and to learn from each other, was acknowledged repeatedly during this two-day event, and it was possibly the first event which did assemble so many specialists on ‘both sides’, to discuss the complexities, as well as the established advantages, of this relatively new technology.

The event was co-hosted by ICOLD and Aqua-Media International.

In several sessions, the need for standards and guidelines to be established for this rapidly emerging technology was highlighted, and it was suggested that organizations such as ICOLD, IRENA and IEA could all have a valuable role to play.

The sessions and panel topics had been planned to address some of the issues where research is still underway, and lessons are being learnt from schemes already in operation.

This report, jointly prepared by three members of our editorial team, presents highlights from two sessions of paper presentations, and four panel discussions.

## Opening addresses

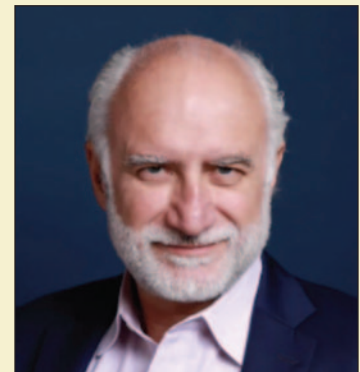
ICOLD President Michael Rogers, in his opening address, drew attention to the vital role of dams and levees in providing critical infrastructure globally, improving the lives of billions of people through the provision of water, power and flood protection. He stressed the particular importance of water storage in view of concerns about climate change.

He explained the role of ICOLD, since its creation in 1928, in advancing the science and art of dam engineering. Speaking later of the vast potential for the synergy of energy from the sun, water and wind, and in particular for solar systems on reservoirs, he said ICOLD was committed to harnessing knowledge and experience from experts around the world, and for

sharing lessons learnt, the challenges and also the solutions. He felt this conference was a great opportunity to discuss the nexus of solar and hydropower.

In her welcome message to delegates, Aqua-Media Director Alison Bartle, echoed the importance of ICOLD’s work, and in particular the work of the Technical Committees. She explained that this conference had come about as the Chair of one of these Committees, Luc Deroo of France, had proposed a session for AFRICA 2021 in Uganda, which had had to be postponed. His Committee on Emerging Challenges and Solutions for the 21st Century, will be preparing a Technical Bulletin on FPV on dam reservoirs, and had thus put together the key topics to explore the relatively new technology. These topics then evolved into sessions for the two-day conference. Bartle continued that this conference, as with Aqua-Media’s international events on hydropower, was designed to be a platform for a practical exchange of experience, aimed at sharing the experience of existing FPV schemes on reservoirs, with delegates whose countries were embarking on such schemes for the first time. More than 40 countries had registered for the conference, from all parts of the world.

ICOLD Secretary-General, Michel de Vivo, expressed his view that the combination of solar and hydro was extremely promising for the future, when there was a huge need for clean energy. Many countries had developed FPV-DR systems, and the results were very positive. He added that the main financing institutions were now supporting floating solar parks on reservoirs. De Vivo summarized some of the main advantages, such as: preserving valuable land, and reducing environmental impact; reducing costs by using existing transformers and power lines; reducing evaporation losses, and improving water quality by limiting algae proliferation; improving the efficiency of the solar parks as the panels could be cooled and cleaned by water; and, the regulation of intermittent solar energy by the storage capacities of the reservoir.



From left, ICOLD President Michael Rogers, Aqua-Media Director Alison Bartle, and ICOLD Secretary-General, Michel de Vivo, who presented opening messages to the conference, on 6 July.



Klaus Jorde, the incoming Secretary of the IEA Hydro's Technical Collaboration Programme (TCP), explained that through the eight working groups, known as Annexes, IEA Hydro's role was to advance awareness and knowledge about hydropower, in the globally changing energy system. His organization shared the common understanding of the need to reach net zero global greenhouse gas emissions by 2050, and IEA had recently published its Roadmap to achieve that, which points out that clean energy from renewable sources must be doubled globally in the coming decades. Hydro, he pointed out, would play a major role in any scenario. He added that the role of hydro must change, from one of mainly supplying power, towards additionally providing for the integration of intermittent renewables. He felt that hydropower must be higher on the agenda of policy and decision makers. He referred to the World Bank's recent report 'When sun meets water', and commented that IEA's TCP would expand its focus to address this topic.

Luc Deroo, Conference Chairman, commented that solar-hydro would be key to electricity production over the next few decades, and he was pleased that the conference was taking place in view of the need to analyse the challenges, including that of safety. He quoted the research of the the National Energy Renewable Laboratory in the USA, which predicted that 7.5 GW of floating solar could be developed globally. While he felt that was perhaps a little optimistic, he said it was important to analyse what should be done to make it more achievable. He commented that there was not one single definition of solar-hydro, but several possible combinations. First, using the reservoir as the available area, and taking the FPV technology to floating PV on (large) dam reservoirs. Second, was combining solar and hydro production, either at a single location, as a hybridized development, or at different locations. The third variant was combining solar production with pumped storage, and one option for this would be the use of twin dams, which was to be described in a presentation.

He said the FPV on dam reservoirs had some specific challenges as well as opportunities, and for this reason, his ICOLD Committee was planning a Bulletin, which would address current technical issues. The four main issues to be covered would be: Design and costs; E&S issues; Dam safety; and Hybridization.

Deroo acknowledged that FPV-DR was not yet mature enough to provide definite answers, but this conference provided a unique opportunity to explore the topics.

### Session 1: Concept, global potential and design issues

This session presented the significant technical potential for this emerging technology as well as the various challenges to its wide-scale deployment on large dam reservoirs.

"I believe that solar-hydro is a key solution or maybe the key solution for the electricity industry in the next few decades, but I believe we still have challenges ahead before FPV can be safely installed on large dam reservoirs. Discussions among experts especially between experts from both the PV industry and the dam industry are therefore very useful," Luc Deroo, Chairman of ICOLD's technical Committee on Emerging Challenges for Dam Reservoirs, and CEO of French consultancy ISL Ingénierie, said in his opening presentation. Deroo's opinion of the vast potential for the combination of the two established technologies, which he described as "a possible game-changer", has been backed up by numerous studies. A study released last September by the US research centre, the National Renewable Energy Laboratory (NREL), estimated the global potential of hydro-linked FPV at up to 7.5 TW, which could generate a significant proportion of the world's future electricity.

While Deroo and industry colleagues are wholly convinced by the benefits of solar-hydro hybridization, the major challenge hindering its deployment is that, for now at least, it remains a new, largely untried technology, at least on large dam reservoirs. As a result, its current higher risk profile has a knock-on effect on the cost and ease of raising financing while numerous questions remain to be answered, noted Deroo, concerning safety for large dam operation, technical issues (most notably with regards to mooring and anchoring) and environmental, social and economic impacts of covering the surface of reservoirs, as well as for downstream users resulting from changes in the operating regime of hydropower plants.

From an economic perspective, the cost of FPV on dam reservoirs remains for now slightly more expensive than ground-mounted PV (GMPV). A cost comparison between 50 MWp of FPV and 50 MWp of GMPV in a 2019 study 'When the Sun meets Water' by the World Bank, ESMAP and Seris, put capex for FPV on a reservoir of just 10 m depth with minimum water level variations at US\$ 0.73/Wp versus US\$ 0.62/Wp for GMPV. Costs were most notably higher for the mounting system and for balance of system. Deroo acknowledged that FPV on a large dam reservoir would engender extra costs with respect to the mooring systems, which are more complex because of greater reservoir depths and water level variations, the longevity of the FPV because of large waves on reservoirs, and the need for various dam safety protective measures. But when taking into account certain benefits especially the better performance of FPV and the avoidance of land issues, it would have an almost equivalent leveled cost of electricity (LCOE), according to Deroo.

*Far left, Klaus Jorde, giving an opening message on behalf of IEA; and, Conference Chairman, Luc Deroo, who described solar-hydro as a key solution for the coming decades.*



*Some of the speakers in the first part of Session 1. Above: Conference Chair, Luc Deroo and Cindy Cisneros Tiango of the ADB; and below, Olivier Philippart of Ciel et Terre International, and Dr Cuiying Zheng of IWHR and CHINCOLD, China, who chaired the session.*

Many questions remained, however, with regard to the environmental and social impacts of FPV-DR, which required further investigation, said Deroo. Benefits of the technology include the avoidance of land issues and a reduction in evaporation while the disadvantages include the impact of light reduction on water quality, algae pollution and biodiversity. Analysis to date showed that up to 5 per cent of a reservoir could be covered with FPV with a negligible environmental impact; “But why only 5 per cent?” asked Deroo. In terms of solar-hydro hybridization, studies needed to look at how FPV-DR compared with alternative solutions such as GMPV associated with batteries, thermal power or grid strengthening.

FPV has to date been largely installed on shallow ponds, quarry lakes and industrial water, but less so on large dam reservoirs, which pose very different challenges and risks, according to Deroo and his colleague, Marine Bernicot, Director for Hydropower and New Energies at ISL Ingénierie, who presented a designer’s perspective of FPV and reservoirs. FPV on large dam reservoirs are exposed to strong winds and higher and more frequent waves, which could lead to early fatigue of the structure’s components, they noted. Dam reservoirs are also subject to greater variations in water levels requiring, for example, a specific design to maintain tension in the cables. Specific mooring designs would need to include fewer and deeper anchors, redundancy of mooring lines, installation of wave attenuators and regular monitoring and ease of serviceability of the moorings and structure. To ensure an optimal design, local appraisal of wind and wave conditions is critical, as well as specific appraisal of panel drag and uplifting coefficients (wind tunnels) and panel wave resistance (wave flumes) and numerical simulation of the interaction of FPV islands and reservoirs, said Deroo. However, evaluation of wind velocity is more difficult as a result of the topography around reservoirs, noted Bernicot, requiring numerical simulation and/or long-term on-site measurements. Significant water level variations would also mean specific designs were necessary to keep tensions in the cables, and prevent the structure from drifting, she added. While damage or failure of an FPV system on a water body without a dam could lead to loss of production and capital, it was not on the same scale of risk as the failure of a dam caused by a drifting FPV island, warned Bernicot.

### Disconnecting FPV and dam safety

The key concern for dam safety relates to an FPV island breaking its moorings and drifting away to either obstruct the dam spillway, or damage intake towers or upstream dam surfaces especially in the case of exposed geomembranes. “The preferred option is to disconnect the safety of FPV and the safety of dams”, stressed Deroo “meaning that if the FPV fails there is not a failure of the dam itself”. This could be achieved by various ‘safety barriers’ to prevent spillway blockage, such as anti-drifting devices, ensuring the location of the FPV island far enough away from the dam, and designing it to ensure that the wind would take it towards the shore rather than the dam, and having large enough spillway dimensions or protection in front of the spillway. This could be cheaper and safer, according to Bernicot, than an alternative option to guarantee a ratio of risk for the dam that is low enough to be acceptable, by reducing the probability of failure

of the FPV through strengthening of the design criteria, such as a lower return period wind. A study carried out by ISL for a project in France had shown that almost double the number of anchors would be required for a project with a return period wind of 10 000 years to one of 50 years, with a consequent impact on the cost and in turn on its price of electricity. “Moreover assessing the structural safety of a FPV island under extreme wind conditions can be tricky both because of the uncertainty of the wind estimation and because of the complexity of the calculation itself. This implies redundancy, safety factors and, of course, careful monitoring to anticipate problems”, Bernicot said. To lower risk, load could be reduced by shaping the island to limit exposure to the wind and to carry out R&D on the structure’s shape to minimize the drag coefficient, as well as by installing upstream barriers at the entrance of the reservoir if it is prone to floating debris, to avoid accumulation against the FPV structure.

Deroo recommended that the best way forward would be to phase development, starting with small-scale projects to monitor behaviour over a few months so that larger projects could be developed with greater confidence.

“There is no formal regulation so far relating to FPV and the best option as always will probably be a smart combination of everything,” said Bernicot. “Some countries such as France and Indonesia already require extensive risk analysis to authorize the construction of FPV on dam reservoirs,” she continued. “Administrations are learning, as we are. I believe this is of high importance for projects to be exemplary and pave the way to the definition of industry good practice. ICOLD, indeed, might well be the right entity to work on such a framework”.

