Hydro Hybridization 2026

(CONFERENCE REPORT)

Following the international SOLAR-HYDRO 2024 conference in Antibes, this year's event extended the focus to broader aspects of hybridization, and once again united experts from the solar PV and hydropower sectors to discuss innovations and success stories, challenges and standards being set to enhance best practice. As a chairperson from DNV commented: Future growth of floating solar PV will not, and should not, only be driven by technical innovation, but also by increasing confidence. Papers on safety, guidelines and risk assessment given at the conference will have played an important role in this respect.

Delegates from more than 35 countries gathered in Porto, Portugal, for HYDRO HYBRIDIZATION 2026 on 30 June and 1 July, providing a truly international forum for those involved in hybrid renewable energy systems, solar PV, hydropower, dam safety, storage systems and grid management. Geographical representation spanned Africa, Asia, Europe and the Americas, and delegates ranged from experts in hybrid systems to newcomers exploring potential and development opportunities in their countries. The rapidly increasing opportunities presented by hybrid energy systems was clear. Success stories, new design approaches, challenges, risk assessment, best practice standards and environmental protection were covered over the two days, making this a practical forum for the profession and the future of hybrid schemes.

Co-hosted by Aqua-Media International and ICOLD, it was the third international conference in this series on hydropower hybridization, and it examined the full spectrum of hybrid renewable energy solutions, including hydropower integration, floating solar PV, energy storage systems and the regulatory policy frameworks required to support large-scale deployment.

Opening messages

Welcoming delegates on behalf of Aqua-Media International, Alison Bartle highlighted the strategic importance of renewable-led energy systems in strengthening energy security. "There has never been a more important time to focus on renewable energy. Climate change and geopolitical instability underline the need for energy independence, making it imperative to maximise the integration of clean, renewable and sustainable energy," she noted.

She then spoke of the appropriateness of Portugal as host for the conference, in view of its wealth of experience in renewable energy development. She recalled that in 2023 the Portuguese grid had run for six consecutive days on renewable energy alone. The Alqueva multipurpose scheme was a flagship project, combining hydro, pumped storage and floating solar PV (FPV). It was a major pioneering scheme for Europe, following the first small Portuguese scheme at Alto Rabagão, now the site of the EDP's unique floating solar laboratory, a research and testing site for new systems, which conference delegates would be visiting on a technical excursion on 2 July. Portugal has future plans to develop up to 10.8 GW of FPV, she added.

The fact that participants covering so many areas of expertise, or with potential and future development plans, had travelled such long distances to be present (for example from Lesotho, Zambia, Mozambique, Indonesia, Ukraine and Brazil), Bartle continued, demonstrated that there had never been a more important time to both focus both energy and intellect on the use of renewable energy.

In his welcome and keynote address, ICOLD President Devendra K. Sharma commented that Portugal had long demonstrated how innovations in water resources can coexist with forward-thinking engineering and renewable energy ambitions. "There is no better place than Porto, where the Douro river meets the Atlantic, to discuss the intersection of power systems technology with a combination of hydro, pumped-storage plants, solar and wind energy systems, for meeting the future challenges of global energy transition", he said. He pointed out that the impacts of climate change were no longer distant projections, they were realities which we navigate through in our daily lives. Extreme weather events, unpredictable hydrological patterns, and the urgent imperative to decarbonize economies demand that we reinvent how we manage our resources, he added.

"Coming from a developing country where water and energy security dictate the livelihoods of hundreds of millions, I view this transition through a lens of profound responsibility", President Sharma said. "In India, we have to reimagine our energy systems with its multiple growth in the coming two decades in order to meet our power demand and goals of net zero emissions."

He noted that historically, dams and reservoirs had been designed with singular or linear objectives, such as flood control, irrigation, or baseload hydropower

Two views of the opening session, during the welcome and overview by Alison Bartle.

Far left: ICOLD President D.K. Sharma: "Hydro hybrid schemes reduce a country's vulnerability to disruption in supply, and increase access to reliable electricity, bringing significant social and economic benefits."

Above: The panel of speakers in the opening session.

generation; but today hydropower assets had to do much more. Hydroelectricity has always been the original champion of renewable energy, providing balancing services and energy storage and acting as the backbone of a flexible, resilient, and fully integrated clean energy for unparalleled grid stability by black-start capabilities, and large-scale storage, Sharma said.

He set the scene for the discussion to follow, by pointing out: "Today, hydro hybridization is our most elegant answer to the challenge of grid stability and energy transition. By combining the reliable, dispatchable power of hydropower with variable wind and solar assets, we create a symbiotic energy ecosystem. Hydro hybrid systems can reduce a country's vulnerability to disruptions in supply and increase access to reliable and stable electricity, which can bring significant economic and social benefits". He went on to outline some of the benefits of FPV, in minimizing land use and reducing evaporation from reservoirs, as well as the possibility to use existing infrastructure. He added that the cooling effect of reservoir water also increased the efficiency of solar panels.

