Using reservoirs for floating PV plants

Utilisation de réservoirs pour panneaux photovoltaïques flottants

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Abstract. The use of reservoirs as base layers for floating solar photovoltaic plants has been dramatically increasing in the last five years, especially in the far East and in areas where land is scarce or expensive. The floating solar technology has now more than a decade's experience, and about 7 years' experience on a large scale. Conversely, hybrid systems combining hydropower with floating solar photovoltaic plants are still in an early stage, while having high future potential. The paper will present the characteristics and benefits of floating solar photovoltaic plants, and discuss a project in Israel, where the existing floating cover of a reservoir was replaced by 616 floating PV panels, which will reduce water evaporation while producing about 230 kWpeak output. The paper will also present and discuss the peculiarities of an innovative project at present under study, where both the upper and the lower reservoirs of a pumped storage scheme to be constructed will be equipped with a floating solar power system, thus combining hydro and solar potentials.

Résumé. L'utilisation de réservoirs comme supports pour les centrales solaires photovoltaïques flottantes a considérablement augmenté au cours des cinq dernières années, en particulier en Extrême-Orient et dans les régions où les terres sont rares ou chères. La technologie solaire flottante a maintenant plus d'une décennie d'expérience et environ 7 ans d'expérience à grande échelle. À l'inverse, les systèmes hybrides combinant l'hydroélectricité et les centrales solaires photovoltaïques flottantes sont encore à un stade précoce, tout en ayant un potentiel futur élevé. L'article présente les caractéristiques et les avantages des centrales solaires photovoltaïques flottantes, et abordera le cas d'un projet en Israël, où la couverture flottante existante d'un réservoir a été remplacée par 616 panneaux photovoltaïques flottants qui réduiront l'évaporation de l'eau tout en produisant environ 230 kWpeak d'énergie. L'article présente et aborde également les particularités d'un projet innovant actuellement à l'étude, où

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les réservoirs supérieur et inférieur d'un système de transfert d'énergie par pompage à construire seront équipés d'un système d'énergie solaire flottant, combinant ainsi les potentiels hydro et solaire.

1 Background

The purpose of water retaining reservoirs, some three thousand years ago planned for storage of water for human and agricultural use, has expanded over the centuries to include flood control, recreational use, fish farming and, in relatively more recent times, hydropower. Multi-purpose reservoirs combining two or more uses are now common.

In the present times, with a dramatic increase in population and in a period of climate change, the increasing demand for power and the scarcity of water in many parts of the world ask for increased efficiency of reservoirs. One way of increasing the efficiency of a water supply or hydropower supply reservoir is to add another purpose to the structure, by installing floating photovoltaic panels farms, which provide additional power and shield from evaporation.

While the theory of photovoltaic (PV) dates to the nineteenth century, and the technology became commercially viable in the 1950s, floating PV is a recent technology, which was developed basically to overcome the high costs related to acquisition of large tracts of land. The first floating PV (FPV) system was built in 2007 in Japan. On a large scale, the first commercial installation was a 175 kWp (kilowatts peak) system built at the Far Niente Winery in California in 2008. Installations of medium-to-large floating PV systems, i.e. with a capacity greater than 1 MWp (megawatts peak), started to take place after 2013. The deployment of FPV initially interested countries such as Japan, Korea, and the United States, but subsequently spread to other countries including, for instance, Australia, France, India, Italy and China, which is currently dominating the market and witnessing a considerable number of installations of large scale FPV systems of tens to hundreds megawatt capacity. In 2016, the first plant greater than 10 MWp was opened, followed in 2018 by several plants presenting capacities in the rage of 100 to 150 MWp.

The use of reservoirs for floating solar photovoltaic farms has been dramatically increasing in the last five years, especially in the East Asia where land is scarce or expensive. As a result, China has opted to take advantage of old collapsed coal mining sites, which have been flooded in favour of floating solar installations, creating new opportunities, and contributing to a cleaner environment. This has helped to reduce air pollution, and to improve working and health conditions of the miners, who now deal with the assembly of solar panels and with maintenance operations.

Another reason why floating solar has grown in these regions is due to government incentive measures. In Taiwan, as an example, unused water bodies have been promoted for the deployment of FPV systems, as agricultural land is fundamental and precious, hence a feed-in-tariff scheme favouring floating solar installations over ground-mounted ones has been introduced. In Korea, instead, a higher renewable energy certificate (REC) weighting is given to FPV systems than for ground-mounted ones.

