

A Review on Floating Solar Photovoltaic Power Plants

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Abstract— The limited fossil fuel resources and higher energy demand concentrates on solar energy, which is free of cost and unlimited source of energy, eco-friendly and sustainable to the environment. But during the execution of the solar projects on land, problems are faced by the government and partners of the scheme such as land availability, land development & land acquisition, substation capacities, evacuation also timely clearances for the project on land and evacuation – these are hurdles for completion of the project. Most of the locations projected by the government considering solar radiation data in the country are hot and dry regions. Though at these locations the radiation appeared to be higher, the energy yield of these points is less due to heating of the solar panels and higher temperature of the surface of solar cells. To overcome these problems an innovative idea has come in front for installation of solar power plants on the water that is canal tops, water bodies, lakes, dam backwater and reservoirs, which generally belongs to the government. This paper reveals review regarding the floating solar PV power plants installed in the world.

Index Terms— renewable energy, solar photovoltaics, solar power plants, floating Solar System, floating solar PV installations in the world, advantages of floating solar power plants, types of floating structures for solar power plants

1 INTRODUCTION

India proposes the generation of solar power from renewable energy sources up to 1.75 GW and 1 GW of solar PV power in next 10 years. The country is forwarding as per the policies declared. As on date around 5000 MW has been commissioned in different parts of country, as per the Jawaharlal Nehru National Solar Mission. [1] To match the targets declared, the progress noted so far is not sufficient and requires hard effort by each state and state departments to achieve the desired targets and make the country consuming green power in the world.

Floating solar PV plants are an emerging form of PV systems that float on the surface of irrigation canals, water reservoirs, quarry lakes, and tailing ponds. Several systems exist in France, India, Japan, Korea, the United Kingdom and the United States.[31-34] These systems reduce the need of valuable land area, save drinking water that would otherwise be lost through evaporation, and show a higher efficiency of solar energy conversion, as the panels are kept at a cooler temperature than they would be on land[35].

The energy obtained from solar PV system is renewable, eco-friendly and sustainable with long life of system. There are various advantages of floating solar PV power plant compared to roof top and ground mounted such as better efficiency of solar panels due to cooling of panel by air above the water bodies, it reduces water evaporation and because of shading of water it reduces algae growth. [11]

Advantages of Floating Solar System

By installing solar panels over a pond, the panels are naturally cooled, resulting in improved power production performance. The cooler environment also reduces stress on the system, extending the system's lifespan. Floating solar is cost competitive with roof and ground-based single-axis tracking solar systems and uses the same commercially available solar panels. Similar to land-based solar, the floating installations qualify for federal and local grant and incentive programs.

Aside from generating power, the systems also provide other environmental benefits. As an example, the solar power generating system shades the water and can reduce evaporation by up to 70%. The systems can also improve water quality. As water bodies are exposed to the sun, photosynthesis promotes growth of organic matter, including algae. By shading the water, algae growth is reduced, minimizing the associated treatment and labour costs. [11].

2 FLOATING SOLAR PV SYSTEM

Floating solar arrays are PV systems that float on the surface of drinking water reservoirs, quarry lakes, irrigation canals or remediation and tailing ponds. A small number of such systems exist in France, India, Japan, South Korea, the United Kingdom, Singapore and the United States. [4],[5],[6],[7],[8]

The systems are said to have advantages over photovoltaic on land. The cost of land is more expensive, and there are fewer rules and regulations for structures built on bodies of water not used for recreation. Unlike most land-based solar plants, floating arrays can be unobtrusive because they are hidden from public view. They achieve higher efficiencies than PV panels on land, because water cools the panels. The panels have a special coating to prevent rust or corrosion. [9]