Presentations by Ciel & Terre of France and Innosea, an engineering subsidiary of AqualisBraemar LOC Group, a global energy and marine consultants, provided some lessons and solutions for anchoring and mooring of FPV on large dam reservoirs, based on their extensive international experience.

Ciel & Terre, the manufacturer of the Hydrelío® technology, a patented PV concept consisting of modular ‘lego-type’ floaters assembling into rows, has installed more than 575 MWp of FPV at 230 projects in 30 countries since 2011. In addition to the manufacture and supply of this technology, it provides engineering expertise, development support and EPC support for FPV. In terms of anchoring, Olivier Philippart, division director of Hydrelío® at Ciel & Terre International, explained that the company systematically simulated stress concentration and put elasticity into mooring lines as well as carrying out as-built surveys and design, which he said were important to ensure that the reality reflected what has been designed. To ensure that structure specificities were taken into account in the calculations for the anchoring system, in-situ testing was carried out to correlate structure simulation as well as dynamic analysis for mooring systems, based on the experience of the offshore oil and gas industry. Philippart pointed out that the Yamakura dam FPV had been reconstructed with a Hydrelío® structure, incorporating the lessons learnt from the accident in 2019 and from other projects. In terms of dealing with structural fatigue, Ciel & Terre had just completed the design and development of a wave breaker, which it is to install on all new projects on large dam reservoirs.



Innosea has been involved in more than 60 projects exceeding 1290 MWp including more than 35 projects totalling around 670 MWp on dam and irrigation reservoirs. To support FPV development in harsher environments on, for example, large dam lakes, mooring system designs and configurations were becoming more and more complex, according to Benoat Danglede, a mooring engineer at Innosea. Today, mooring systems for FPV are generally similar, with a choice between using the bank or bottom of the reservoir, tensioned or a catenary mooring system and either a mutualized system with different lines on one anchor or a system without mutualisation. Mooring systems typically comprise many lines and anchors. This, said Danglede, resulted from the same characteristic of all floater technologies, that as floaters are the main cost of FPV, developers seek to minimize their number and weight. However, this led to relatively weak mooring connection points and required a high number of lines to withstand the same environmental loads, he said. Ongoing innovation and development of new mooring systems would help manage risks but would also extend the use of FPV to new types of sites and conditions, he added.

Planning and development for a typical FPV project could take from three to five years, with five years more generally for projects on large dam reservoirs, according to Félix Gorintin of Innosea. Specific challenges to large dam reservoirs included the fetch over large reservoirs which could induce large waves typically of more than 2 m and which could severely impact both the layout and floater selection, he said. Seasonal water variation could also cause severe operational challenges for both design and construction planning, while site accessibility could limit the size of the installation. Solutions suggested by Innosea included: changing the location of islands and moving them towards more protected areas; the addition of wave breakers; and, the design of specific moorings and floating structures to resist more extreme events. “At the design phase it is crucial to cross check data sources to assess the environmental loads better, in particular extreme winds and directionality, while pull-out tests in the detailed design phase for the anchor selection is crucial to finally choose the best anchor design,” added Danglede.

From the various choices for floating systems, high strength, composite concrete buoyancy tanks and bracket systems were recommended as the cheapest, most adaptable for large water variations and easiest to install, according to Sun Changjiang, a Project Manager at PowerChina HDEC. Based on his compa-

ny’s experience as the EPC contractor for the 47.5 MWp FPV on the Da Mi hydropower reservoir in Vietnam, Changjiang said that high strength composite concrete buoyancy tanks and bracket systems had been marginally cheaper at \$0.192/W compared with \$0.2/W for a floating pipe system and HDPE buoyancy tanks and bracket systems. Anchor block anchoring systems were, meanwhile, better for deeper water reservoirs and poor geological conditions, while pipe anchoring systems were better for shallower water and good geological conditions. Changjiang said that the FPV at Da Mi had been anchored to the bank using concentrated foundations with each foundation used to secure several mooring ropes of sufficient length, to enable movement during large level variations.

### Benefits of solar-hydro hybridization

Solar-hydro hybridization has many virtues at all time-scales and offers a wide range of benefits. There are various solar-hydro hybrid options from slightly hybridized solar hydro (ShSH) to full solar hydro (FSH) but the main objective is to take advantage of the storage capacity offered by a hydropower reservoir to transform variable solar into a more dispatchable form of energy, and facilitate in turn the integration of solar PV onto the grid. It offers complementarity at every time scale. On a minute-by-minute scale, hydro can smooth out the cloud effects on solar power production. At a daily scale hydro can store a share of solar production and on a seasonal scale with distinct wet and dry seasons increased solar production could help conserve water during dry-sunny seasons.

Synchronizing the operation of solar and hydro can therefore produce fully dispatchable renewable electricity and improved system operation at different time scales, as well as greater availability of water in dry seasons or years and for other purposes such as irrigation. In addition, it would reduce PV curtailment, and lower interconnection costs and water evaporation rates, but increase firm capacity by displacing hydro output from day time to peak time, as well as average annual hydro production as a result of increased reservoir levels allowing higher power per m<sup>3</sup> turbed. Studies carried out by ISL Ingénierie on the feasibility of installing a 70 MWp FPV at the Manantali reservoir in Mali had shown that the hydropower plant would generate up to 5 per cent more power from the same amount of available water, according to Bernicot.

“In our experience, hybridization at an existing hydropower plant always brings value, but must be finely tuned to meet other water users and to take into account the constraints of hydropower operations,” Deroo concluded.

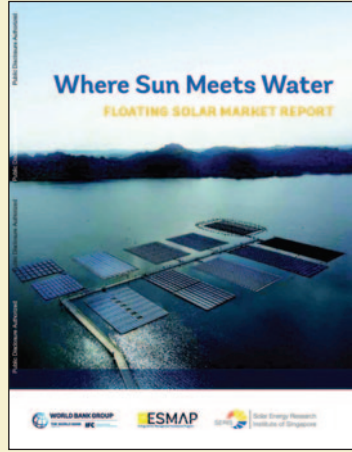
### World Bank backs solar-hydro hybridization

Multinational financial institutions have been quick to recognize the potential and benefits of solar-hydro hybridization, but also the support such a new concept will require as it makes its first steps. The World Bank is taking a keen interest in the opportunities of developing solar with greenfield hydro or by installing solar at existing hydropower facilities. Its role entails raising awareness of hydropower-connected possibilities, supporting regulatory considerations and de-risking investment in first demonstration plants, explained Bente Brunes, Senior Hydro Specialist at the World Bank under the Energy Sector Management Assistance Programme (ESMAP). From various project studies, it

*The FPV system on the Da Mi reservoir in Vietnam, discussed by Sun Changjian of PowerChina.*



*World Bank Senior Hydro Specialist Bente Brunes, who presented the Bank's perspective on FPV; and the World Bank floating solar market report, produced by the ESMAP team at the Bank.*



has developed a set of key characteristics for the design of solar-hydro hybrid plants. At the core is a master control system, which allows for the coordinated operation and connection of both hydro and solar with the management of other input variables, said Brunes. This enables the plant to satisfy its main objectives, which are to provide grid stability, enable optimal use of water and maximize energy production. The hydropower plant should ideally have fast regulating units and a reservoir with a minimum daily storage capacity, she said. The solar component is more adaptable, given its modular design and can comprise FPV or GMPV or a mix and match depending on the reservoir and on available land. Attention also needs to be paid to the E&S design to adhere to the requirements of IFIs such as the World Bank. The benefits of solar-hydro hybridization are especially noticeable in areas where there are pronounced dry and wet seasons, such as in the case of the Manantali hydropower dam in Mali, which was the subject of a World Bank-financed study. Two options were studied from adding 70 MW solar to the existing 205 MW plant, increasing annual generation from 840 to 992 GWh, or a 170 MW plant, which would increase generation to 1165 GWh/year. The study showed how hybrid operations would result in a higher reservoir level in the dry season.

#### ADB support for FPV in the Pacific Islands

The Asian Development Bank (ADB) views FPV as a key solution to overcoming energy, food, climate change and economic insecurity across its 14 Pacific Island member countries. “FPV is a low-carbon adaptive technology that is set to become the platform for transformational development in the Pacific,” said Cindy Cisneros Tiangco, a Principal Energy Specialist in the ADB’s Pacific Department. “Solar PV is the least-cost generation technology in the Pacific, and FPV is therefore well placed to tap the enormous water and solar resource potential in the region. FPV can also integrate sustainable value-added end-uses beyond electricity to create multiple revenue streams,” she continued. It could power fresh water supply systems including desalination plants, aquaculture, vertical farming and even alternative fuel production such as hydrogen. In addition FPV could incorporate adaptive nature-based solutions for coastal protection and reef regeneration. The development of FPV would also help reduce the Pacific Island’s overreliance on imported petroleum for energy and transport, and its huge outlay on fuel imports while reducing emissions.

*The accident which took place at the Yamakura FPV plant in Japan, during a typhoon in 2019. The failure mechanism was discussed in a presentation by experts from Nippon Koei.*

At present the 14 Pacific Island countries had an annual combined fuel import bill of more US\$ 1 billion. Around 65 per cent of these islands’ electricity supply was generated by petroleum products, she added.

To increase renewable energy investments, including FPV, in the Pacific the ADB has developed “innovative financial modalities”, including the 2017 Pacific Renewable Energy Investment Facility (PREIF), which uses a streamlined approach to process a large number of small projects with cumulative financing of up to US\$ 200 million up to 2024 that is expected to leverage US\$ 500 million in co-financing and private sector investments, and the Pacific Renewable energy Program (PREP) of 2019, which is a project financed and donor-backed guarantee programme for private sector financing. Both the PREIF and the PREP will support and ensure the success of the ‘Preparing Floating Solar Plus Project in the Pacific’, which is designed to assess the potential for, and develop a roadmap for, financing FPV in the smaller islands. Cross-sectional integrated FPV projects in Kiribati, Tonga and Tuvalu are being processed under the PREIF, for implementation within 2022-23, while the next set of projects in other islands will be undertaken up to 2025. The technical assistance will also prepare innovative business models and procurement and capacity building. The ADB has also embarked on several FPV initiatives elsewhere in Asia. Its private sector arm successfully financed the 47.5 MWp FPV on the 175 MW Da Mi hydropower reservoir in Vietnam, while regional initiatives are ongoing in Central and West Asia and South Asia (India, Bangladesh and Nepal) where the ADB has provided technical assistance for pilot testing, scaling up, building expertise in FPV, formulating innovative financing to encourage private sector financing and institutional capacity building.

#### Lessons learnt from Yamakura dam accident

Land scarcity in Japan offers a promising opportunity for the development of FPV to promote the further deployment of solar power. Japan has an estimated total potential FPV capacity of 39 GW on around 210 000 irrigation reservoirs, according to the New Energy and Industrial Technology Development Organization. However, the failure of one of its first FPV projects, a 13.7 MWp FPV plant on the reservoir impounded by the Yamakura dam in the Chiba



Prefecture near Tokyo, as a result of a major typhoon in September 2019 highlighted technical and safety issues that still need to be addressed. Stress deviation and concentration was identified as the first cause of failure of the floating facility, according to a presentation by J. Fukuwatari and Y. Ueda of Nippon Koei, a Japan-based engineering consultancy.

The presentation of the failure of the FPV plant was based on the findings of a technical working group set up by the Ministry of Economy, Trade and Industry (METI). The stress deviation and concentration, which was confirmed by stress analysis in the area adjacent to the first anchors to be pulled out of the ground, was the result of the non-rectangular shape of the FPV island, which mimicked the shape of the reservoir, said the presenters. The stress deviation caused the force deviation acting on the anchors to be greater than the design force, leading to a ‘failure chain’ to adjacent anchors and connection pins. The anchor arrangement was also considered as a cause of failure. Six main factors for the failure of the FPV facility, which caught fire and resulted in the destruction of about 77 per cent of the solar panels, were identified and examined by the technical working group. Although the maximum wind speed during the typhoon was greater than the design capacity of 41.53 m/s, wind speed was determined not to be a cause of failure. The design wind force, meanwhile, exceeded the forces experienced during the typhoon, according to model testing and CFD analysis.