Conversely, hybrid systems combining hydropower with FPV plants are still in an early stage, while having high future potential. In 2017 the first FPV combining solar and hydropower, having a total capacity of 220 kWp, was installed in Portugal. Other projects across the globe of larger scale are currently under discussion and development.

2 Floating photovoltaic plants

2.1 Characteristics and benefits

FPV panels are installed in arrays on water, be it lakes, lagoons, reservoirs for hydropower or water supply or fish farms, oceans. They are placed on floaters on a pre-established water surface and moored with site-specific arrangements. The design and installation of the system may differ depending on the type of reservoir: in particular, pumped storage reservoirs require special design of the floaters, whose connections must be very flexible because when the reservoir is empty rigidity may become an issue, since the floaters can break due to puncturing by the subgrade. For such reasons many companies provide guarantees only of a few months in case of reservoirs that are periodically emptied. The type of impounded water is also an aspect to be considered: the presence of some chemicals may affect the selection of plastic and aluminium components, while the contact with drinking water may require using special materials.

Besides allowing conserving valuable land, FPV plants can provide other significant advantages as compared to overland PV plants. From a power generation standpoint panels installed on water are more efficient due to mainly two aspects: on a large water surface obstacles that can block sunlight are removed/minimised, and water underneath the panels has a cooling effect on the panel, positively affecting the output voltage. FPV also have a beneficial effect from an environment's perspective, in that the panels are a barrier to sun rays from above, and to water evaporation from below. The shading provided by the panels inhibits the growth of algae thus potentially improving the quality of the water, while the partial surface barrier according to research can reduce water evaporation of 25 to 40%.

Concerning the effect on water quality and marine life however, it must be analysed case by case depending on the reservoir and on the objectives. In reservoirs where the objective is to minimise algae proliferation, covering more than 60% of the reservoir generally reduces algae, mainly due to less UV radiance. This can be a blessing to the owner of the reservoir who can reduce costs of chemical treatments or filtration systems. In reservoirs where on the contrary aquatic life needs to be preserved, the percentage of the cover must be adequately assessed. One rule of the thumb is that > 50% of coverage will create problems, with < 20% covering there will be no problem if the FPV system is designed properly allowing for air and light to come in. That is why it is preferable to design several smaller islands instead of one big island, and allow light going under the PV panel between the two floats by adjusting the distance between the floats with spacers. With between 20% and 50% coverage sometimes the effect is not immediate, and it might take longer to be analysed.

2.2 A case history in Israel

2.2.1 Background and design

Hefer is an example of upgrade of a reservoir that was turned into a multi-purpose reservoir. Owned by Hefer Energies Agricultural Cooperative Association, Hefer is a 4.6 m deep reservoir of well water used to irrigate agricultural areas. Due to the high evaporation rate of the site, between 1.5 and 3 cubic meters per square meter per year, a floating cover had been installed on the almost 4,200 m2 surface, to minimise loss of precious water.

Hefer Energies Agricultural Cooperative Association intended to upgrade the reservoir so that besides supplying irrigation water it could also supply power to be sold to the grid. Carpi teamed with Makor, an Israeli company having experience in 800 solar projects, to develop an FPV system that could provide some advantages as compared to other systems on the market. The FPV system designed for Hefer is innovative in three aspects: the tilt angle of the panels, the improved floaters for the electricity system, and the positioning of the inverters.

The tilt angle of the panels is 5° instead of the 12° generally used. A panel with lower tilt angle, when hit by sun rays, will create a shadow that depending on the inclination of the rays can be significantly smaller than the shadow created by a panel with higher tilt angle. Therefore, panels with lower tilt can be spaced closer than panels with higher tilt. Lower tilting, by requiring less space between panels – about 21% less space as compared to higher tilting – allows decreasing the size of the floating structure to install the same nominal power or installing more nominal power on a given surface. Another important advantage resides in its capability of significantly reducing the pressure of the wind on the structure, as detailed in chapter 3.

The floaters are made according to a unique and patented bi-float design, with floats having a minimum thickness of 3 mm and made from high performance materials (virgin polymers with UV and antioxidant additives). An injection molding process provides durability and precision in manufacturing, resulting in greater stability and buoyancy thanks to the bi-float design that withstands loads like operation and maintenance personnel, heavy materials, and snow. Logistics and storage of such floaters are easier because the floaters are compact, nestable and stackable, requiring 3 to 4 times less space than other floaters for transport, reducing total CO2 emissions, and storage space at site. The few parts of which the floats are composed make installation easy - no specialized personnel required - and fast. Walkways are more robust and safer, providing easy and secure walking access to all solar panels for cleaning and maintenance tasks.