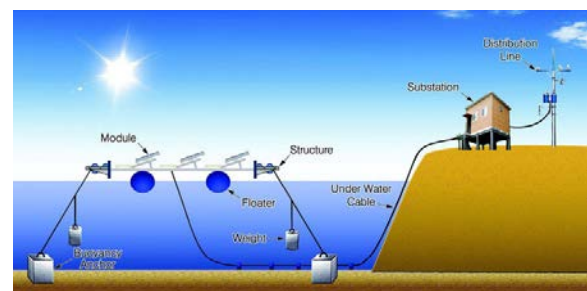


Fig. 1. Floating PV plant outline

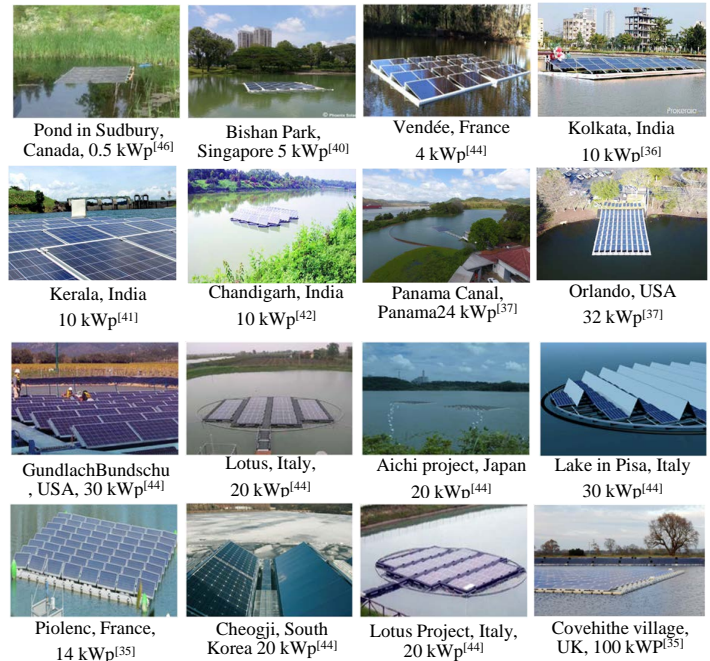
Components of Floating Solar PV System

1. Pontoon/Floating Structure - A pontoon is flotation structure and has buoyancy enough to float on water and support a heavy load. The structure is designed such as it can hold number of panels.
2. Mooring System - A mooring refers to any permanent structure to which a floating structure may be secured. A floating structure is secured to a mooring to forestall free movement of the floating structure on the water. An anchor mooring fixes a floating structure's position relative to a point on the bottom of a waterway without connecting the floating structure to shore.^[10]
3. Solar Module - A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring. Mostly crystalline solar PV modules have been used for the floating solar systems.
4. Cabling - Due to their outdoor usage, solar cables are specifically designed to be resistant against UV radiation and extremely high temperature fluctuations and are generally unaffected by the weather.

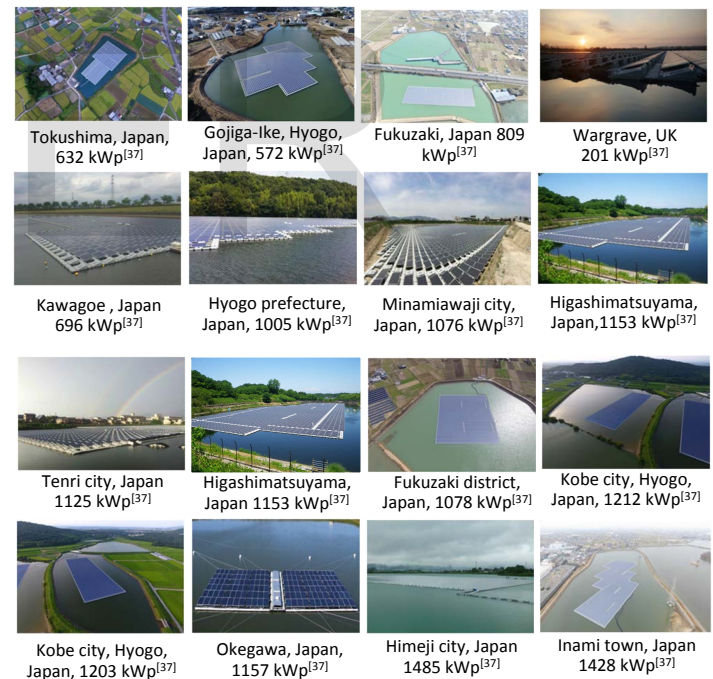
3 VARIOUS FLOATING SOLAR PV INSTALLATIONS

The propriety nature of the technology somewhat limits the literature available on floating PV installations. The fig. 2 illustrates the floating PV projects developed worldwide to date for electricity generation.