President Sharma told delegates that ICOLD has 29 Technical Committees with more than 800 global experts who are working for dams and also addressing the hydro-hybrid frontiers. "As we innovate," he said, "we must remain anchored to our foundational principles of safety first, climate resilience and inclusivity and knowledge exchange", and he elaborated on each of these:

- *Safety first*: In integrating new technologies in hydro-hybrid systems it is important never to compromise the structural or operational integrity of the dams. Hybrid operations introduce new cycling patterns and harmonics in the power grid that require rigorous engineering standards and continuous monitoring. When dams are planned for the large number of future pumped-storage schemes, dam safety must never take a back seat.
- *Climate resilience*: Hybrid designs need to account for the shifting hydrology of tomorrow to ensure that these systems function optimally under altered precipitation regimes.
- *Inclusivity and knowledge exchange*: The technology discussed during the two days of the conference must not remain confined to developed nations. We must actively bridge the gap, ensuring capacity building and technology transfer to the developing nations in under-represented regions where energy transitions are most urgently needed.

Klaus Jorde, Executive Committee Secretary of IEA-HYDRO, giving his opening address on behalf of his organization, highlighted two main aspects which he said were important when considering global hydro development.

First, he referred to IEA's published study on how to achieve net zero greenhouse gas emissions by 2050. The study had found that this would require a doubling of globally installed hydropower capacity, requiring a major effort in the years to 2050. "We are lagging behind significantly", he said, adding that there was already a failure in achieving the 1.5 ˚C temperature reduction called for in the Paris Agreement. But he stressed that this did not mean that future hydropower development should not continue to try to achieve the goals.

As the second point, Jorde noted that the role of hydropower was changing, from providing renewable and dispatchable energy to being a facilitator or catalyst for the integration of large shares of intermittent renewables in electrical systems. "Flexibility and storage are key assets in fulfilling this role", he said, "flexibility to balance the grid on timescales of sub-seconds, to hourly, daily, weekly, seasonal or even multi-annual scales".

Jorde observed that storage traditionally provided by reservoirs and pumped storage was now increasingly being sought in run-of-river plants. Depending on the capability to respond to different types of grid regulation requirements, different markets could be served, such as primary frequency regulation, day-ahead markets, winter reserve, black start capability and many other services required to balance the grid.

Stressing the key role of hybridization, Jorde pointed out that a reservoir with solar panels or wind turbines would allow for the transfer of very cost-efficient energy from renewable sources into highly valuable, fully dispatchable, stored renewable energy. He added that combining hydro plants with battery storage systems could create multiple benefits depending on the size and location of the battery systems. Benefits extended from a simple reduction of wear and tear on the turbines, extending their lifetime, to the ability to provide a variety of grid services, creating additional revenue without additional stress on electromechanical equipment. "The combination of extremely fast batteries with the high capacity that hydropower offers, provides unique service opportunities", he said.

Batteries could also help to mitigate environment impacts, Jorde continued, for example in the case of hydro peaking operations, and he noted that in the sessions, there would be case studies where additional hydro capacity could be unlocked by the addition of

Ana-Paula Moreira, EDP, Portugal: "The priority now is to establish coherent regulatory frameworks, streamline permitting processes, and develop market mechanisms that value flexibility and system services appropriately."

battery systems. While these benefits of batteries were clear, Jorde pointed out that optimal options would depend on the specific type of hydro plant, as well as the regional electricity supply situation.

On the subject of battery storage, he said: "I believe we are at a very early stage of a very promising development for hydropower; batteries are becoming cheaper, and they offer the opportunity to maximize the services that hydro plants can provide, to optimise the operation of the hydro plant, and to maximize the value stream which can be activated by such hybrid systems".

Jorde concluded that hybridization is an interesting new field of research, and is being addressed within IEA-HYDRO's various tasks and international working groups.

Maria João Coelho, Director of ELECPOR, a supporting organization of the conference, welcomed delegates and explained that her organization was the Portuguese Association of Electrical Companies. Members were principally power utilities, and other leading players operating in the power sector. ELECPOR was also the Portuguese representative within the pan-European association Eurelectric.

She commented that the members of ELECPOR represented about 53 per cent of Portugal's installed capacity, adding that activities spanned both renewable and conventional (thermal) generation, as well as pumped-storage, electrical network regulation and system operation. Many members were actively involved in the development of hydropower, pumped storage, and the integration of renewable systems, as well as emerging energy technology, both within Portugal and in several European and International markets.

As the Portuguese representative in the opening session, she welcomed international participants to her country, noting that the presence of delegates from nearly 40 countries reflected the importance of hydropower and hybridization, and the increasing relevance of international collaboration in addressing the challenges of the energy transition.

She told delegates that Portugal was particularly pleased to host the discussions, as over the past two decades the country had made a strong commitment to renewable energy, and together with other European countries, to encouraging the integration of renewables. She referred to the fact that there had been periods in recent years when renewables had literally covered total electricity demand for several consecutive days, demonstrating the remarkable progress made in transforming energy systems.

She stressed that hydropower remained the most valuable source of renewable energy available, and combined with solar, wind, pumped storage and batteries, it could provide flexibility and essential system services; it could also ensure security of supply. "Hybridization allows us to make better use of existing infrastructure and natural resources, and to maximize the value of reservoirs and transmission systems." She added that from the Portuguese perspective, it was increasingly important to address climate-related challenges, as water scarcity, droughts and extreme weather events become more frequent.