The design of the system decreases the costs of the anchoring and mooring solutions. Whilst lower (5°) tilting produces less energy (about 2 to 4% at 25° latitude) this can be compensated by the possibility of installing more solar panels with the money saved from the anchoring and mooring and lowering the tipping risk because of strong winds.

The inverters were placed on the water instead than on the shore, as it is generally done also in FPV, identical to a normal ground-mounted system.

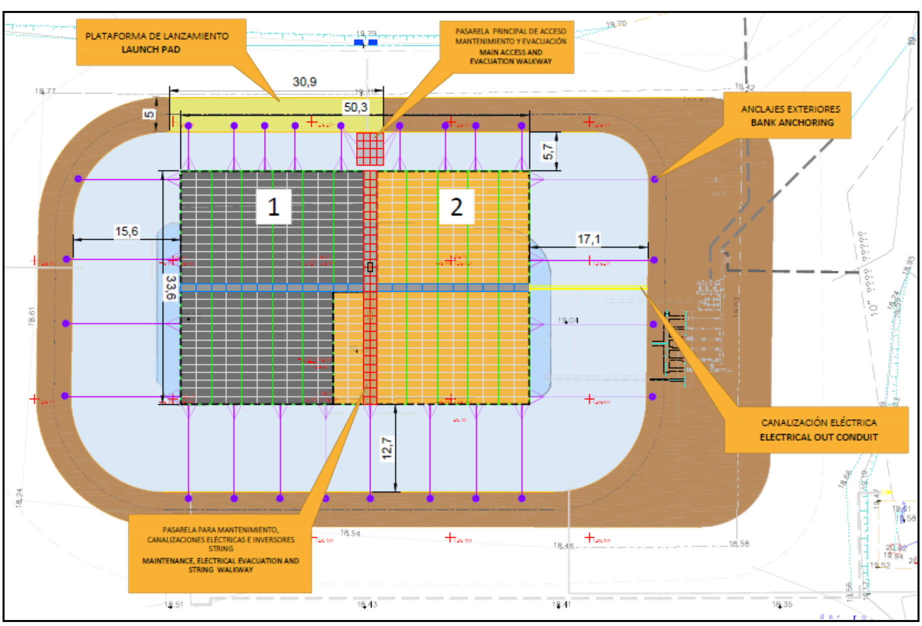

Fig. 1. Hefer: scheme of the floating PV.

A computer-controlled device is integrated in the design, by which if anything unforeseen happens to the floaters or to other components, which affects the efficiency of the panels, the computer will detect and signal the malfunctioning. This monitoring system, generally integrated in the inverter system, is normal practice in Israel and is part of all Carpi floating PV systems, to check the efficiency of output. Since periodical cleaning of the panels is essential for efficiency, selecting a system allowing cleaning by robots can be an added value.

2.2.2 Installation

At Hefer, the floating cover was removed and replaced by 616 floating photovoltaic panels installed on a surface of 1573 square meters, representing about half of the water surface in regular operation, as shown in Fig. 1.

The PV panels and floaters were assembled at crest and then lowered to the water surface (Figs. 2 and 3).

Fig. 2. Preparing to lower the 5° tilt FPV panels and floaters into Hefer reservoir.

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Fig. 3. Lowering the FPV panels into the reservoir.

Each panel has a peak power of 380 Wp. The slightly inferior energy output of each panel is compensated by the higher number of panels that can be placed on the same surface, due to the lower tilt angle. At Hefer, the system will produce 234 kW (DC) and 184 kW (AC), while almost totally preventing water evaporation in the area covered by the panels.

Fig. 4. Hefer: FPV system under final inspection.

These floaters and PV panels are faster to install and easier to maintain. To ensure power generation efficiency, in the area of the site panels must be frequently cleaned from soiling by birds; the system installed at Hefer allow carrying out this routine cleaning also by robots, which on the contrary is not possible with other types of floaters and panels.

Fig. 5. Hefer: FPV system completed.

Installation was carried out in 6 weeks in May-June 2020 by a team composed by 5 technicians. Since this was considered a trial installation, to allow the owner assessing whether to protect the uncovered area with a floating cover or with shade balls, or to extend the panels to the entire water surface, the strategy was to carry out the works with minimum personnel over a long period of time. The same installation could have been performed in 1-2 weeks by a larger team.