The wave calculation results identified an additional force of 0.4 to 2 per cent acting on the anchors and connecting pins, but these values were not considered to be the cause of the failure either. The effect of repeated loading on the anchors and connecting pins was also assessed by stress analysis, but no deterioration was detected. Conversely there was an identified problem relating to the foundation strength of the anchors. The working group also concluded that redundancy and fail-safe concepts should be considered in the design standard as the failure of only a few anchors caused a ‘failure chain’ of the entire FPV system. In addition, the safety factor of the anchor design was ‘1.2’ from the mechanical uncertainty of anchor material. However, the uncertainty of the ground conditions was not considered. It was not considered a direct cause of the accident but the safety factor should be revised, it was found.

Based on the working group’s conclusions, the FPV facility has been reconstructed with amendments to the design of the float and anchoring system. This included most notably a change in the shape of the float system to divided rectangular islands as the rectangular shape mitigates stress deviation and concentration, while division of the floating system prevents a localized failure becoming a system failure. In addition, extra reinforcement measures were applied, including the installation of additional connecting wires between the floats, use of reinforced connection pins and additional weight to prevent rolling up of the float system. The working group’s findings were shared with all FPV owners and instructions were sent out in April 2020, including the requirements to check the safety of FPV against possible forces and loads acting on the floating structures, and if necessary take structural reinforcement and carry out inspections to check any damage or deterioration of the components. However, the engineers from Nippon Koei noted that no dam or civil engineer had been sufficiently involved in the



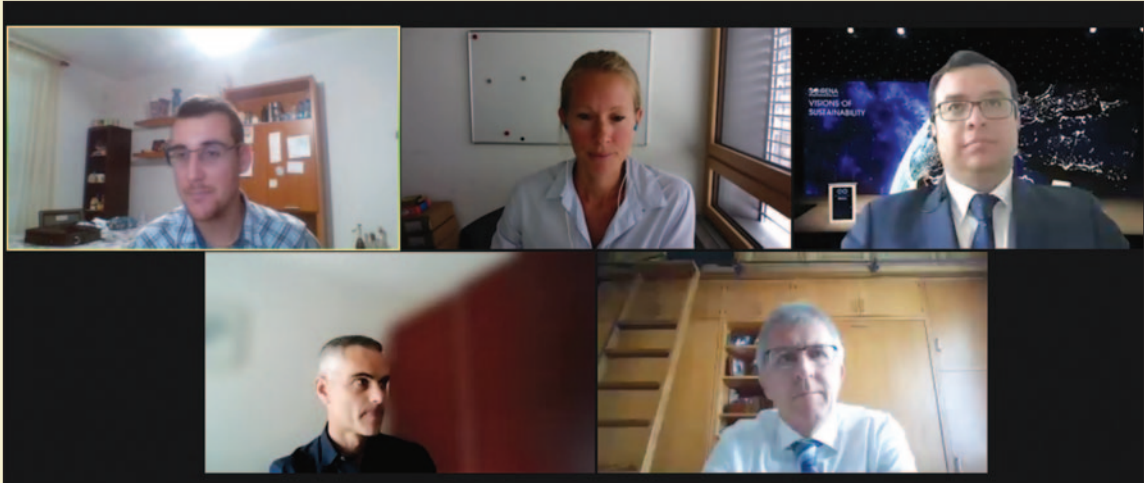
discussions of the working group, and that risk management had not been discussed, despite the FPV island having drifted close to the intake tower and saddle dam. The more active involvement of dam and civil engineers in terms of safety and the future development of FPV would be desirable, they concluded.

*The speakers in the second part of Session 1.*

#### **Establishing good practice and quality standards**

Finding the right balance between ensuring safety and managing risks on the one hand, and driving down costs on the other hand, is imperative to avoid further accidents such as that at the Yamakura dam, stressed Michele Tagliapietra, a Project Manager at DNV, a Netherlands-based independent assurance and risk management company. “If we keep trying to push down the costs to ground-mounted solar PV levels without taking on board properly the new challenges, we will see more accidents again and again. Costs are decreasing and are getting close to ground-mounted PV levels, but that should not be the main driver for FPV and should not come at the cost of safety and liability. Avoiding land use, finding alternative areas for FPV and combined operation with hydro dams should be the real advantages and drivers”, he said. “FPV is still a niche market, and is still potentially subject to failure but growth could stop abruptly if there is a decrease in appeal and trust because of additional failures,” he continued. “However, if knowledge sharing is promoted and quality and trust are increased thanks to best practices and standardization, then the market can grow to its full potential.” To help achieve market growth, DNV published in March 2021 the world’s first floating solar recommended practices, a joint industry project, with input from 25 companies involved in FPV across the value chain. The document provides a comprehensive set of requirements, recommendations and guidelines for the whole lifecycle of FPV projects, with a focus on FPV projects in inland and near-shore water bodies, and covers feasibility and design to installation and O&M as well as health and safety. The ‘Recommended Practices’ can be used in various ways, explained Tagliapietra, from providing guidance and reference to enforce FPV specific requirements, or as a checklist while developing and designing projects. It can also be a useful document to those seeking an introduction to the technology or to increase understanding of FPV. “We believe that if these recommendations are followed, then the quality and reliability of FPV around the world is going to increase, ultimately boosting development of the

The panellists who contributed to Session 2, which was chaired by Emanuele Quaranta, from the EC's Joint Research Centre (shown top left),



industry as a whole,” he added. Specific recommendations for FPV applications in hydro dams include ensuring detailed assessment of geological, wind, wave and water variation levels for the design and installation of anchoring and mooring systems. Studies of sedimentation and watershed profile developments, together with soil composition studies and assessment of the slope of the water bed at different locations are imperative to select the most suitable anchor system. “The recommended practices are an important step towards standardization and a fully safe and reliable FPV industry, but they only represent one step among many. We believe that it is important to reach and define internationally recognized floating specific standards and test procedures for components as well as system design standards. It will be even better if this were backed up by standard practices and certification,” he concluded.

### Session 2: Potential for FPV-DR

This session took the form of a panel discussion, chaired by Emanuele Quaranta, from the European Commission's Joint Research Centre, in Italy.

In his introductory talk, he drew attention to the enormous global potential for FPV, based on research by NREL in the USA, which indicated that 3 to 7 TW could theoretically be developed.

He first spoke of the benefits and impacts of hydropower, commenting that locally it was quite easy to weigh these, but on a regional scale, such as the European Union, it could be more complex. Compromises had to be made between adopting environmental safeguards, while also aiming to meet renewable energy targets. Quaranta moved on to the benefits of retrofitting existing hydraulic structures, one of the areas of study within the EU SustHydro research programme being undertaken at his institute. One sub-topic, he said, was the retrofitting of an existing hydropower fleet, considering different retrofitting strategies, aimed at improving generation and flexibility, without additional impacts. In this context, he underlined the benefits of adding floating solar PV at hydro reservoirs; this offered a number of benefits, he said, including the reduction in reservoir evaporation achieved by the presence of the panels. Studies suggested that this reduction could be up to 70 per cent. A study to quantify the energy gained by this reduced evaporation was being undertaken as part of the SustHydro research.

Francisco Boshell of IRENA gave an introductory talk on the role of FPV in the global energy transition. Looking at the current market status, he said that global installed FPV capacity in 2020 had been 2.6 GW, and there were already 339 projects in 35 countries. Accelerated growth could be noted in the last three years, he said, when 1.5 GW of the capacity had been implemented. China was the largest market for FPV, he added, with the highest installed capacity in the world.

Boshell observed that the scale of individual projects was also increasing, with examples being a 181 MW scheme in Taiwan, and a 150 MW scheme in Anhui, China. Although smaller, there were significant schemes in Europe, such as 27.3 MW in the Netherlands, and 17 MW in France.

He stressed the benefit of combining pumped storage with FPV, to provide flexibility to the grid. He summarized the grid services as: load shifting and a reduction in the curtailment of renewables; frequency regulation; fast and flexible ramping; black start capability; and, firming of capacity.

He added that it was estimated that there would be 300 GW of pumped-storage capacity in operation by 2030.

Regarding FPV schemes in the pipeline for development over the next 5 to 10 years, Boshell said that between 20 and 40 GW could be developed, mainly in Asia; the leading countries would be Indonesia, Korea, India, and China; and in Europe, the Netherlands has 2 GW of FPV planned.

In the ensuing discussion among panellists, both the benefits and challenges of FPV schemes were debated frankly, and many questions were submitted from delegates.

Outlining the energy situation in Switzerland, Annelen Kahl said that her country had a target to generate all electricity from renewable energy by 2050; precipitation in winter was solid, she pointed out (ice and snow) and therefore solar power, and particularly alpine PV plants, had a big role to play. Challenges, however, were that mountain peaks cast shadows, and there was also a problem of wind load. She noted that Switzerland had 45 large artificial lakes, mostly in alpine settings, so that favoured the development of FPV plants. She added that there was a strict national policy for landscape protection, which made land-based solar PV problematic.

One participant asked the panel to comment on why there was not more FPV in Africa. Boshell said there

was indeed great potential in Africa. Many nations were now considering incorporating hybrid as part of modernization, in line with their sustainable development plans.

Panellist O. Tricca of the European Investment Bank (EIB) endorsed the view that in view of the number of ageing hydro plants in need of modernization, this represented a good opportunity to incorporate FPV during an upgrade scheme.

In his introductory talk, Tricca said that EIB was keen on financing innovation, and was promoting hybrid renewable energy schemes generally. But he referred to problems in encouraging investment in FPV, saying that hydropower investors would generally not come forward with a combined project in mind, and may not be convinced of an incentive or financial benefit. He added that EIB had not yet received requests for funding FPV schemes, and that it would be important for schemes to demonstrate the value they added. Tricca said that he saw FPV as having the potential to decrease the levelized cost of hydro, but added that it would not mitigate the classic risks perceived by investors in relation to hydropower.

Panellist Arnaud Rousselin of EDF, France, who has been involved in the design and construction of hydro schemes around the world, and now also several floating PV schemes, said he agreed with Tricca in general. He said that developers coming from the hydro side towards FPV faced difficulties in making them competitive and getting them into the market.

In many cases, the concept of auctions relating to hybrid schemes might not be included in terms of reference; when bidding on a greenfield project, he said, EDF might suggest the option to add a floating solar system on the reservoir, but it would be regarded as an 'extra'. However, in cases where there was a direct agreement with a utility, avoiding an auction or another competitive process, it would be easier to go forward with an FPV. Other issues, Rousselin said, concerned permitting: no appropriate regulatory frameworks were in place, for example for environmental impact assessment, as environmental impact issues were not yet clearly defined.

The same problem applied with regard to grid code design criteria, for example, and no real standards existed for dam safety, jamming of spillways, and so on.

He suggested that this was an issue which could be addressed by IRENA and IEA, as better promotion of the technology was essential. He remarked that IEA's recent market report was a fantastic tool to promote hydropower, directed towards policy-makers, but floating solar did not feature in this.

Boshell confirmed that IRENA was working towards analysis on modernizing hydro plants, including adding solar PV, and the development of guidelines and recommendations to decision makers, as part of a collaborative framework for hydropower. Countries were encouraged to have government-to-government dialogue on sharing best practice, and at least 60 countries were currently engaged in this. The work would include issues such as grid codes, and mechanisms to deal with auctions.

Tricca then contributed two comments from a financing standpoint. First, FPV should not actually be considered as truly innovative technology, in his opinion, but more as an improvement to existing technology. There should be no doubt in this respect, he said, that it was bankable.



*The 150 MW Anhui FPV scheme in China, referred to by Boshell of IRENA as an example of a major FPV plant in Asia.*

His second point was that the benefit of combining two technologies should be demonstrated by an economic analysis. There should be complete clarity with respect to the PPA, grid code and auction. A comparison should always be made with using the technologies separately.

Another question to the panel concerned the specific advantages of combining pumped storage with FPV, as opposed to classical hydropower.