She commented that hydropower, pumped storage, floating solar and other such technologies could contribute not only to energy resilience, but also to more sustainable resource management.

Speakers in the session on policy, planning and regulatory issues.

Policy, planning and regulatory aspects

The first session took the form of a panel discussion on policy, planning and regulatory aspects. It was chaired by Ana-Paula Moreira, who is currently part of EDP's Renewable Generation Assets management team in Portugal.

The discussions during this session provided a clear and encouraging picture of the growing role that hybridization can play in accelerating the energy transition. Across different technologies, geographies, and business models, there was broad consensus that hybrid projects have the potential to unlock significant additional value from renewable energy assets, improve system flexibility, and support the integration of increasing shares of variable renewable generation into power systems.

One of the strongest messages emerging from the session was that technology is no longer the primary barrier. The technologies required to develop hybrid solutions, including the combination of hydropower with solar, wind, and battery storage, are already available and have demonstrated their technical feasibility in multiple projects worldwide. However, while technology readiness has progressed rapidly, regulatory and market frameworks had not evolved at the same pace. Participants highlighted that without clear rules, stable remuneration mechanisms, and appropriate valuation of flexibility services, investment decisions would remain challenging and deployment would be slower than desired.

Another important takeaway was the central role of hydropower within hybridization strategies. Hydropower assets possess unique characteristics, including flexibility, storage capability, reliability, and operational experience, that make them natural anchors for hybrid systems. The discussion reinforced the idea that

hybridization is not about replacing existing hydropower assets, but rather about enhancing their value and expanding their contribution to increasingly complex and dynamic electricity systems. By integrating complementary technologies, hydropower can further support grid stability, optimize the use of network infrastructure, and maximize the utilisation of renewable resources.

The session also highlighted the need to move beyond pilot projects and isolated demonstrations. While valuable experience has already been accumulated through several pioneering initiatives, the sector must now focus on establishing scalable, repeatable, and bankable business models. Participants stressed that future success will depend not only on technical innovation but equally on the ability to create investment frameworks that provide confidence to developers, investors, regulators, and financial institutions. Scaling up hybridization will require projects that can be replicated across different markets while delivering predictable economic returns.

A further insight was the growing importance of integrated system thinking. Hybrid projects can no longer be evaluated solely from the perspective of individual generation assets. Instead, optimization must consider the interaction between generation, storage, market participation, network constraints, and ancillary services. This integrated approach requires close cooperation among asset owners, system operators, regulators, and policymakers. It also reinforces the need for market designs that reward flexibility and system value rather than focusing exclusively on energy production.

Finally, the session demonstrated that the pathway for accelerating hybridization is becoming increasingly clear. Stakeholders broadly recognize the opportunities and understand the technical solutions available. The priority now is to establish coherent regulatory frameworks, streamline permitting processes, and develop market mechanisms that appropriately value flexibility and system services. Achieving this alignment will create the conditions necessary for hybrid projects to move from promising concepts to widespread deployment, ultimately enabling renewable energy systems that are more resilient, efficient, and capable of supporting long-term decarbonization objectives.

Role, planning approaches and benefits

Luc Deroo, CTO of ISL Ingénierie, France, chaired the second session which focused on the role of hybridizaton, planning approaches and benefits. Concluding the session, he recalled that there had been six presentations on hybridization, covering hydro and solar, hydro and batteries, and sometimes hydro plus solar plus batteries. He noted that across the presentations one could clearly see three different timescales.

At a scale of a few seconds or minutes, turbines are called upon to respond to frequency fluctuations of the grid; fluctuations in solar output caused by passing clouds. Batteries can limit wear and tear on turbines, and to a certain extent can increase their service life. It is important to note that fairly small batteries suffice in that respect.

At a scale of days, a hydro-solar combination is an obvious solution. Turbines are stopped in the middle of the day when solar power is being produced, and hydro energy is dispatched during morning or evening peaks. This obviously works for hydro plants with reservoirs, but it can also work for run-of-river plants, although only during the dry season.

Chairman Luc Deroo, of ISL, France: "The flexibility of hydro-hybridization and its benefits for the grid are well known. But there is far more to hybridization: solar-hydro saves water".

At the seasonal scale, two presentations, dealing with Batoka Gorge and Manantali, took this reasoning further. Both papers argued that the central role of solar power is to save water in the reservoirs. There is less need to draw down reservoirs, so progressively, day after day, water accumulates, and is available for dry periods at Batoka, and for agricultural needs at Manantali. In both cases the effect is considerable, and this is the central point.

Where water resources are under strain, solar and wind make it possible to reduce reliance on hydro for baseload generation, and the role of the hydro reservoir is therefore elevated: peak electricity production; reserve capacity for 'dunkelflaute' periods, and above all, security against droughts.

Some key figures could be taken away from the session, Deroo said.