Small Size Power Plants (up to 500 kWp)



Medium Size Power Plants (500 to 1500 kWp)



Large Size Power Plants (above 1500 kWp)





Higashimatsuyam
Japan, 7550 kWp^[37]

Fig. 2 Timeline of Floating PV Projects

3.1 Projects in 2007-2010

The Aichi project was the first solar project known to have ever been constructed on water. It was realized by a group of researchers from the National Institute of Advanced Science and Technology in Japan ^[12] and financed by the Japanese Ministry for the Environment ^[13]. The aim of this research was to introduce the concept of floating PV systems as well as an analysis of the effect of module temperature on the PV system performance.

The Far Niente Wineries claimed to have the first significant, grid-connected solar system installed on water. The installation was managed by SPG Solar. The so called Floatovoltaic system is made up of modular crystalline PV panels mounted on pontoons in a pond (Fig. 3). The floating structure has in-built walkways between each row of panels to allow for ease of access for cleaning and maintenance of the panels (Fig. 3).



Fig. 3. Far Niente, Napa Valley, California (image taken from Google Maps)

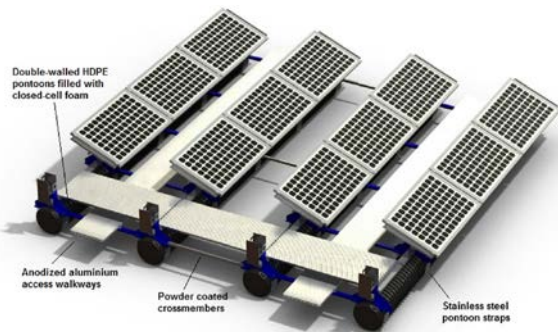


Fig. 4. Floatovoltaic Concept at Far Niente, California ^[12]

A second vineyard in California, Gundlach Bundschu, also adopted the same approach as that constructed in Far Niente. The installation was also managed by SPG Solar. The difference between the two systems was the PV array size: the system installed in a pond at Far Niente exceeded the 175kWp while that at Gundlach Bundschu was reasonably smaller at

30kWp

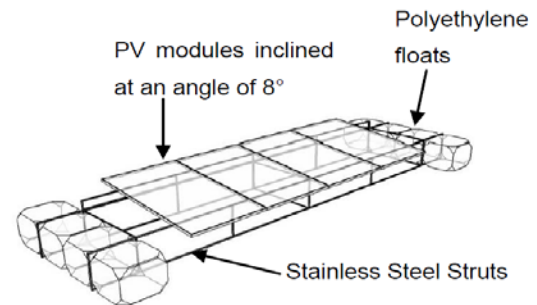


Fig. 5. Schematic of floating structure ^[17]

One of the largest projects realized so far is that of Bubano in Imola Italy. This is a 500kWp rated system situated in a lake which was accomplished through the collaboration of two local companies. The system, called "Flotovoltaico®", is connected to the grid and consists of 'floating islands' made up of polyethylene cubes at the two sides of an array connected by struts for the panels to sit on (Fig. 5) ^{[13], [17]}.

The next floating solar project was established in Solarolo, Italy in 2009, which would later be called the 'Lotus Project'. This 20kWp array was designed by D.A.E.I.T. s.r.l., to sit on top of an irrigation pond, with ducts below the panels for air-cooling. The array is tilted at an angle of 8° to maximize the power density by making use of more panels in the given space. The floating structure itself was designed to allow access to individuals for maintenance or other activities; in fact the floats run straight to land for the system to be easily accessible (Fig. 6).



Fig. 6. Lotus Project, Solarolo Italy ^[18]

The only project known to be installed in 2010 was that at a Winery in Suvereto, Italy. The difference between this system and any of the systems discussed so far is that it is installed with a tracking mechanism which rotates the array according to the motion of the sun; also a reflector is installed in front of the panel to maximize on the amount of solar radiation received. The safety and tracking feature were analysed by a research group at Scienza Industria Tecnologia (SCINTEC), while the design and construction was taken care of by Terra Moretti Holdings. This concept is referred to as Floating Tracking Cooling Concentrating Systems (FTCC). A major percentage of the structure is made out of metal struts that hold the crystalline panels at an optimal angle of 40° and reflector in front while also tracking the sun's motion (Fig. 7).