Quaranta replied that one clear benefit of hybridizing pumped storage with FPV was that the solar PV could be used for pumping.

Rousselin pointed out, however, that one potential difficulty of installing FPV at a pumped-storage reservoir was that the water level could fluctuate a lot; so benefits would depend on the filling regime of the reservoir. He added, however, that pumped storage combined with solar PV made sense if there was adequate space in the upper reservoir, and when there would be excess power from PV for pumping.

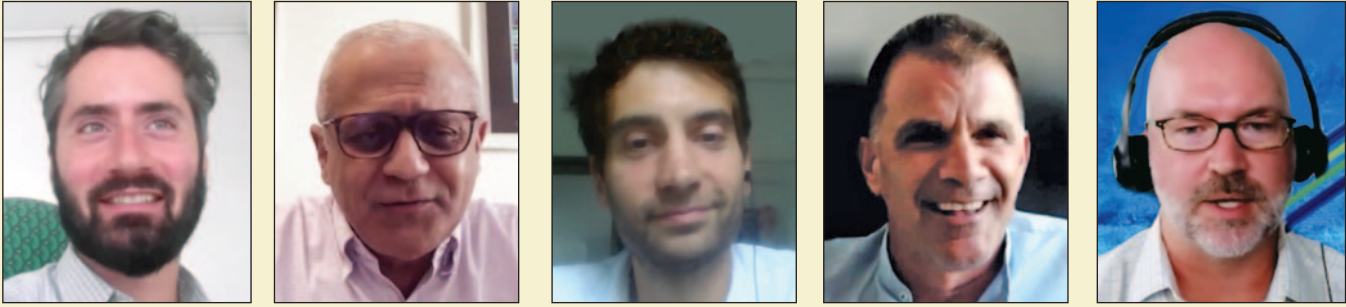
Later, a question from the audience came back to the issue of reservoir level variations, and the difference it could make. Rousselin said it certainly had an impact, in particular as the capital cost of the required mooring system would be higher.

Luc Deroo of ISL, France, drew attention to the very high potential for FPV, and hybridization. He referred to the estimate that if just 14 per cent of a hydro reservoir was covered with solar panels, a gain of 1 GW could be achieved. Thus, in Europe alone, around 250 GW of new capacity could theoretically be gained.

Rousselin pointed out some limiting factors, such as many lakes being important for tourism, and the fact that public acceptance of solar panels would be questionable. But on the general merits of FPV, he said that in countries with dense populations, where there was a high value on land, which could be required for agriculture, forests, and so on, FPV really made sense. Kahl later commented that in Switzerland, it would be hard to get permission to develop solar plants on land, but she added that in her opinion, a good option would be to develop a hybrid system very close to reservoirs, rather than actually on them, to avoid the extra issues associated with floating panels.

Quaranta asked Kahl if icing could be a real problem in the case of FPV installations on high alpine lakes. She replied that it could be a challenge, as ice could become stuck to the solar panels, and therefore could





Above, Félix Gorentin, who chaired the Session 3 panel, and the four panellists (listed in the text below).

add weight; this would then cause fresh snow to become attached too, adding even more weight. This could put extra stress on the mooring system. It was agreed in the subsequent discussion that it was not impossible to install FPV on high altitude lakes prone to freezing, but that model studies should be carried out for such cases, taking into account, for example, the extra predicted weight.

### Session 3: Design issues, risk analysis and risk management

This session also took the form of a panel discussion, and was chaired by Félix Gorentin, a solar power expert from Innosea (part of the AqualisBraemer LOC group), an independent company involved in energy and marine construction. He said that his company had been involved in 60 floating solar PV schemes, 35 of which were on dam reservoirs.

Gorentin commented on the diverse range of expertise on the panel which comprised (shown above, to the right of Gorentin, in the following order):

- a project developer from BASE Sustainable Energy, Brazil, Demostenes Barbosa da Silva;
- an engineering mooring expert from DNV, Alex Argyros;
- an EPC contractor from Makor Energy, Ofer Ilan; and,
- an expert mooring component supplier from Seaflex, Charles Gery;

Setting the scene for the discussions to follow, Gorentin said that over the past four years, the floating solar PV market had grown dramatically. Larger and larger projects were being commissioned (150 MWp or more). Nevertheless, regularly there was news about accidents and damage. Examples were:

- the Yamakura failure in Japan, described earlier in Session 1, where a typhoon had lifted anchors resulting in the islands of panels splitting, and a fire;
- in the UK, the Queen Elisabeth II floating solar farm had also caught fire (and there had been similar news recently at the Piolenc FPV in France);
- at the Lingewaard floating solar farm in the Netherlands, following a storm, the mooring lines had broken and part of the island had been lifted and had 'folded' over the rest of it;
- during construction of the Huanain scheme, in Anhui province, China, panel islands had collided;
- at the Nij Beets scheme in The Netherlands, trees had been uprooted during a thunderstorm and temporary anchors had failed;
- in Korea, a freezing lake had caused compression and floater failure; and,
- most recently, in Albania, an FPV island had sunk, and this case was still under investigation.

Only a fraction of FPV potential had been developed, Gorentin continued, so it was vital to exchange knowledge and experience, and in particular to learn from incidents and failures. In the light of this, he proposed the following main topics to be covered in the discussion.

- (1) *Extreme event characterization for FPV plants.* What can happen? How to model such events? This could include: how to withstand high waves (1.5 m+); water level variations (10-25 m) and the implications for FPV design.
- (2) *Mitigating the risks through resilient design and preventive measures, including:* embedded prevention measures (float design); layout definitions and design margins; and, anchor and mooring line management.
- (3) *Challenges during construction and the early phase of operation of an FPV on a dam, including:* temporary mooring management, and how to deal with the risk of extreme winds during construction; and, coping with V-shaped bathymetry and large water depths (> 50 m).

#### Extreme event characterization for FPV plants

Commenting on the first topic, panellist Demos Barbosa da Silva, Brazil, said that FPV plants would certainly be submitted to extreme wind loads, so safety would depend on a good design, a thorough risk analysis, and the preparation of mitigation measures. Key factors, he continued, were to know the predominant direction of the wind, and to have good knowledge about wave behaviour. Gaining a reasonable understanding about extreme events would require not only risk assessment, but also probability analysis, taking account of environmental and climate conditions. He added that a bathymetry assessment at the FPV location was essential for the design of an efficient and safe mooring system.

Regarding wave action, Barbosa da Silva said that low frequency waves in a hydro reservoir (generally less than 1 Hz) were associated with a higher energy density, and greater impact over the floating structures and the mooring system. Higher frequency waves were associated with repetitive efforts of lower energy intensity, representing major risks to the resistance of the floaters. He stressed that these factors must be evaluated together to ensure the lowest possible risk for the FPV. When winds blow in a certain direction, forming a fetch of considerable length (several kilometres), he continued, waves higher than 2.5 m and longer than 10 m would be formed, at a frequency of 0.14 Hz.

Gorentin asked about the importance of having long-term historical data on wind and wave action when making the decision to go ahead with a project, and Barbosa da Silva replied that it was actually difficult to

rely on historical data, especially in view of climate change, and it was more important in his opinion to have accurate recent data, and to have data relating to each season.

Alex Argyris, an expert on moorings at DNV, said these had become a “hot topic”, also in the oil and gas industry, as there had been a number of failures. Failures normally stemmed from degradation (wear and corrosion combined with fatigue), he said. He announced that in view of the rapid growth in floating solar and wind systems, his company would be issuing recommendations for best practice, and he had been leading this work. Research had been done at all stages of the lifecycle, and this had been followed by work to control or avoid degradation.

Panellist Ofer Ilan, CEO of Maker Energy, stressed that it was essential to have a clear understanding of all risks before beginning the design of an FPV project, so appropriate mitigation measures could be adopted. In his experience, especially when a developer wanted to implement a scheme fast, it could be discovered during the installation that the mooring system had not been considered adequately, and this could lead to a major risk, or even a failure. Gorentin agreed that risks were often underrated, and as hydro schemes were capital-intensive, the corresponding risks would be greater. He asked Ilan how he managed risks from the EPC point of view.

Ilan replied that he tried to be involved at all stages of project from the very beginning, well before knowing whether he had won the job, as this was essential to organize the project well, and avoid problems later. It was advisable to do a preliminary design for moorings, even if the design did not yet exist. He said another lesson he had learnt was to work with several producers of floaters before making a final choice; each had its strengths and weaknesses, and as the conditions of each reservoir would be different, it was crucial to study the best type.

Charles Gery of Seaflex then joined the discussion, supporting the view that variations in wind strength and water depth were the main challenges to be dealt with regarding mooring systems, and in particular how the various materials used for ropes, chains and cables could cope with these, and what effect they might have on the environment under water.

Concerning current R&D, Gery mentioned a research programme under the auspices of the European Maritime and Fisheries Fund, called FRESHER 2020, supported by the EU, in which he was involved, working with EDP, Portugal, among others, to optimize mooring systems for hydro reservoirs, while also aiming to reduce costs.

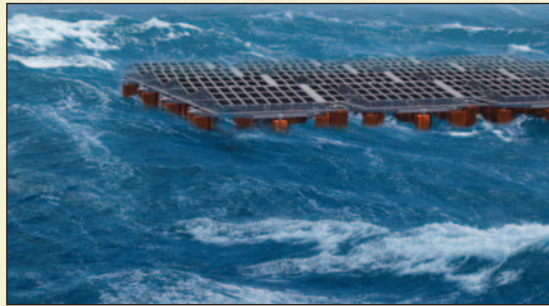
Seaflex had also been working on the development of a new multi-connector system, he continued, and on decoupling horizontal and vertical loads from the systems.

Gorintin asked about the kinds of warranties which would be given for the components, and Gery replied that a Seaflex system supplied to Sweden 40 years ago was still in operation, and this gave the company the confidence to issue warranties of 20 to 25 years.

Gorintin commented that this could represent a challenge for the manufacturers of other components.

#### Wave depth and water level variations in reservoirs

Argyros acknowledged that waves of 1.5+ m depth could be an issue, but as long as studies had been done and the design allowed for this, then it could be dealt



*Several talks focused on extreme wave action, and the need to conduct fetch calculations.*

with. He commented that such waves would be more of a problem for the panels than the moorings. Challenges would be more associated with varying water levels.

Gery said that with the elastic mooring system developed by his company, waves were dealt with as part of vertical water level variation.

#### Anticipating extreme events

Gorentin then questioned the panel on how to anticipate extreme events, if there were no records of wave heights in the reservoir, for example.

Barbosa da Silva said that at one hydro reservoir in the mid-west of Brazil, the water level variation was as much as 47 m. In such cases, longer cables would be used, and there should be flexibility in the mooring system. It would be very important to make a good assessment of anticipated future conditions, by modelling.

He then drew attention to the important issue of sedimentation in hydro reservoirs, and said this needed a high level of attention, because of the reduced head, and the impact this would have on the mooring system. Regular monitoring and O&M was essential to manage this potential impact, he stressed.

Argyros added that at one project, which was at an early stage, there had been good data on wind, but not on waves, so it had been necessary to apply fetch calculations. But he agreed with Gery that wind loading was in fact the most important factor, and wave height could be dealt with within vertical movement calculations.

During some questions from the audience, Luc Deroo referred to the accident at the Yamakura plant in Japan described earlier, and asked the panel if they had come across other accidents from which lessons could be learned.

Several examples were mentioned. Ilan said there had been a failure at a 1 MW project in Israel, but at a fish farm rather than a hydro reservoir. This had occurred in 1 in 50 year wind conditions, when the mooring had proved inadequate. Gorentin referred to a similar scale incident in the Netherlands, also in extreme wind conditions, and he added that in France there had been an incident of two islands of panels colliding, while temporary moorings had been in place.

Gorentin then stressed the need for extreme conditions to be anticipated better in the light of climate change, as hurricanes and typhoons were likely to increase.