Concerning batteries: Pairing turbines performing frequency regulation with a small battery reduces wear and tear factors by up to 80 or 90 per cent. This can be achieved with batteries of modest capacity, for example a power rating of five to 10 per cent of the hydropower, and storage capacity of just 20 to 30 minutes or so.

Concerning hydro-solar: For the three hydro-solar hybrid projects presented, the solar component corresponds to 35-40 per cent of the hydropower (and this may not be the ceiling). In these cases, the hydro-solar combination increases the dispatchable energy by about 15 per cent during the dry season, compared with zero in the case of stand-alone solar. It should be possible to go further than this, possibly with the addition of batteries, to ease the strain on the turbines, and

The panel of speakers in the session on FPV, discussing advantages and presenting case studies.

Patrick Sipatela of the Zambezi River Authority, who spoke of the contribution of hybridization to climate resilience, in the context of the planned scheme at Batoka Gorge.

Far right: Andrés Franco, who chaired the session on hybridization case studies.

also, most likely, with a pumping component. This has been demonstrated, for example, at Pinnapuram in India, where there is 3 GW of solar power, and 1.7 GW of pumped storage.

In conclusion, an important point to be stressed is that hydro-hybridization provides flexibility and allows for renewable energy penetration, as is well known. But there is far more to hybridization: a solar-hydro system saves water!

Hybridization ~ Case studies

Andrés Franco, CEO of Isigenere, Spain, chaired the session on hybridization case studies, from which a number of key conclusions emerged.

The first message was that hydro hybridization is no longer just a conceptual discussion. The papers presented highlighted a clear shift from isolated demonstrations toward more complete hybrid systems where hydropower, floating solar, batteries, wind, grid infrastructure and control systems are treated as one coordinated asset.

The case study of the Alqueva scheme in Portugal is a clear and prominent example of this transition from concept to implementation. The project shows that floating PV can be integrated into an existing pumped-storage asset by using the reservoir surface, existing electrical infrastructure and hydro flexibility. However, the main lesson is broader: that is, reservoir-based floating PV is not simply a solar project on water, but a multidisciplinary engineering challenge. It requires hydraulic assessment, bathymetry, wave and wind analysis, dam safety review, emergency access planning, electrical integration, O&M planning and regulatory alignment. Anchoring and mooring are central to safety, cost and bankability, while monitoring, instrumentation and validation are essential to reduce perceived risks for dam owners, insurers and lenders.

Speakers who presented a range of examples of hybridization case studies.

The Lastivka project on the Stryi river in Ukraine expands hybridization to a regional energy-system scale. It proposes an integrated energy hub which combines pumped storage, wind, solar and small hydro through a common grid interface, with a role in post-war resilience and ENTSO-E integration. The project demonstrates that hydro hybridization can be justified not only in terms of internal rate of return (IRR), but also in terms of energy security, decentralized "producer-consumer" clusters, local reliability, balancing capacity, regional development and strategic grid value.

The case study of the Knoydart scheme in Scotland offered a smaller-scale yet highly practical perspective on hydro-hybridization. Being on an isolated mini-grid, the project highlighted that every load change, motor start and maintenance outage matters when there is no main grid connection. In this context, hybridization is not just the addition of a battery. It requires strategic oversizing of infrastructure, digital control, demand-side management, productive use of electricity and financial reserves for future asset replacement. The main lesson is that hybrid systems must be designed around their real operating conditions, not only around nominal installed capacity.

A paper by EPFL and IEA-Hydro, Switzerland, on MPC-driven battery hybridization of run-of-river cascades addressed real-time coordination between batteries and hydropower units while preserving grid performance and machine life. A key insight is that the most advanced model is not always the most useful operational model. The neural-network model in the case study presented was highly accurate, but too computationally demanding for real-time control, while the simplified physical model was less detailed but more practical. This raises an important research issue: that is, control models must be accurate enough, explainable enough and fast enough to operate safely.

A paper Dornier Suntrace, Germany, focused on the commercial and system-sizing aspects of hydro-hybridization. The company's AHEAD framework demonstrates that the value of adding floating PV to hydropower depends on the following factors: hydrology, reservoir storage, tariff structure, dispatch rules, curtailment and the ownership model. The optimal size of the solar system is not fixed: benefits increase up to a certain FPV-to-hydropower ratio, after which curtailment and diminishing returns appear. Economically, value depends on whether coordinated dispatch can be monetized. Where contracts, PPAs and market rules do not recognize flexibility and time-shifting values,

Far left: Nkekeletse Malakia Makara of the Lesotho Highlands Water Commission, putting a question to the panel of speakers.

Quentin Boucher, SuperGrid Institute, France, who chaired the session on grid management.

technically sound hybrid projects may fail to capture their full potential.

Finally, a paper by ISL Ingénierie, France, on the solar-hydro hybridization of three hydro plants in Cameroon brings these themes into the context of real-world project development across several hydro assets. ISL's work on the Memev'ele, Lom Pangar and the Mbakaou schemes confirms that solar-hydro hybridization is highly site-specific. The goals may be to smooth solar intermittency, increase peak energy production and improve water-resource management, but the best solution depends on each plant's hydrology, storage, grid limits, demand profile and operating rules.