Fig. 7. FTCC PV System at 'Petra's Winery', Italy

3.2 Projects in 2011-13

The same research group who investigated the tracking feature at Petra's Winery above (Section 3.1) also developed the following installation in a Lake in Pisa, Italy. This time, the panels were placed horizontally with reflectors forming a V-shape on either edge to maximize the amount of incoming radiation. In turn, this implies higher working temperatures, however in this case, the panels were in closer proximity to the water, and so the cooling effect was more effective than the configuration of the Suvereto project above (Section 3.1). Note that a tracking system was also employed for this configuration. Results prove that this configuration yielded higher results to the Suvereto project and so it makes it a favored concept. In fact, it was reported that this configuration yielded an increase of 60-70% in annual output compared to conventional land based PV systems [12], [19], [20].



Fig. 8. FTCC PV System in Pisa [19, 20]

A new organization to enter this scene is Ciel et Terre whose first floating photovoltaic project was to construct a floating PV system in a vacant and flooded quarry at Piolenc in France (Fig. 9). Metal struts hold the array together while also maintaining the modules at an angle, tilted to the sun. Floats are placed and connected under each row of panels within the array to keep the system afloat. The floats are specifically made from High density polyethylene (HDPE) for particular resistance to UV and corrosion which in turn results in a more durable option compared to metal structures.



Fig. 9. 14kWp Floating System in Piolenc, France [21]

The next floating solar system seen in 2011 was in-

stalled at a water treatment plant in New Jersey, USA. It was designed by ENERActive which features a unique mooring structure which allows the array to rise and fall with the water level of the reservoir while still holding the array securely. In fact, this was the most challenging part of this project.

The last project presented in 2011 is the first of a number of investments by the Korea Water Resources Corporation (K-Water). This 100 kWp solar system is situated in a South Korean dam called Hapcheon. The materials chosen for this structure contain enhanced water and moisture resistance to reduce the possibility of structure freezing and thus rupture [22], [23].

SCINTEC, together with Koinè Multimedia, is again seen to help design another floating solar project also an FTCC, this time in Cheogju, South Korea. This project, built by Techwin, was particularly challenging since the panels were to be placed in water which is subject to freezing in the winter months (Fig. 10). Special attention was given while selecting each individual component to be able to withstand both the seasonal freezing and thawing cycles.



Fig. 10. 20kWp FTCC System in Cheogji, South Korea with can withstand water freezing temperatures [24]

A research project was set up in Singapore and is located in Bishan Park. It was developed by Phoenix Solar as a pilot project. This 5kWp system is mounted at an angle of 10° where the modules are placed on linked UV-resistant floats. The structure is moored to the lake bed from the 4 adjacent points [25].

Another research project of 0.5 kWp was also set up in 2013 on a small pond in Sudbury, Canada (Figure 4.9). The nature of its structure is different to the projects we have discussed so far since the solar cells are not mounted on a pontoon or float but rather the cells themselves are extended on the surface of the water. The idea behind this is to make use of laminated thin film solar cells with air pockets enclosed within to allow for a flexible floating concept directly on the water's surface. The developers of this project, MIRARCO, claim that such a system would not endure as much stresses given by waves, tides and high winds as is experienced by the pontoon mounted systems [19].



Fig. 11. 0.5kWp Flexible Floating PV System^[12]

The largest floating solar project known so far was indeed installed this year over a water reservoir in Okegawa, Japan with a capacity of 1,157kWp. The developer of this significant plant is Ciel et Terre, who after receiving successful results with their Hydrelío © floating solar system at Piolenc in France, moved on to this larger project in Japan.

Submerged solar panels have also been the subject of thought for a few specialized groups. So far, the only way to produce power under water is through the use of batteries. The US Naval Research are looking into solar 25 cells capable of absorbing the small wavelength spectrum of visible light available at certain depths underwater. Specific semiconductors (GaInP cells) have been used in such experiments since they show better performance to absorb wavelengths in the blue and green spectrum as opposed to the silicon cells. This concept is still being studied and needs to be analyzed to present results for long-term deployment^[26]. Silicon cells have indeed been analyzed under water and results show that they work less efficiently once they are placed more than a few centimeters below the water's surface^[27].