Argyros commented that this was the case for any infrastructure; for FPV, as wind speeds increased, there would be other effects such as higher precipitation or droughts. At DNV, he said, there was a department specializing in climate change issues, dealing with the issues to be addressed, such as landslides, heavy rainfall and droughts, in areas at particular risk

A question was then addressed to him about failure modes of moorings; he replied that much work had been done, and that guidelines did exist. The main reasons for failures, he said, were: in the case of chains, degradation and bending fatigue; and, in the case of fibre or wire ropes, generally problems associated with their installation.

Gery later agreed that a lot depended on the materials used, and supported the view that polyester ropes, with only small amounts of steel, would have more favourable operating and maintenance costs.

Gorentin asked Agyros about the possibility of monitoring mooring lines, and his reply was that it was possible with a camera or acoustic sensor to monitor whether the line was in place, and tension could also be monitored to indicate fatigue; but degradation caused by corrosion was not so easy to monitor. It was agreed that a line could be temporarily taken out for testing, or underwater inspection equipment, as used in the marine industry, could be applied. But it was agreed that the operating expenses associated with mooring systems was relatively high because of the risks involved.

A question followed about the risks of floating debris, and Barbosa da Silva replied that the use of netting, barriers or booms was effective, and in his opinion this was a less serious problem than sedimentation.

He added a comment on the effect on fish, as he had experience of monitoring fish species around FPV panels, and he reported that there were actually increases in the fish population, as the fish found the panels useful for protection.

#### Mitigating risks through resilient design

The discussions then moved on to the topic of mitigating risks through resilient design, and preventive measures. Gery was asked for more details of the EU FRESHER scheme in this respect, and he said two main points had emerged. One was, as had been mentioned earlier, the possibility to decouple vertical loads from horizontal ones, in cases of significant water level variations. The other concerned the aspect of multiconnectors: it was possible to take one anchor point and one mooring line, and then divide them between two, four, six or eight points on the floaters, to spread the forces throughout the system.

Barbosa da Silva then referred to three key points from his experience. First, he said that adaptation of the mooring system should be very specific to each case; one could combine approaches and combine technologies, but the mooring system would always be the most important aspect.

At projects in Brazil, he reported that he had to design his own floaters, having studied stress impacts, and this had demonstrated the great importance of the connecting points, which needed to be adapted to specific wind and wave conditions.

Third, he stressed that monitoring was a key issue, particularly as climate change could bring some new challenges which may not have been predicted in the past.

Gorentin asked about appropriate designs for different dam locations, coming back to the point of sharing loads, and asked if there were any lessons from the off-shore industry.

Agyros replied that in aquaculture and wave energy schemes there were various concepts for sharing loads, and these included providing multiple lines to the same anchor, as had been mentioned by Gery.

Gery underlined the importance of mooring designers working closely with the manufacturers of the floaters, for example when deciding on the number of floaters to be installed.

Ilan said that a single floater would require significantly more ropes and anchors. There would generally be fewer points of connection, and some anchorage might be underwater, so that waterproofing could be an issue; he stressed that these things were project specific.

It was important to recall that the industry was young, and still under development, he said, and so it was necessary to weigh up design not just once or twice, but three times. He called on organizations such as DNV or ICOLD to help establish more systematic decision making, and to help advance tools for design decisions.

Gorentin asked more about fixing anchors in deep water. Ilan replied that this could certainly be more expensive, involving the use of boats and GPS systems, and the placement of concrete structures under water which might not be environmentally friendly. It could also be more time-consuming, but was in any case necessary for some projects.

Gery commented that bathymetry was extremely important at the design stage, to understand well the lengths of mooring lines required to deal with the site, and failure to be aware of this could affect the performance of the system. He commented that his company had developed a system which was 'forgiving' in this respect, in that the anchors could be moved by several metres, and so could be adjusted.

Gorentin asked if there was a tendency to avoid sites with deep water, and Gery replied that it might not be feasible in some cases to avoid deep waters, but he observed that it was possible to adjust the angle of the moorings, which could be helpful.

M. Bacchelli of Carpi, Switzerland, working with Maker Energy on FPV, commented that his company specialized in underwater inspections and repairs. But he said that at extreme depths (>50 m), this would require saturation diving, and this could be rather expensive; it was therefore preferable to avoid interventions at such depths.

The final question by Gorentin concerned the risk of vandalism and potential need for security systems.

Ilan agreed that such problems certainly existed, as in some cases projects could involve the use of valuable copper; also there could be problems if some environmental groups 'did not like the look of the project'. Barbosa da Silva suggested that the use of some security cameras could be worthwhile.

In closing the panel discussion, Gorentin again stressed the great value of having had the whole value chain represented on the panel, including developers, manufacturers and an EPC contractor. Discussions had covered current challenges very well, and the number of questions from the audience had been impressive.

#### Session 4: International experience

Regulatory issues are a key impediment to FPV development in India, according to Arun Kumar, a Professor at IIT Roorkee. "For speedy upscaling of FPV, both central and state governments need to create a clear policy and regulatory framework under which solar-hydro projects are implemented and remunerated," said Kumar. In addition, he called for pre-feasibility and feasibility studies to be undertaken by stakeholders led by the Government to create

a pipeline of FPV projects, including on off-river and non-traditional sites, to reduce the implementation time, while experience in terms of performance and E&S impacts for pilot projects needed to be studied, documented and shared. The Government should also consider initially supporting the roll-out of FPV given that the capital costs for FPV were about 20-25 per cent higher than ground-mounted PV systems, he felt.

Challenges include the lack of a track record for these projects in India, the many different owners of water bodies in different states, which makes the permitting process time consuming, and the absence of standard agreements for water rights and a policy for use of water bodies for FPV. These could delay project allotment and implementation. In addition, the supply chain was fragmented and the availability of standard technical specifications for materials and equipment was a challenge, Kumar continued. "At present just a handful of small projects totalling around 1.1 MW are in operation in India, but more than 15 projects totalling more 1800 MW are under construction or planned by central utilities, while private developer Greenko is planning two 80 MW projects on the upper and lower reservoirs of the 1200 MW Pinnapuram pumped storage project along with 3000 MW of ground-mounted PV", Kumar said.

With more than 5200 large dams, and a further 437 dams currently under construction, India has an estimated FPV potential on reservoirs of approximately 280 GW. Its development will be driven by Government efforts to meet an ambitious national renewable energy target of 450 GW by 2030. As of April 2021, India has an installed renewable energy capacity of 141 GW, of which 36 per cent is hydro and 28 per cent solar, representing 37 per cent of total national capacity of 382 GW.

In Indonesia, in contrast, new regulations were introduced in 2020 to allow for the deployment of FPV on dam reservoirs under certain conditions. Their installation should not have any negative impact on the spillway, intake and dam body, explained Aries Firman, Vice-Chairman of INACOLD, while the location and design of FPVs should support the management of the local water authority and should not exceed five per cent of the total reservoir surface. This was posing a problem for the developer of an FPV project in the Krakatau industry area, Firman said, as the project's gross area exceeds 8 per cent of the reservoir surface area. The developer has, as a result, requested dispensation from the authorities for this project, as it is off mainstream, and is looking at an arrangement involving two separate FPV islands with capacities of 9.6 MWp and 6.4 MWp. Given that Indonesia is prone to major earthquakes, developers needs to consider seismic activity, as well as the possibility of associated landslides, to mitigate the risk of anchor failure, noted Firman, as was the case with a 145 MWp FPV on the Cirata hydropower dam reservoir, which is expected to be commissioned in 2022.

#### Grid capacity constraints in Vietnam

Vietnam has to date commissioned two utility-scale FPVs, but further plans for large-scale projects may be postponed or even cancelled as a result of grid constraints, according to Michel Ho Ta Khanh, a local independent consultant. Vietnam has seen soaring growth in solar PV in recent years, with total installed



capacity of 16 500 MW as of the end of 2020, representing about 25 per cent of total installed capacity, including around 10 000 MWp of rooftop solar capacity, which represented a 25 fold increase in the last year. This has resulted in grid curtailment as total installed capacity already surpasses grid capacity by 18 per cent, said Ho Ta Khanh. He presented an overview of the country's first utility-scale FPV, which was commissioned in 2019 at a cost of around US\$ 64.5 million.

The Da Mi hydropower reservoir was selected as one of the best sites for the 47.5 MWp project, he explained, as the site is largely protected from winds and typhoons by mountains, with typically no waves higher than 1.5 m, and a water level fluctuation of less than 3 m as a result of a free overflow spillway. The FPV was fixed by a combination of onshore, submerged and basement anchors. Concrete blocks of 15 m<sup>3</sup> were transported by boat and dropped to the bottom of the reservoir by steel cables to secure the structure and to avoid drilling and pollution of the lake, which is also a site for fish farming. No particular risk was foreseen for the dam, explained Ho Ta Khanh, as the FPV is sited far from the embankment dam, which moreover has a thick upstream rockfill which would give protection in the unlikely case that the FPV structure would break free from its mooring and drift against the dam. The Government of Vietnam set a fixed offtake price for this FPV of US\$ 0.0935/kWh with a return on its investment expected in 14.5 years, said Ho Ta Khanh. A fixed price of US\$ 0.0769 per kWh has been set for production from all future FPV projects. Various other large-scale projects are under study including 1465 MWp of FPV on the reservoir of the Tri An hydropower dam reservoir, a 481 MWp project on the Hoa Binh hydropower reservoir and several also on the Son La hydro reservoir.

*Prof Arun Kumar of IIT, Roorkee, India; and the 1 MW Kawas FPV array, on a cooling water reservoir in Gujarat, India, operated by NTPC.*

#### PPA challenges and grounding risks

Arnaud Rousselin, a civil expert at the EDF Hydro Engineering Centre, highlighted some of the benefits but also the challenges for two FPV projects that EDF Renewables is currently developing on hydropower reservoirs in France and in Laos. The main advantages for the 20 MWp Lazer project in the Hautes-Alpes department, which will be EDF's first FPV facility when commissioned in 2022, and two options under study on the Nam Theun 2 hydropower reservoir in Laos are the avoidance of land acquisition costs and processes and the power system benefits from hybridization. Rousselin noted that a proposed 240 MWp FPV project on Nam Theun 2 reservoir would cover an area of 3.2 km<sup>2</sup>, less than 1 per cent of the total surface area of the reservoir. It would, however,

*The Nam Theun 2 hydro reservoir in Laos, where an FPV is to be implemented (shown here as a computer simulation). The various options for the scheme were discussed by Arnaud Rousselin of EDF.*



cover a significant area of agricultural land if installed instead as a ground-mounted scheme. In addition the 240 MWp option, which would involve its hybridization with four 250 MW Francis units that generate for Thailand's grid, would increase average annual output by 350 GWh, about 6 per cent of the NT2 hydropower plant's output, of which an estimated 72 per cent or 250 GWh could be used to save water, enabling the owner-operator to meet its PPA commitments from the hydropower production in dry years, as well as provide more peaking capacity. Its development would also allow for numerous synergies, including mutualization of infrastructure such as grid connection and the O&M teams. A challenge for both projects is the threat of grounding of the FPV facilities when the reservoirs are at a minimum operating level with a consequent impact on water management.

Rousselin noted that the Nam Theun 2 is an annual storage reservoir, but has wide water level fluctuations of up to 12 m, making it important to ensure the accuracy of bathymetric surveys.

The design of the Lazer FPV had to take into account not only the risks of grounding but also ice and snow, as the reservoir surface can be completely frozen and panels can be covered with a thick layer of snow. Another major risk is spillway jamming during flooding in the case that the FPV's anchoring system breaks. For the Lazer project, Rousselin said that there was no possibility of using a conventional anchoring system, which could have damaged the reservoir embankment and the bottom clay layer, which ensures water tightness, so instead it will make use of dead weights.

*Floater designed by BASE Sustainable Energy, Brazil, for (left) the Itumbiara and (right) the Belo Monte reservoir FPV schemes discussed by Barbosa da Silva.*



The biggest challenge for the development of either of the two hybridization options at Nam Theun 2 (an 80 MWp FPV facility linked up with two 35 MW Pelton turbines that generate for the domestic national grid, or the 240 MWp option with the Francis units that generate for export to Thailand) is the issue of either inserting a new PPA for the FPV into one or both of the two existing hydropower PPAs or creating a separate stand-alone PPA for the FPV facility.