Other main conclusions from the session on hybridization case studies include:

- hydro hybridization should be treated as system optimization, not as the simple co-location of assets;
- floating solar on hydropower reservoirs has strong potential, but the engineering requirements are more demanding than for conventional land-based PV;
- storage can mean different things: batteries provide fast response, hydropower reservoirs provide daily or seasonal shifting, and pumped storage provides long-duration flexibility; and,
- bankability will increasingly depend on evidence: that is, data from monitoring, validated design assumptions, clear standards, tested mooring systems, and transparent O&M responsibilities.

Several areas remain for future discussion and further development. First, more long-term operating data from floating PV on reservoirs is needed, especially in terms of mooring fatigue, anchor performance, electrical reliability, environmental effects and operation and maintenance costs.

Second, improved methodologies are required to monetize reduced turbine wear, ancillary services, water savings and flexibility. Further work is also needed to develop contractual models for cases where hydro, solar and battery assets are separately owned. In addition, clearer regulatory frameworks are required for dam safety responsibilities, reservoir surface rights and emergency procedures.

In conclusion, the papers presented during this session demonstrate that hydro hybridization is evolving into a practical field for engineering and investment. The opportunity is significant, but the most successful projects will not be those that simply add more renewable capacity. Rather, they will be those that integrate hydrology, structures, controls, market design, environmental constraints and long-term operation into one coherent system.

Grid management

The session on grid management was chaired by Quentin Boucher, lead of the Electricity Market Economics Division at SuperGrid Institute, France. The papers presented during this sessions, and the ensuing discussions, provided an excellent overview of the diverse challenges facing modern power systems as renewable energy penetration continues to increase across both isolated and interconnected networks.

The session highlighted the emergence of microgrids with very high shares of renewable energy, underlining the importance of strong interconnection between assets and the complementary roles of hydropower storage and battery energy storage systems (BESS). Under these conditions, appropriate control strategies are critical for maintaining stable and reliable grid operation. The examples presented demonstrated how advanced control architectures are becoming essential to balance variability while preserving system stability and operational resilience.

The discussions also pointed to the increasing complexity of larger power systems, where growing numbers of distributed energy resources and smaller generation assets are being connected at both transmission and distribution levels. As these developments continue, increasingly streamlined coordination will be required to coordinate a wider range of assets and operating conditions. In this context, hybridization may offer additional opportunities to improve operational flexibility of small assets while enabling owners of small hydropower schemes to diversify revenue streams through the provision of multiple services.

More broadly, the continued expansion of renewable generation is placing additional pressure on grid connection infrastructure. Maximizing the use of existing

The panel of speakers who presented papers on grid management.

connection points is therefore becoming an increasingly important consideration for developers and network operators alike. This reinforces the potential value of combining existing hydropower assets with solar PV and battery storage, allowing multiple technologies to share infrastructure while improving the overall utilization of available grid capacity.

Power quality was identified as another critical challenge. The session outlined how advanced control systems can unlock greater flexibility from hydropower hybridization and help plants respond more effectively to rapidly changing grid conditions. Hybridization can also contribute to reducing equipment stress under increasingly dynamic operating regimes, while creating new opportunities to provide grid support services and enhance overall system performance.

Overall, the session demonstrated that future hybrid power systems will increasingly rely on smart control strategies to maximize the benefits offered by hybridized assets and to ensure the effective integration of solar and wind generation. The ability to coordinate multiple technologies seamlessly will be a key factor in delivering reliable, flexible and resilient power systems.

Realizing this potential, however, will require continued collaboration between developers, regulators and transmission system operators. While the technical advantages of hybridization are becoming increasingly evident, further work is still needed to establish clearer regulatory frameworks, harmonized requirements and streamlined approval processes. Addressing these issues will be essential to facilitate broader deployment of hybrid projects and unlock their full value for both asset owners and power systems in the years ahead.

Floating solar PV ~ Best practice, safety and challenges

Camélia Farchado, Senior Solar Engineer at DNV Sarl, France, chaired the session focusing on safety issues relating to floating solar hydro, and best practice. She commented that over the two days there had been multiple discussions on the importance of FPV planning, of proper site investigations and design, of technology and of environmental considerations. But she pointed out that the issue of greatest importance now, and it would remain so in the future, was safety: the ability to develop and operate projects in a safe way.

The session had included an introductory talk by authors from EDF and INRAE, France, entitled 'Towards best practice for the realization of floating PV on dam reservoirs', and other topics had included challenges on new major FPV schemes in Indonesia, plans for FPV at Kpong in Ghana, an innovative anchoring system for a 44 MW FPV scheme in France, and underwater placement of anchoring systems.

As discussion time had been limited during the session, Camélia Farchado was invited to take some time in the conference closing session to speak of DNV's work over the past few years in developing guidelines to support the safe design, construction and operation of FPV projects on different types of water bodies. She explained that a report on 'Recommended practice' had been issued several years ago, which had become one of the most widely followed references in the solar industry. Since then there had been quite a lot of evolution and changes in the industry, and with the participation of many stakeholders in the industry this report, a guideline emerged.