The float system installed in Hefer, by reducing the impact of forces due to wind, and therefore the forces acting on the materials, improves the mechanical performance of the overall system, and the functioning of the anchoring system. All this means less risk during installation and operation in case of strong winds. Durability of the system and safety of the maintenance staff are also higher.

It must be noted that at certain sites meteorological conditions, and wind in particular, may be a crucial issue. Anchorage against strong winds must be calculated both for temporary precautions during installation (size and spacing of concrete blocks tied to the slopes), and for permanent anchorage to ensure safe operation (robust anchorage structures of various types, often located inside the reservoir). The possible damages that can be caused by floods and how to prevent them are also being investigated in several parts of the world, including a research under completion in the Netherlands. Inverters systems with rapid shutdown are a safety precaution that can be applicable in sites subjects to floods.

3 Future developments: floating photovoltaic and pumped storage

Over the last decade, it has become difficult to predict future energy needs due to the many variables in a world of rapidly changing technologies, industrial and individual needs, environmental concerns, and climate change. Also, the recent pandemic may have unpredictable consequences. It is however desirable, and it seems likely, that the trend towards increased use of green power will continue. Low-cost wind and solar will likely become important providers of energy; and since flexible storage of energy is needed to help manage such systems, storage will play a major role in the future. Pumped storage has wider and longer experience than other storage technologies like large scale batteries, flywheels, compressed air, and is more environmentally friendly than some of them. Combining pumped storage with floating photovoltaic farms will increase the efficiency of the system in providing energy and stability to the grid, in a sustainable and resilient way.

This concept can be applied in an innovative way by installing on the upper and the lower reservoirs of a pumped storage scheme a floating photovoltaic farm, thus combining hydro and solar potentials. The scheme can be designed to withstand particularly demanding environmental and operational conditions: significant UV radiation, cyclones, high seismic risk, total daily emptying of the reservoirs, water level variations and long lifespan.

In such hybrid systems, the energy generation of both floating solar PV and hydropower components complement each other. During daytime, when PV generation is particularly high, generally between 11 a.m. to 4 p.m, the output of the hydropower plant is reduced and water is stored in the reservoir, so that during late night and early morning hours, or also during low solar irradiance periods, the saved energy can hence be utilised by releasing water and increasing the hydropower system's energy output.

With this innovative hybrid solution, it is estimated that the installed capacity of large hydropower plants could be greatly increased by covering only about 1 to 4% of the reservoir's total surface with floating photovoltaic panels. This will also enable a better management of water resources, and a better use of transmission assets.

The system installed at Hefer is under study for application at a pumped storage scheme in tropical climate in an area of extremely strong winds. Its important technical advantage in such site conditions is that the 5 degrees tilt reduces wind resistance while maximizing energy production: a 5° mono-pitch closed system has a pressure coefficient of 0.48, while a 12° open canopy system has a pressure coefficient of 2.1, resulting in around 440% higher wind load. With a 5° tilt wind speeds of 180 km/h and waves of 1.0 m can be accommodated, and even stronger winds and bigger waves can be sustained when used in combination with wave barriers and wind breakers, which reduce the force of the wind and wave that impacts the floating solar structure.

The system can adapt to the variations of the water level, even if the floats must be placed on the slopes of the reservoirs, thanks to the flexible connections and to the design of the floats, which can support each other to avoid slipping on the reservoir lining. The low tilt and the possibility of the floats to rest on the slopes can provide higher peak power by area (138 Wp/ m2 with 350 Wp panels). Even in case of total dewatering, when the floats will rest on the bottom of the reservoir, there will be no risk of perforation of the material, thanks to the flexible connections and the thickness of the bottom of the floats. As the system is modular, it can grow in a flexible way, following the needs and resources of the owner; and in the case of very deep reservoirs special anchoring and mooring systems are available.

4 Conclusions

Floating photovoltaic panels are now an established technology to add value to a reservoir and to provide an evaporation shield, by shading the water surface. Moreover, solar cell efficiency is increased due to the cooling effect of water, enabling a reduction in the lifecycle carbon footprint of the solar plant equipment. Combining floating photovoltaic to pumped storage can open new and promising scenarios. Thanks to this solution, a considerable increase in the energy production is obtained, and the overall cost of floating photovoltaics is reduced as the required infrastructure and transmission line is already present within the system. Floating photovoltaic systems can be installed in both upper and lower reservoirs of a pumped and storage facility, thus increasing the efficiency and productivity of land and water usage.

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