"Work is ongoing on finding an option that is acceptable to all stakeholders", Rousselin said. "This is such an important parameter that when we develop new projects we try, whenever possible, to propose hybridization right from the beginning and try to have a joint PPA for both the solar and hydro generation," he concluded.

### Powering Amazon communities

Brazil also has significant potential for solar-hydro synergies, according to Dr Demostenes Barbosa da Silva, CEO of BASE Sustainable Energy. By covering less than 10 per cent of the surface area of only the ten largest hydropower reservoirs, Brazil could double its power generation capacity, he said, as well as increase land use efficiency and reduce GHG emissions. "Large-scale hydro-solar synergies can make an important contribution to help mitigate climate change," he said in his presentation on the developments and perspectives for FPV in Brazil. It could also help bring clean electricity to remote communities in the Amazon, he explained. "One very important outcome of FPV development in Brazil has been experimental implementation in rivers and streams in the Amazon Forest. Hundreds of riverside communities currently rely on diesel gensets, which cause environmental impacts. Numerous technical challenges remain, according to Barbosa da Silva, most notably in terms of anchoring in the country's hydro reservoirs, which can have very large variations in water levels. To date, developers had installed anchors using large catenaries on the surface, and have studied extensively the bathymetry of the sites. The issue of large volumes of floating debris such as logs could also pose problems for operation efficiency, he continued.

To achieve large-scale deployment, further steps need to be taken in developing local engineering expertise and in sharing project experience, he said. Brazil needs to secure increased financing to continue R&D, including the development of tracking systems, as well as improvement to designs to reduce production costs by optimizing the geometry and guarantee structural safety.

BASE Sustainable Energy has been at the forefront of FPV development in Brazil. Starting R&D in 2014, the company commissioned in 2016 the country's first FPV on the Porto Primavera hydropower reservoir with state hydropower producer CESP, using its first generation floater technology. In 2018 it launched development of the second generation of floaters, which were patented in 2021, and have been installed at the 200 KWp project on the Itumbiara hydropower plant reservoir in 2020 and the 50 KWp Belo Monte hydropower reservoir in 2021. These projects, he said, have demonstrated the robustness of the technology for Brazilian hydro reservoirs.

### New regulations pave way for hybridization in Portugal

Portugal is playing a leading role in the deployment of FPV and solar-hydro hybridization both in terms of actual project developments but also in introducing regulato-

ry changes to promote its use. The successful commissioning in December 2016 of the 218.4 KWp Alto Rabagão FPV plant, the country's first FPV project and the first to be connected to a hydropower plant, has provided "a learning platform for future projects", according to Miguel Patena, Director of Innovation and Technology at EDP Produção. Hybridization, he said, became a reality in Portugal in 2019 with the issuing by the Government in June of that year of a decree-law with two main objectives: promotion of the further deployment of renewables and overcoming the scarcity of network availability to connect new generation capacity.

To achieve these objectives the decree-law allowed for the licensing of production units in pre-existing power production centres, that using a different source of renewable energy, do not require increased injection capacity into the public network. The decree-law also provided the possibility of installing storage infrastructure at powerplants, strengthening the response capability from renewable energy sources. Further regulations were implemented in March 2020 with the issuing of an ordinance aiming "to establish the non-exhaustive requirements for connecting generator modules to the public network in compliance with EU regulations". As a result, in May 2021, after a period of licensing that took more than two years, EDP received a generation licence for the 5 MW Alqueva FPV plant, which will be Portugal's first hybridization project, demonstrating the complementarity between hydro and solar PV as well as between two storage sources (pumped storage and battery). The battery energy storage system (BESS) will allow for the testing of various functionalities, such as PV smoothing, virtual powerplant, arbitrage and frequency and voltage regulation. EDP used a multi-contract model as a way to reduce cost and risk and ensure the most suitable supplier for each component of the hybrid plant, explained Patena, with the project divided up into four packages. The first package was an EPC contract for the floating equipment, power electronics and connections and control systems for the FPV. Package 2 for the mooring and anchorage system was awarded through the EU-financed R&D programme FRESH-ER. Packages three and four for the BESS and for the metering and control systems to integrate into the Alqueva 2 hydropower plant distribution control system were both awarded as EPC contracts. The interfaces and limits of supply for each contract need to be "as clear as water", Patena concluded.

In the Q&A session, Patena highlighted several of key points from EDP's experiences to date. First, that complying with dam safety rules as was the case with the Alqueva FPV project has "a high impact" on the overall cost. Second, he noted that technical anchors or heavy dead weights remained a costly part of the overall project cost, as a result of a lack of competition between suppliers. Third, one of the challenges for EPD was managing operations of the FPV in conjunction with the pumped-storage and battery systems, he said, by designing an energy management system (EMS) that would optimize operation to ensure its economic viability, as the project was market-based and did not benefit from a PPA.

### African potential and prospects

The second part of the session focused on Africa, and highlighted the continent's significant technical potential, as well as the growing interest among national



Far left, Miguel Patena of EDP, describing Portugal's experience with Alto Rabagão and plans for hybridization at Alqueva.

Left: Arnaud Rousselin of EDF, who described the Lazer FPV scheme in France, and the development planned for NT2 in Laos.

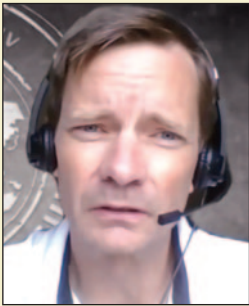
utilities in exploiting this potential to compensate for reduced hydropower production during more frequent dry periods and conserve water while helping to sustainably satisfy the current and future energy needs.

The potential for FPV was underlined by a study in January 2021 by the European Commission's Joint Research Centre in Ispra, Italy that showed that by covering just 1 per cent of the surface area of Africa's 146 large reservoirs would see the installation of 29 GW of additional capacity, which would represent a nearly 50 per cent increase in the capacity of those reservoir's hydro installations.

Numerous studies have been carried out, are underway or planned for the implementation of FPV or co-located ground-mounted solar PV systems at existing reservoirs across the continent including in Kenya, Uganda and Liberia, among others, but to date just one 1 MW FPV and a 50 MW ground-based PV park are operating at the site of the Bui hydropower plant in Ghana. The limited experience of FPV on the African continent raises the risk profile for investors, according to Ryan Anderson, acting Head of Solar, Smart Grid and Storage at Multiconsult, who also noted the slightly higher cost of FPV compared with ground-based solar installations. Multiconsult has significant experience in FPV in Africa, having completed numerous studies, including a pre-feasibility study on FPV and hybridization for the Mt Coffee hydropower scheme in Liberia. It is also finalizing a pre-feasibility study with KenGen on three existing hydropower reservoirs.

"Compared with ground-based PV at sites next to reservoirs, FPV offers greater solar panel efficiency from improved cooling effects, increased hydropower production from reduced evaporation, and avoids the land acquisition costs, processes and associated risks," he said. Both forms also benefit importantly from a shared connection point, he noted, but the estimated required tariff or LCOE of ground-mounted PV is as of today around 15 per cent cheaper than FPV, which currently ranges from €6.8-5.2 /kWh. "I do think that it is fair enough to note the risk picture going into FPV, given the very limited experience in Africa. How long will be the lifespans of the floats, panels and moorings and how well will the owners carry out O&M on a relatively new technology? And then there are the E&S concerns. With limited experience, we just do not know all of the implications here and I think what we will see is a step-by-step development where more and more experience will be acquired in each of the countries that are now looking at pilot projects," he commented.

"However, as of today, the economic viability and risk profile associated with FPV, especially when compared with ground-based solar PV, does not present an obvious business case for many sub-Saharan African countries," he concluded. "The potential to share grid



Discussing FPV in Africa during Session 4 are, from left: Ryan Anderson (Norway), Musa Mukulu (Uganda) and Moussa Kaboré (Burkina Faso).

connections and hybridization may very well tip it into a real viable case. Hybrid operations are where the true value lies for Africa, when we consider both combining FPV with existing reservoirs or nearby ground-mounted solar PV with the same reservoirs, but the regulatory frameworks are far behind. If African utilities and regulators want to see hybridization emerge so that hydropower can increasingly enable the introduction of cheap variable renewables they are going to have to make significant progress on the regulatory framework to incentivize such investments and operations”.

#### Regulatory gaps

Anderson noted that while there are likely gaps within the regulatory frameworks relating to FPV, it may be advisable for utilities and regulators to avoid overregulating the sector unnecessarily by making minor modifications concerning environmental impacts and grid connections using existing solar PV regulations. More work was however needed, he felt, to promote hybridization. “There really has to be some investments and changes to the way reservoirs are operated, especially in the case of rehabilitation of hydro plants to increase peaking capacity, but we are quite a long way from incentivizing IPPs and gencos to make the necessary changes. In Africa, one has typically a flat PPA structure in which there is no incentive to adjust the production pattern and to realize more peaking power. Almost all new generation by IPPs is done on the basis of take-or-pay PPAs. One could structure into those PPAs some level of remuneration related to confirmed power or peaking services, or differentiated tariffs that may incentivize investment. If solar power is really to be the centrepiece of the power sector in Africa, there is some real value being offered to the power grid by introducing this flexibility and the question is then how you incentivize that. Over time we hope we will see ‘time of use’ tariffs, but until that happens utili-

The 1 MW pilot FPV project, on the Bui reservoir in Ghana, described by Anthony Osafo-Kissi of the Bui Power Authority.



ties and regulators will need to build those incentives into their PPAs. The community of policymakers and development partners should really think of making some progress on this as it will take some time,” he added.

#### Land scarcity favours innovative solutions

The lack of a legal and regulatory framework was mentioned by Musa Mukulu, Manager for Research and Business Development at the Ugandan state power producer UEGCL, as one of numerous obstacles to the roll out of FPV in Uganda. “We will need support to set up regulatory frameworks, otherwise we might find ourselves fire-fighting when starting to implement FPV,” he said. “We will need capacity building for the regulator and government bodies to review and approve environmental and technical reports,” he added. Other challenges included the continued difficulty in accessing infrastructure financing, as well as the proliferation of water hyacinths and floating islands on the reservoirs.

However, he felt FPV presented numerous upsides. “Land scarcity for infrastructure development is becoming a major challenge, in Uganda and will require innovative solutions such as FPV,” he said. Out of a total surface area of 241 km<sup>2</sup>, 197 km<sup>2</sup> or 82 per cent is land, of which 18 per cent is water bodies and 53 per cent is used for agriculture. Stand-alone FPV or PV in hybridization with existing hydropower would also allow diversification of the country’s generation mix, which is predominantly based on hydropower, enabling greater integration of variable renewables. “This could be done without using scarce land resources, and with no resettlement of people, while its development could easily be phased as demand grows,” he concluded. As a result, UEGCL is in the process of securing grant financing from the Government of Sweden to conduct studies into the installation of FPV on the reservoirs of four major hydropower facilities along the Nile including Karuma, Isimba, and Bujagali, with the aim of setting up a pilot project on one of the reservoirs. A request for proposals to carry out the study is expected to go out to tender later this year.

#### Ghana hosts Africa's sole FPV

Preservation of land space was also one of the reasons put forward by Anthony Osafo-Kissi of the Bui Power Authority, the state-owned operator of the 404 MW Bui hydropower plant, one of Ghana’s key generation assets, for the development of the continent’s first FPV and co-located solar plant.

The 1 MW pilot project on the reservoir of the Bui facility was commissioned in early 2021, along with the first 50 MWp tranche of an eventual 250 MWp ground-mounted scheme adjacent to the dam. The projects were constructed by China’s Meinergy Technology on the basis of an EPC+F contract at costs of about US\$ 1 million and \$47.5 million, respectively. Both the FPV and GM PV currently operate as stand-alone plants, but both are planned to be operated in hybrid modes with the hydro plant. Analysis of the operation of the two solar projects is ongoing, which will help inform BPA on their eventual hybridization with the Bui hydropower plant. Currently, an additional 100 MW ground-mounted PV plant is under construction and will be commissioned in the second

quarter of 2022. The procurement process for the final 50 MWp phase of the ground-mounted solar PV plant is nearing completion as well as for the expansion of the 1 MW FPV, which is to be increased to 5 MW.