DNV had then set up a foundation for the development of two guidelines, again with input from multiple (> 25) industry stakeholders, to be used as standards for validation and certification. The first standard, DNV STE 309, sets out technical requirements for the design of moorings, and systems to keep the solar array safe and in the correct position throughout its operating lifetime. Farchado commented that while a 'lifetime' had initially been considered to be around 15 years, this had now extended to 25 years, and there was pressure, from lenders, to push towards 40 years.

The standard also addresses environmental loading from wind, waves, currents and water level variations, and it establishes design principles and methodologies on how systems should be analysed and verified, to ensure operational functionality, and most importantly

Camélia Farchado of DNV, France, who chaired the session on FPV best practice and safety, and gave details of two recently released DNV guidelines relating to FPV safety. She commented: "FPV is entering a new phase of industrial maturity".

Speakers who presented on FPV safety challenges and related studies.

Far right: Nicolas Nerincx of DN&T, Belgium, who gave a talk on best practice.

safety, of the system itself and also of those on site operating it, in normal operation and also in extreme conditions.

The standard defines performance requirements for structural integrity, testing of materials, and so on, and introduces a risk-based methodology in which engineering requirements are calibrated according to both the severity of the environmental conditions and the consequences of failure. The approach is built around the concept of consequence categories and location classes (types of water bodies), ensuring that design efforts, testing programmes and acceptance criteria are well aligned with the project-specific risk levels.

Another complementary standard is DNV STC108. This focuses on the structural design of the solar floats and associated structural components, there being multiple types of floats for different water bodies. This defines the structural integrity, quality of materials and testing of the design, in the same way as for the mooring systems, and evaluates the float itself in different environmental conditions, as well as possible failure modes, based on all types of hazard. Load transfer mechanisms are taken into account, not just for the float itself, but the floats with a module above it, with joints, or with people walking across it, and the float in combination with the anchoring and mooring system. Specific attention is paid to the behaviour of polymers and other composite materials, including resistance to salinity and erosion, and durability to serve for 15, 25 or even 40 years Also included are the requirements for those carrying out routine inspections.

Farchado explained that the standards are available on the market, and some of those who had helped develop them (some of which were present at the conference) had already started evaluating projects against both standards.

One of the strongest conclusions from the session was that floating solar PV is entering a new phase of industrial maturity. Within the relatively short time they had progressed from prototype schemes on a kW scale, to projects of tens of MW, and from panels on small lakes to offshore.

"Future growth of floating solar PV will not, and should not, only be driven by technical innovation", Farchado said, "but increasingly by confidence". She felt that there should be full confidence that these systems can be designed safely, confidence that risks are understood and can be managed, and confidence that the performance can be maintained for decades of operation. She predicted that major industrial-scale FPVs would be developed over the next few years, and concluded that the sharing of experience, as had been done during the conference, was extremely important.

Dr Aries Firman of Indonesia: "Innovation begins at the design stage and progresses through laboratory-scale development to full-scale deployment".

Floating solar PV ~ Innovation and case studies

Dr Aries Firman, member of the Dam Safety Commission of Indonesia, and Vice Chairman of the Indonesian National Committee on Large Dams (INACOLD), chaired the session on FPV innovations and case studies. The presentations and discussions that followed generated several key takeaways, with valuable perspectives shared by both speakers and audience members. The session also underscored that a number of issues and challenges remain to be addressed, with the following to be noted:

- Innovation begins at the design stage and progresses through laboratory-scale development to full-scale deployment, with various lessons learned from case studies contributing to continuous improvement.
- The innovations presented during the session, including advances in anchoring systems, mooring technologies, and the integration of FPV with pumped-storage, can be considered as breakthroughs in promoting more integrated renewable systems rather than standalone solutions.
- Examples of product development aimed at enhancing the performance of future FPV projects covered all key aspects, including anchoring systems, floaters, mooring lines, hybridization, and so on.
- The real-world application of these innovations may encounter challenges because of site-specific conditions and constraints, including those associated with FPV projects integrated with pumped-storage stations.
- Case studies should not be limited to success stories

The large line-up of speakers in the session on innovation and FPV case studies, reflecting the amount of progress in recent years.

alone, but instead should capture and disseminate challenges during the whole life cycle of an FPV project. These lessons should be shared across the industry regardless of project size related to the solar power investment in the addition to the hydropower, and also the safety of both renewable energies which have significant potential for complementarity.

Moreover, the topics below should be addressed in more detail during further discussions:

- The current development of FPV as a standalone scheme, unrelated to existing hydropower operations, also requires innovative approaches to enable practical solutions for the benefit of both operators as, in many cases, FPV and hydropower operators have differing priorities and objectives.
- One critical element of FPV systems that is essential to ensuring the safety of the overall structure, and has yet to be fully implemented in pilot- and full-scale projects, is instrumentation for monitoring tools. Similar to the dam body, which is equipped with piezometers, extensometers, and so on, instrumentation must also be installed for mooring lines, anchoring, floaters, and so on. This is crucial for safety evaluation, when the design values versus the actual results from the reading of all surveillance devices, would determine whether the overall structures remain in the green zone, transitions to the yellow zone, or enters the red zone throughout the FPV's entire life cycle.
- Recognizing the importance of the anchoring system in ensuring the safety of FPV structures. There should be a clear description on pull out tests for non-permanent anchors by destructive testing, in addition to proof load tests for permanent anchors by non-destructive test in the specification and method of statement.