3.3 Projects in 2014 and onwards

Born in France, the Hydrelío system is an innovative system to realize water-based solar power generation. High design technology made it possible to build water solar photovoltaic facilities using anchors. Hydrelío is a float module system developed by Shell Tail to build water solar photovoltaic (solar power). The basic module consists of two floats made of high density polyethylene (HDPE). The main float can be fitted with solar panels with standard 60 cells installed and the second float connects the floats and serves as a foothold for maintenance. Connect these floats with a connecting pin system to form solar islands.

Hydrelío system (Fig. 12)^[29] is a small and area that enables the implementation of solar power generation projects without deforestation, soil pollution, and water pollution by effectively utilizing irrigation ponds, reservoirs, and dams scattered throughout Japan. It is a particularly innovative water-installed solar system that is particularly suitable for. In addition, since the natural cooling effect is obtained for modules and cables by installing on the water, it is expected to have higher power generation efficiency compared to the ground installation type, realizing excellent cost effectiveness such as shortening the construction period with a simple structure.

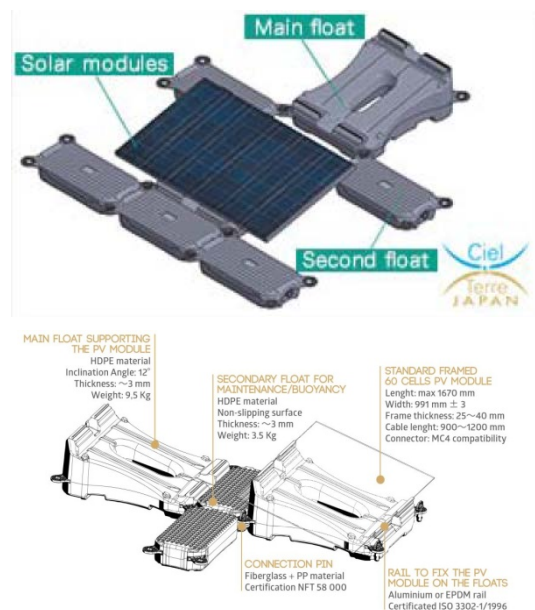


Fig. 12. Floating solar technology Design, Ciel & Terre's, France^[29]

REC is showcasing its floating solar photovoltaic (PV) installation at a government site in West Java for the first time in Indonesia^[28]. REC has partnered PT Kas Green Energy, a local independent power producer (IPP), to introduce the concept of a floating solar installation through a pilot project at Electricity & Renewable Energy Museum (Museum Listrik dan Energi Baru - MLEB), Taman Mini Indonesia Indah. REC solar PV panels are quickly installed on "Hydrelío"^[29] pontoons which are 100% recyclable and are easy to dismantle. Made of high density polyethylene (HDPE), they can be installed safely on drinking water reservoirs and are resistant to UV light.

Young-Kwan Choi *et al* has compared and analyzed the generation efficiency of floating and land photovoltaic systems. Floating PV has shown greater generation efficiency by over 10% compared with the general PV systems installed overland. This paper compares and analyzes the empirical data of the floating PV system, which K-water has installed, with that of the existing overland PV and has verified that the generating efficiency of floating PV system is superior by 11% and more^[23].

Jinyoung Song and Yosoon have analyzed the potential of floating PV systems on a mine pit lake in Korea to break this misconception^[30]. According to this analysis, however creating a pit lake in an open-pit mine and using it for a large-scale floating PV system is economically beneficial and could significantly reduce greenhouse gas emissions^[30]. Considering the environmental and economic gains from greenhouse gas reduction and electricity sales, a floating PV system on a pit lake of an abandoned mine site is considered an efficient reuse option for abandoned mines.

4 CONCLUSION

The review presented in this paper shows the timeline of concepts and floating solar PV projects that have been established to date. These systems were either constructed for research purposes or for commercial use. All grid connected systems are kept afloat using pontoons or floats with panels rigidly connected to these floats.

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