### Pumped storage with solar

Combining solar with pumped storage also offers numerous opportunities across the African continent. Moussa Kaboré of the Burkina Faso Committee on Dams (BUCOD) presented the outline results of a feasibility study carried out on the development of a hybrid solar-pumped storage plant on the Sirba river, a tributary of the Niger, in eastern Burkina Faso. The study, which was carried out in 2019 on behalf of the Ministry of Water and Sanitation by ISL Ingénierie of France in partnership with local engineering consultancies IFEC and Emergence Ingénierie, looked at two options for the development of the Bassiéri hydropower project. The second solution looked at creating an upper reservoir on the left bank of the river, which would also host either a FPV or an adjacent ground-mounted system with capacity of around 350 MWp. The pumped-storage plant has been designed with an installed capacity of 85 MW and guaranteed injection power of 60 MW, which would generate 590 GWh/year. The Government of Burkina Faso is currently looking for financing for the project, and is considering the project's development on a public private partnership basis. The pumped-storage option showed what Kaboré termed "an interesting return on investment". Given that Burkina Faso has around 1000 dams, discussions are underway to study the energy valorisation of reservoirs by taking advantage of the potential for FPV, he said.

With global electricity demand projected to more than double by 2060, most notably in developing countries around the equator, and solar power estimated to meet 50-60 per cent of global electricity demand by then, the world will need large-scale storage, most notably pumped-storage hydro, according to François Lempérière, a renowned hydropower and dam expert, and former chairman of the French Committee on Large Dams. Pumped storage, he points out in his paper, is the best solution for daily or weekly storage, which is what will be needed the most in the future. A promising alternative to traditional pumped storage (which typically uses heads of 100-1000 m between two reservoirs linked by long tunnels and which are most cost-effective in mountainous areas) is the concept of "twin dams" that is, associating two dams along a large river, exchanging water operating under heads of 20-100 m without connecting tunnels but with large discharges. Twin dams are cost effective capacity and would be suitable for Africa, Lempérière points out.

One example of such a concept could be considered for the Kariba dam on the Zambezi river, which impounds a 300 km-long reservoir and generates around 7 TWh/year. Expanding the reservoir upstream and transforming Kariba into Super Kariba, by separating the existing reservoir with a new dam, associated with a very large solar farm, either FPV or ground-mounted solar, would make it possible to reach annual production of 500 TWh of dispatchable electricity for a cost of less than US\$0.05/kWh, Lempérière suggests. The scheme would operate under a 60 m-head with a pumping capability of 100 GW for 10 hours.

Annual production would be 250 TWh of stored and turbined solar PV power and 250 TWh of direct PV power. It could be implemented through phases of 5-10 GW over 50 years, and would bring power to 100 million people. Something similar could also be developed at the Aswan dam in Egypt, supplying up to 1000 TWh/year. The 300 km-long Aswan reservoir currently stores  $150 \times 10^9 \text{ m}^3$  of water and supplies 7 TWh/year of hydropower.

It is would possible, Lempérière suggests, to divide the Aswan reservoir into two shorter reservoirs and to associate the then downstream reservoir with a new 100 km-long reservoir in the dry and uninhabited tributary of Al Allaqi for pumped-storage operation. The pumped-storage capacity of 200 GW could be implemented in phases over 50 years. At full capacity, the twin dam could store 500 TWh/year of solar energy in addition to 500 TWh of direct PV solar supply. The total cost could be as low as US\$0.03/kWh, Lempérière calculates, noting that the water storage of the twin Aswan reservoirs could be preserved for irrigation and water supply and would not be driven by hydropower production.

### Session 5: Coupling solar hydro hybridization

In his introduction to this panel discussion, the session Chairman, Dr Ralf Bucher of Tractebel, Germany, noted that there is now more than 2.5 GW of installed FPV capacity with the largest scheme being a 40 MW plant in Huainan, China. A question for hybridization is the delivery of benefits in terms of energy production and resource preservation, he said. To discuss this, Bucher introduced the six panellists who then shared their ideas on these and other issues.

Dr Thomas Reindl, Deputy CEO of the Solar Energy Research Institute of Singapore, spoke about the work his organization was doing to monitor and measure FPV growth.

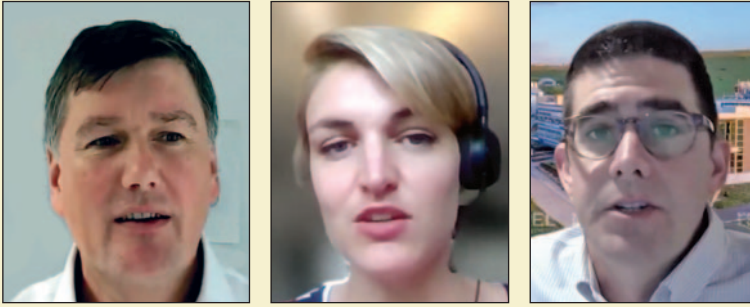
He noted that various countries in Asia were leading the way with new developments, including Laos and Thailand. Reindl differentiated between schemes that were co-located but had independent infrastructure, to those that shared infrastructure with varying levels of hybridization. He said benefits of hybridization included: optimization of reservoir operation, smoothing of seasonal variability, and the better utilization of transmission line capacity.

Reindl further identified a number of legal and commercial considerations for FPV hybridization projects. These included the possible need to re-open existing PPAs from the hydropower plan and ascertaining to whom the surface water rights belonged.

Sebastian Sterl, Associated Programme Officer at IRENA, spoke about complications of on-going negotiations regarding the operation of the Grand Ethiopian Renaissance Dam (GERD) in Ethiopia. Sterl described research that proposed a solution to harmonize GERD hydro production with solar and wind power. Such a solution could, Sterl said, both safeguard Ethiopia's power generation benefits, while largely retaining flow seasonality downstream. In addition, a hybridized project would allow GERD to decouple operationally from a guarantee of downstream releases. This could be achieved by an electricity generation-based agreement (from hydro, solar and wind combined) rather than a water-based agreement.

During the Q&A session, Sterl was asked to explain how the proposed solution would help water regula-





Chairman, Dr Ralf Bucher of Tractebel (shown far left), Imke Meyer of Mott MacDonald (centre) and Dr Nathan Lee from NREL, USA (right) spoke about the various benefits from solar hydro hybridization.

Dr Thomas Reindl of the Solar Energy Research Institute of Singapore differentiated between schemes that were co-located but had independent infrastructure to those that shared infrastructure with varying levels of hybridization.

tion. He responded that it would be beneficial at at least three levels, including daily, seasonal, and inter-annual regulation.

Luciano Canale, Vice President of Scatec, Norway, spoke about of the projections for solar and hydro in the future energy mix and how the two technologies could be implemented to compliment each other as a result of their differing characteristics. For example, he noted that solar was generally lower in complexity, shorter in time to market and lower in cost than hydro project developments.

Imke Meyer, Solar Practice Lead, Mott MacDonald, UK, spoke of her ongoing work analysing the feasibility of installing a 200 MW FPV on an existing very large hydro reservoir. When considering the impacts of operating the whole system, Meyer noted that because the existing hydro scheme was part of a cascade project, additional complexity was to be expected.

Dr Nathan Lee, a researcher at NREL, described the work of the laboratory, including the role of informing various energy sectors in the USA and beyond to help drive energy generation and economic development, as well as energy sector planning support. “There is certainly an increasing interest in FPV as a competitive option for power generation”, he said. Various factors were behind this, he added, “These vary by region and include competing land use pressures and energy needs, climate goals and energy security goals”.

Zafar Samadov of IMDC, Belgium, gave a short talk regarding the challenges of both onshore and offshore solar installations. Using case studies from Indonesia, India and the Ivory Coast, he noted that onshore installations has the key advantage of facilitating simpler designs because of calm conditions, whereas offshore projects had the advantage of essentially unlimited area and the possibility to combine with hydrogen production and marine farming.

Dr Thomas Reindl was asked by Luc Deroo to elaborate on the work undertaken by his organization. Reindl introduced the 1 GW Long Shang Shia project in China. He said the scheme was controlled in harmonization with an existing hydro installation and essentially “it is being treated as a 5th turbine of the hydro project in the control systems”. The solar farm was so large, he said, that very often even as clouds pass overhead, the entire array was not in complete shade at any one time. Therefore peaks and troughs in generation were not so pronounced. “Now is the time we can move forward at larger scale; the risks are understood and the banks are willing to give non-recourse financing. This is a key milestone”, Reindl added.

Lee echoed the comments made by Reindl, and said that floating hybridized projects were now scaling up. He gave the example of CHEF in Brazil, which was planning a 5 MW floating project in the next few years. He identified Colombia as another country with plans and potential for scaling up FPV projects. Similar work was ongoing in the Lower Mekong region of Asia, he added.

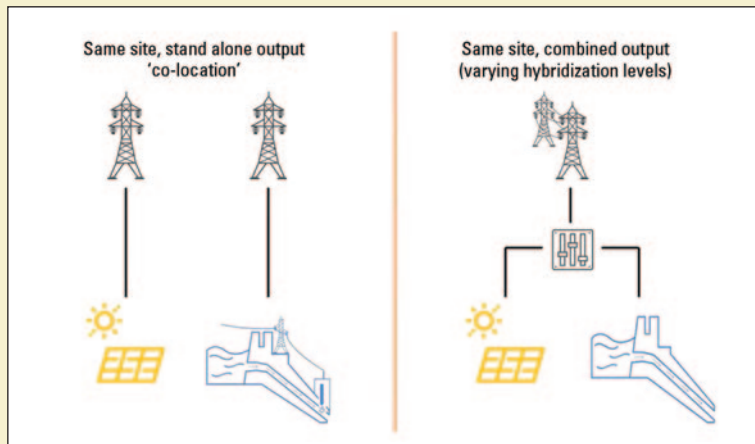
Canale then mentioned that his company was focusing on hybridization of FPV with hydro. He referred to a project in West Africa, at an early stage of development, that he was currently working on. The original feasibility studies for the hydro project had revealed that the tariff would be too high for the off-taker. However, after further hybridization studies (with either floating or land-based PV), it was shown that the tariff would be reduced to an acceptable value while maintaining an acceptable rate of return to the developer. Furthermore, Canale noted it would be possible to reduce the dam height while maintaining energy output when the hydro project was coupled with a solar scheme. Such a design change would also have the advantage of reducing resettlement of nearby populations and speed up the construction phase. “Hybridization on greenfield projects such as this offers significant opportunities and opens up new options for development”, Canale said.

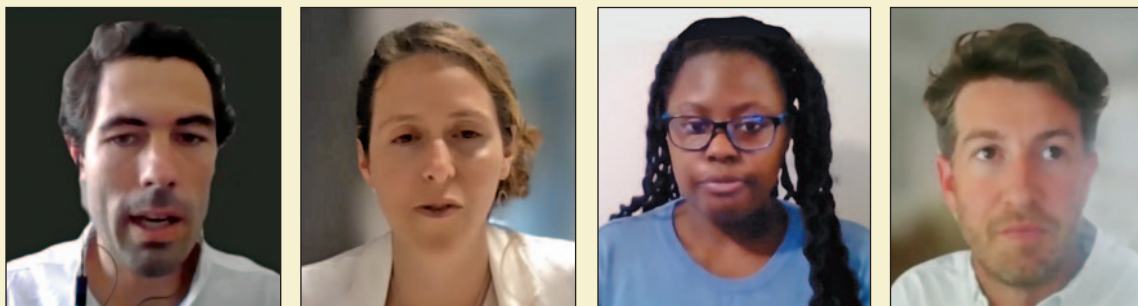
Meyer was asked a question regarding the challenges of modelling energy yield. She replied that benefits of increased energy generation from cooling effects were reported, adding “but the reservoir is often in a valley so the topographic arrangement needs to be considered, as this can reduce the effect caused by reduced wind circulation”. Further complications came from the fact that solar expertise as well as hydro expertise needed to be combined and coupled together, she said, questioning issues such as: Is there going to be an efficiency increase from reduced evaporation, can this be quantified? For very large reservoir surfaces, the effect is probably too small to integrate into yield models but together these and other benefits likely to be meaningful.