Overall, the session successfully showcased innovations in FPV and presented case studies on its applications across various types of projects, including hybridization. The examples covered both pilot-scale initiatives and large-scale developments, highlighting the need for further research to address the dynamic challenges associated with the implementation of FPV schemes.

Storage systems

The session on storage systems was chaired by Pierre Duflon, who is responsible for the worldwide business development of decentralized pumped-storage projects at Andritz Hydro. This session emphasized the critical role of energy storage, in various forms, in enabling the transition to renewable energy by better integrating intermittent sources like run-of-river hydro, but mainly wind and solar energy. The strategic importance of storage technologies were highlighted, particularly pumped storage, as well as the evolution towards hybrid and decentralized systems to ensure grid reliability and flexibility.

Pierre Duflon of Andritz, France: "Storage has emerged as a game-changer. The energy transition's challenge lies not in energy production, but in storage and management."

Storage has emerged as a strategic game changer. The session highlighted that the energy transition's main challenge lies not in energy production, but in storage and management, with pumped-storage providing large-scale, long-duration storage, and generating flexibility, essential for grid stability. The future of storage is hybrid, integrating multiple technologies to build agile and resilient energy systems.

In terms of the evolution of storage systems, storage is evolving from large, centralized plants to decentralized solutions and hybridizing existing assets, shifting from pure energy production to providing grid flexibility as a service. This transformation supports a grid that is powerful, agile, resilient, and intelligent.

Benjamin Peltié, head of the Hydropower and New Energies Department at ISL Ingénierie, France, presented a paper on the design and optimization process for small or decentralized pumped-storage in France and the French Islands, focusing on the selection of the main specifications and electromechanical design. This choice drives the optimal integration of intermittent renewable generation sources and helps stabilize the grid. These long-term, high efficiency and cost-effective solutions are environmentally friendly, and share low O&M costs.

André Mendes, of the COBA Group, Portugal, presented a a comprehensive overview of the small Santiago pumped-storage project in Cape Verde. This project will be developed in a challenging environment because of the arid climate, limited river water, and the small size of the electrical grid. With an installed capacity of 20 MW, it will represent approximately 50 per cent of average peak demand. The design is based on closed-loop operation between two off-stream reservoirs, with a desalination plant to compensate for evaporation and seepage.

Focusing on reservoirs, which are a key element of pumped-storage schemes, José Machado do Vale, MV Consulting, Portugal, presented the application of geomembranes at various projects. The rapid filling/drawdown cycle and related erosion, as well as seepage, are critical for the stability and safety of the reservoirs. Three geomembrane applications were described, including the Pinnapuram hybrid hydro plant in India, a nuclear scheme in the USA, and the upper reservoir lining of the Calheta III project in Portugal. Marine pumped-storage plants will require

Speakers sharing experience on various types of storage systems, and their operational characteristics.

specific membrane solutions to prevent seawater leakage into the surrounding ground, such as double-membrane systems.

Another storage solution, discussed, already identified as a key technology for fast response applications and smaller energy storage capacities, was the battery energy storage system (BESS). Sergii Chaplik, director at SH Energy Technology, Czech Republic, presented a paper on the thermal optimization of batteries thanks to an optimized charging cycle, taking advantage of ultra-short high voltage charging cycles (50 ns at 10 × V) separated by rest intervals. During rest intervals, the chemical diffusion allows a 15 per cent faster charge at a lower temperature of Li-ion batteries. This charging method is applicable for existing batteries and uses a compact electronic module integrated into the battery charger.

Dr Frederic Evers, Gruner Stucky, Switzerland, discussed hydropeaking possibilities of combined storage systems including all the constraints around them. Hydropeaking is an operational feature of storage hydro plants and results from flexible generation to balance variable demand, as well as increasing shares of wind and solar power production. However, rapid changes in turbine discharge cause pronounced short-term fluctuations in downstream rivers, potentially leading to ecological degradation and can conflict with environmental regulations. Compensation basins are commonly used to buffer turbine discharge before releasing it in a controlled manner.

Eva Weissgärber, of Floecksmühle Energietechnick, Germany, discussed another way to store additional hydraulic energy, specifically at low head, run-of-river plants, using inflatable rubber dams. The integration of intermittent renewable energy sources is pushing hydro plants in the direction of faster flow variation to stabilize the grid, and therefore induces rapid flow and level variations downstream of the plants. Adding inflatable rubber dams in the tailrace pond allows for the temporary storage of a larger water volume and peak-shaving of the flow variation.

In case of flood, the rubber dam can be completely deflated to allow the full water passage without disturbance.

In conclusion, storage is global, diversified and versatile, and hybridization is progressing towards the optimal use of each technology and system to guarantee a stable energy supply, both in terms of energy quantity and also, increasingly importantly, in terms of power quality.

High efficiency or the effectivity of core equipment (turbines, pumps, motor-generators, and so on), or support systems, including reservoir membranes, penstocks and transmission lines, is the key for affordable and long-lasting solutions.

Environmental aspects

The session on environmental aspects was chaired by Dr Sacha de Rijk, an expert in freshwater ecology and water quality at Deltares, The Netherlands.

In summing up the session, she reflected on the broader context for the topic, noting that the global transition to renewable energy is accelerating and creating increasing demand for space to deploy solar systems. FPV technology is emerging as an attractive solution because it combines renewable energy generation with existing water infrastructure. However, the increase of FPV schemes also raises important questions about the sustainable management of freshwater ecosystems and biodiversity.

Dr Sacha de Rijk of Deltares, Netherlands: "FPV is an attractive solution, but it also raises important questions about the sustainable management of freshwater ecosystems and biodiversity."

Freshwater systems are already under significant pressure from climate change, pollution, water scarcity, and biodiversity loss. At the same time, societies require more renewable energy to meet climate targets. This creates a challenge: how can we increase solar energy production without compromising the ecological health of lakes, reservoirs, ponds, and coastal waters?

The suitability of FPV systems varies considerably between different aquatic environments. Artificial basins, such as irrigation ponds and water storage facilities, generally offer the most straightforward opportunities. These systems often have relatively lower ecological value and simple hydrodynamic conditions. In addition to generating renewable energy, FPV installations may reduce water evaporation and help limit harmful algal blooms.

The situation becomes more complex in natural water bodies. Small lakes and ponds frequently provide important habitats for fish, birds, bats, and aquatic vegetation. While commercial FPV projects are already being developed in such environments, ecological impacts require careful assessment. Research indicates that coverage ratios are a critical factor. High levels of panel coverage can alter water temperature, reduce oxygen concentrations, and decrease primary production, potentially affecting the entire aquatic food web. These findings highlight that renewable energy production and ecosystem functioning compete for the same resource: sunlight.

Larger water bodies, including hydropower reservoirs, present another set of opportunities and challenges. These locations often benefit from existing energy infrastructure and can accommodate larger FPV systems with lower coverage ratios. However, they are characterized by more complex hydrodynamic conditions and often support multiple functions, including recreation, tourism, water supply, and biodiversity conservation. Designing systems that balance

Two of the speakers in the session on environment. AI-driven fish passage, presented by O. Chazal of Fishheart, Finland, and the advantages of FPV in reducing reservoir evaporation from Y. Wahby of Morocco. There was an additional pre-recorded talk by Gilles Lecaillon of Ecocean, France, on the protection of marine life.

these interests requires careful planning and interdisciplinary expertise.

The most ambitious frontier for FPV lies in offshore and nearshore environments. Although several pilot projects are underway, the technical, financial, and ecological feasibility of large-scale deployment remains uncertain. Challenges include exposure to waves, tides, currents, corrosion, and extreme weather events. Furthermore, the environmental impacts on marine ecosystems are still poorly understood. Significant research and innovation will be needed before these systems can become a widely deployed solution.

A key message emerging from current research is that there is no universal approach to floating solar development. The environmental impacts of FPV depend strongly on local conditions, including water depth, surface area, flushing rates, wave action, and existing ecological values. Equally important is understanding the ecological baseline before construction begins. Without knowledge of current species, habitats, and ecosystem functions, it is impossible to evaluate the true effects of a project or design appropriate mitigation measures.

Future challenges therefore extend beyond technology alone. The sector must develop better tools for environmental monitoring, impact assessment, and adaptive management. Artificial intelligence, remote sensing, and advanced ecological monitoring techniques could play an important role in helping operators optimize energy production while minimizing ecological impacts. There is also increasing interest in biodiversity-enhancing measures, such as habitat structures that can support aquatic species around FPV sites.

Looking ahead, coordinated research across all aquatic environments will be essential. Policymakers, researchers, developers, and water managers need a shared evidence base to support sustainable expansion of floating solar. Regulatory frameworks must balance climate objectives with nature protection, while project developers should consider environmental design from the earliest planning stages.

Floating solar has the potential to contribute significantly to the renewable energy transition. However, its long-term success will depend on finding the right balance between clean energy production and healthy aquatic ecosystems. The central challenge is not simply how to deploy more floating solar, but how to do so in a way that safeguards biodiversity, protects water resources, and supports sustainable development for the future.

Technical visit

The event concluded with a technical visit, on 2 July, to the Alto Rabagão dam and reservoir, home to Portugal's first floating solar PV plant and the country's pioneering open FPV Research Laboratory, recognized as a European benchmark for the development and validation of emerging floating solar technologies. This proved popular with 45 participants, many from African nations planning FPV projects. ◊

Networking opportunities during HYDRO-HYBRIDIZATION 2026

Clockwise from top left: The reception and dinner for chairpersons and speakers on 29 June; Welcome Reception and networking party in the exhibition on 30 June; Apéritifs overlooking the Douro on 1 July; and, the Farewell Dinner at the Pestana Palácio do Freixo.