Ralf Bucher closed the session by thanking all participants, and noting that the discussions had demonstrated further opportunities for significant development of the sector in the future.

### Session 6: Environmental and social aspects

Francisco Ribeira Telles, a Senior Specialist at EDP, chaired the panel discussion on environmental and social aspects. He introduced the session by noting that panellists would debate some the main environmental





*Francisco Ribeira Telles, Senior Specialist at EDP (pictured far left) chaired the session on environmental and social aspects. Panellists in this session included (from left to right) Agathe Grenier (EDF), Sadé Cromratie Clemons (University of North Carolina), and Simon Howard (Mott MacDonald).*

and social challenges related to FPV on dam reservoirs and how these could be minimized while optimizing environmental and social benefits.

Bas Hofs (Researcher of Corporate Social Responsibility, Evides) discussed water quality issues at and around floating PV panels. He noted that the cost of comprehensive water quality analysis investigations could be expensive (around € 1 million), but was necessary for a complete understanding. Hofs noted that one challenge posed by FPV related to the fact that “birds love to sit and rest on solar panels” which could lead to a build-up of excrement and bacteria. This bacteria accumulation could, in turn, contaminate the water body, he said. One solution to this was to position the solar panels at an angle, rather than laying them flat, to deter the birds from resting and congregating on the panels.

Dr Jørn Stave, a Senior Environmental Consultant at Multiconsult, spoke about the effects of hybridization schemes on biodiversity. He observed that operators needed to take impacts into consideration at an early stage, to avoid greater costs at later phases of a project’s development. The chairman asked Stave what the main considerations affecting E&S aspects were. He replied that project location was critical. For example, if the existing hydro project reservoir, where a proposed FPV was to be installed, was in a protected area (for example a national park), even a small FPV installation could have very complex impacts and require significant studies and approval mechanisms. Potential conflicts with other reservoir users also needed to be considered. He cited water use, recreation, navigation and fishing as examples of this. In a separate comment to another question, Stave suggested that the benefits from a FPV project needed to be shared with local populations.

One question submitted from the audience was whether there was a rule of thumb that could be used to guide what the maximum percentage of covered area should be on a reservoir. “Unfortunately, I do not know of one”, responded Stave. “Reservoirs can often be very biodiversity rich”, he cautioned, “and there are knock-on effects to the downstream areas and even terrestrial biodiversity, so less than 10 per cent has sometimes been used. However, in cases where the reservoir water quality or level of biodiversity is already very poor, this figure could be significantly increased” he added.

Agathe Grenier, an Environmental Engineer at EDF, noted that environmental data availability at FPV projects remained limited. She noted that EDF was currently conducting several studies to improve this. She said “The impacts and benefits of FPV are highly dependent on the reservoir baseline conditions, so it is very important to have a good understanding of

the reservoir ecology and status before a project goes ahead”. She added that it was also very important to gather and share data within the industry, as the sector was still relatively new. Grenier said that dissolved oxygen content in a water body was one of the most important measures of water quality. “Covering a reservoir surface can disrupt plant growth and oxygen production, but the actual amount of change and specific impacts must be monitored and understood for a given scheme, as generalizations are not reliable”, she said. Grenier noted that EDF was currently modelling the impacts of different shading regimes on a water body, to understand better some of the details of the relationship between this and water quality.

Sadé Cromratie Clemons, an MSc Student, at the University of North Carolina spoke of her experience working on the life cycle analysis and cost benefit analysis of floating photovoltaic systems in Thailand. She noted that there remained a lack of information for end-of-life analysis. “Recycling of the PV systems varies from country to country and region to region and in some cases ends as landfill”, she said.

Simon Howard, Principle ESG Consultant, Mott MacDonald, introduced some further considerations that should be given to environmental and social aspects at floating solar schemes. These included general impacts associated with construction during the early phase of a project.

During the operating phase, Howard noted, as the solar panels created a barrier to sun and wind, this could increase stratification and impact water quality. There was also the potential for leaching of FPV materials into the water body, he added. The direct impact of shading could also reduce plant and algae growth while at the same time altering the thermal structure.

Responding to a delegate’s question about impacts to aquatic ecology, Howard noted that where the cover of an FPV installation was only a relatively small proportion of the total reservoir surface area, impacts were not expected to be significant. He added that his team was currently working to gather more case study data on this issue, through the analysis of biodiversity and water quality.

In a final question before closing the session, Telles asked the panel for their opinions and experiences regarding the aesthetic impacts of FPV projects. Howard commented that opinions varied from region to region. He said that while he might not want a transmission line or powerplant located near his own home, but in some regions where he worked, in sub-Saharan Africa for example, such developments were often welcomed and seen as a symbol (and real mechanism) for development and electrification.

Luc Deroo appreciated the endorsement from policy-drivers of the importance of FPV, but he cautioned: “We are not there yet”, referring to challenges still to be faced.

Far right: In his concluding remarks, Steve Usher of *Hydropower & Dams* spoke of the potential environmental and social gains from siting solar installations at existing reservoirs.

## Closing session

ICOLD President Michael Rogers expressed his thanks to the organizers, and to the Chair of ICOLD’s Committee on Emerging Challenges and Solutions for the 21st Century, for his initiative in proposing the conference topic, and for his work in this field on the Committee.

Over two days of the conference, there had been much to learn about the planning, design and construction, financing, and challenges of floating PV on reservoirs, he continued, and it had been demonstrated that with good planning and operation, hydro and solar resources could certainly be complimentary assets, and that solar panels, co-located with hydro on dam reservoirs, operated by the same owner, had some clear advantages to help advance global sustainability.

Rogers commended the attention which was being devoted to dam safety, and to avoiding the problem of blocking spillways, and noted that this was a key issue for further research.

The first footsteps in this young science of solar-hydro collaboration had an important place in future technical meetings, Rogers concluded.

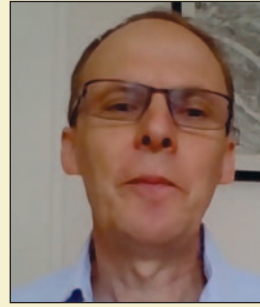
Conference Chairman Luc Deroo commented on the density of the discussions which had taken place in the sessions, adding that clearly many saw a bright future for floating solar on dam reservoirs, and for the hybridization of hydro and solar plants. The value of saving water for other uses, through avoided evaporation on reservoirs hosting solar panels, was one of the major benefits of these schemes, so the saved water could be used for other purposes, especially in arid countries.

Positive prospects for this technology had been underlined during the conference by speakers from IRENA, the World Bank, the European Union, the Asian Development Bank, and the US Department of Energy through its National Renewable Energy Research Laboratory, Deroo observed. “But we are not there yet”, he continued, adding that FPV was still at a pioneering stage, and there were challenges to be faced including manufacturing to deal with extreme wind and wave action, as well as water level variations; also, optimized solutions needed to be found, at a reasonable cost, to ensure safety.

Speakers had demonstrated clearly the efforts being taken by suppliers and researchers in this respect, and it had been valuable to share experience of failures, such as at Yamakura in Japan. Across the whole profession, there was a need for guidelines, and more sharing of case studies.

However carefully designs would be done, Deroo said, it was inevitable that some failures would occur, and this highlighted the importance of safety barriers in reservoirs.

Concerning hybridization, Deroo said it was clear that relatively little had been done to date, as had been reflected by the presentation of Olivier Tricca of EIB, and in this respect a clear case should be made for this technology. As Arnaud Rousselin had said, if proposals for hybrid schemes were not included in original tender documents, it would be virtually impossible for a developer to propose them later, on a competitive basis. In many cases, it could be clear after a project had been developed that a hybrid scheme would have been valuable. So strong cases needed to be documented to inspire planners, Deroo said. The initiatives



and leadership of the World Bank and ADB represented important steps forward.

It had been agreed in many talks that each FPV-DR scheme would have its own unique characteristics, and in this respect Deroo stressed the great need for simulation and the development of mathematical models. “Solar-hydro operation should be simulated and tested to account for all aspects, from the minute scale to the year scale”, he said.

*Hydropower & Dams* Deputy Editor (at Aqua-Media International), Steve Usher, commented on the exceptionally engaging discussions which had taken place in the sessions. He announced that this had inspired the Aqua-Media team to develop this topic further, both in the journal and at future conferences.

He had been impressed to hear that around 40 GW of FPV projects were in the pipeline, and reiterated some of the benefits of developing these which had been discussed, including the reduced need for land acquisition, and the resulting reduction in environmental and social impacts

Usher added that the range of topics covered had shown that there was scope for future projects to be designed, built and operated well. The importance of safety had been demonstrated well by the Japanese case study in Session 1, and other failures which had been discussed.

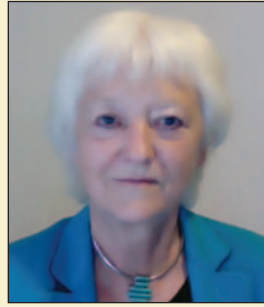
Félix Gorentin, who had chaired the panel discussion on design issues and risk management, presented some key ‘take-away’ messages on these important topics.

First, concerning extreme events such as large waves, he said there had been agreement on the need for a proper assessment of local conditions, through combined in-situ measurements and modelling. For cases where reservoirs had large water level variations (10-25 m), then key issues would be to ensure a good selection of the mooring type and its configuration. It had been useful to hear about failure modes from past experience.

Gorentin commented that risk perception for FPV was quite different from the case of classical solar PV, or from the perception of dam authorities.

Concerning the mitigation of risk by resilient designs and prevention measures, it had been concluded that floater technologies were more resilient in storms. There were also opportunities to deploy specific systems such as floating wave breakers. As regards anchor and mooring line management, it could be concluded that mooring was the driving factor in the layout of a project, and it was felt that this was not always adequately considered at the right level.

Challenges during construction and the early phases of operation of FPV plants at dams had also been discussed, and panellists had agreed on the need for temporary mooring management to be carefully assessed and integrated in construction planning.



Finally it had been agreed that dealing with V-shaped bathymetry, and large water depths (>50 m) should be avoided if possible, because of the increased costs of installation and maintenance, as well as other complexities.

Demos Barbosa da Silva commented that the discussions had provided a great opportunity to go into great depth on the key technical issues associated with FPV on reservoirs, and he felt it had been extremely valuable to have many experts, from so many countries, together on the same virtual platform. He concluded that the conference had played a significant role in helping the planet to move forward with an efficient and safe energy transition.

In closing the conference, Alison Bartle expressed satisfaction at the fact that FPV on reservoirs had been viewed from all perspectives: by the full range of stakeholders researching, planning, implementing and operating the schemes; and, literally, in terms of view-

ing the systems in cross section, from below, from drones flying above, and also when being tossed around by large waves.

Safety, and the related dialogue between FPV designers and dam safety engineers had been key. Bartle commented that at virtually all conferences on dams or hydropower, safety underpinned discussions. These were mature technologies, benefitting from centuries of experience. This underlined the importance of the focus on safety in the case of this relatively new technology of combining solar PV with hydro and dam reservoirs. There had been frank discussions on failures, which was, as always, a constructive way to learn, and move forward.

“Our aim,” she said, “was to focus not only on the synergy between renewable energy sources, but also between planners, engineers and operators in both sectors, and to bring them together for frank discussions.” She noted that 47 delegations had been represented, from nations with rich experience of FPV to small Pacific islands, and others embarking on future plans for adopting this technology. As at the Aqua-Media Hydro Conferences, discussions had also formed a bridge between policy- and decision-makers and practitioners. ◇

*ICOLD President, Michael Rogers, commended the attention being devoted to dam safety, in the development of FPV systems.*

*Alison Bartle, Director of Aqua-Media, felt the conference had fulfilled its aim of bringing together high level experts from the solar PV and dam engineering professions, as well as policy-drivers and practitioners.*

In response to the high level of interest in floating solar PV on reservoirs, demonstrated at this conference, a new section for FPV news and technical updates now features in *Hydropower & Dams* (see p105).



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