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DESIGN AND IMPLEMENTATION OF FLOATING SOLAR POWER PLANT

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Abstract: Floating solar power plant is an innovative approach of using photovoltaic modules on water infrastructures to conserve the land along with increase in efficiency of the module. Additionally, the water is also conserved due to reduction in evaporation of water from the water body. The plant can be installed on a pond, lake, reservoir, or on any other water body. This paper focuses on the floating PV technology, describing the types of floating PV plant along with studies carried out on some floating solar plants. India, with huge energy demand and scarcity of waste land for solar photovoltaic plant in cities, can harness solar energy through floating PV plant technology for sustainable energy production. In this paper, some of the floating PV plants installed in India are reviewed. Feasibility of installing 1 MW floating PV plant each at Kota barrage and Kishore Sagar lake in Kota, Rajasthan are also presented. Energy that could be produced by the two plants along with amount of water saved from evaporation and reduction in CO2 emissions are also calculated in this paper. 1 MW floating plant at Kota barrage could produce 18,38,519 kWh energy per year and could save 37 million litres of water and can reduce about 1,714 tonnes of CO2 emissions annually. 1 MW floating plant at Kishore Sagar lake could produce 18,58,959 kWh electrical energy per year and could save 37 million litres of water and can reduce about 1,733 tonnes of CO2 emissions annually.

Keywords: *PV modules, Inverters, Cabling, Dual-axis-tracking Technology, FSPV(Floating solar power plant), Grid.*

I INTRODUCTION

Solar energy can be utilized for power generation in numerous ways. One of the barriers in harnessing solar energy is large land requirement. This problem can be addressed by using Floating Photovoltaic (FPV) system. Floating PV system is an innovative and new approach of installing PV modules on water bodies. By installing FPV system, evaporation of water from water bodies can be reduced to 70% and power gain is increased by 5.93% due to back water cooling of PV modules. The first floating PV system was installed at California, USA in 2007. However most of the plants in the world were installed after 2014. Worldwide, installed capacity of floating solar plants has already reached 94 MW, of which maximum are installed in Japan. Most of the floating PV systems were installed on man-made water bodies such as a) reservoirs; b) storage, irrigation, or retention ponds; and c) lakes, with plant size varying from 4 kW to 20 MW. In this paper, floating PV systems are described and different types of the floating PV plant are explained. Studies conducted on floating PV systems in various parts of the world are summarized. Some of the floating PV systems installed in India are also reviewed. Feasibility analysis of installing 1 MW floating PV plant at two different sites, Kota Barrage and Kishore Sagar lake in Kota, Rajasthan is done. The energy that could be produced by the FPV systems, amount of water saving from evaporation, and reduction in CO2 emissions are also estimated for Kota Barrage and Kishore Sagar lake. The benefits of floating PV system are: a) Increase in efficiency due to cooling effect of water; b) Evaporation is reduced due to shading of water surface; c) Algae growth on water is reduced; d) Since the system is installed on water, therefore the effect of dust on PV module is less prominent; e) Installing PV system on water will conserve land; f) Floating solar PV can be installed in water intensive industries such as wineries, dairy farms etc. and thus providing electric energy and reducing the evaporation of water; g) Floating PV requires almost no evacuation and are affordable as well as simple to construct; h) Floating PV installed in industries or factories can help reduce carbon footprints; and i) Floating PV construction does not require any foundation work and deployment itself is quite straight forward.

II NEED OF FLOATING SOLAR POWER PLANT

The total installed electricity generation capacity of the country has reached over 366 GW3. Out of which renewable energy share (RE) is 23.60% (84.4GW4) and with recent cabinet approval of the addition of large hydro power plants (45 GW) as an RE source, the current share of RE in the total installation will become 35.18%. India has done a remarkable job in terms of deployment of RE-based installation, growing almost 3.55 folds in the last 5-6 years, most of which have occurred in the onshore wind (37.27 GW) and solar PV (32.53 GW) sector. The majority of this growth in solar has been triggered by the launch of Jawaharlal Nehru National Solar Mission (JNNSM) on January 11, 2010. The target set under the mission was to achieve 20 GW of grid-connected solarpower by the year 2022, which was later revised in the year 2015. The new targets under the mission are to achieve 175 GW RE capacities of which 100 GW is from solar by 2022. Out of this, 40 GW of the target is for installation of solar rooftop and 60 GW is for large-scale solar plants. To achieve its targets the Government of India has also taken various innovative policy measures such as viability gap funding (VGF), development of solar parks, and solar renewable purchase obligation (RPO), etc. At present India's grid-connected solar PV sector is majorly dominated by the ground-based installations (93%6) and rest is contributed by rooftop based solar PV installations. The installation cost of utility-scale solar PV in the country has declined by 84% between 2010-2018, making India the world's topmost country in achieving the lowest installation cost for utility-scale solar PV

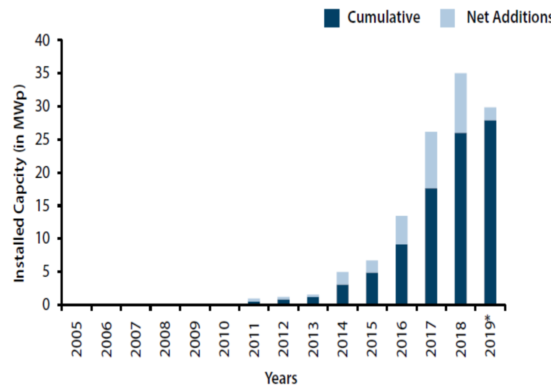


Figure 1: Year-on-Year installation of grid-connected solar PV

However, the pace of utility scale solar PV deployment in the country has been reducing refer to Chart. Among several reasons, challenges related to the availability of land and, delays in land acquisition are considered as one of the key reasons behind this slow pace. Hence, in order to achieve the targets set under the JNNSM, it is a must to explore the other alternatives. Deployment of solar PV at distribution transformer (DT) level and floating solar PV (FSPV) are some of the alternative solutions that are emerging to boost solar installation. FSPV has an advantage in deploying solar PV as it is not dependent on land availability. There are more than 400,000 km2 of the reported man-made reservoirs in the world*7* out of which India has a share of about 70,000 km2. This shows a vast potential that can be trapped for clean energy generation. Recently there has been an interest in FSPV globally as well as in India. Further, it is also seen that if the capacity of FSPV deployment is scaled up, the tariff may also come down closer to the tariff discovered for ground-mounted solar PV.

- **Higher gains in energy production:** Correlations between the solar PV array yield, solar PV array temperature, and local weather conditions such as ambient temperature, wind speed, solar irradiance, etc. are well known8,9. These correlations indicate that reduction in ambient temperature and higher wind speed reduces the solar PV array temperature which in turn results in higher energy yield. As the ambient temperature at the vicinity of a waterbody is generally lower than the ambient temperature at land and wind speed tends to be higher over open water surfaces as compared to on land, it resulting in an evaporative cooling effect. This effect results in lower operating temperatures of the PV cell, which in turn improves the energy yield. The improvement as much as by 10%.

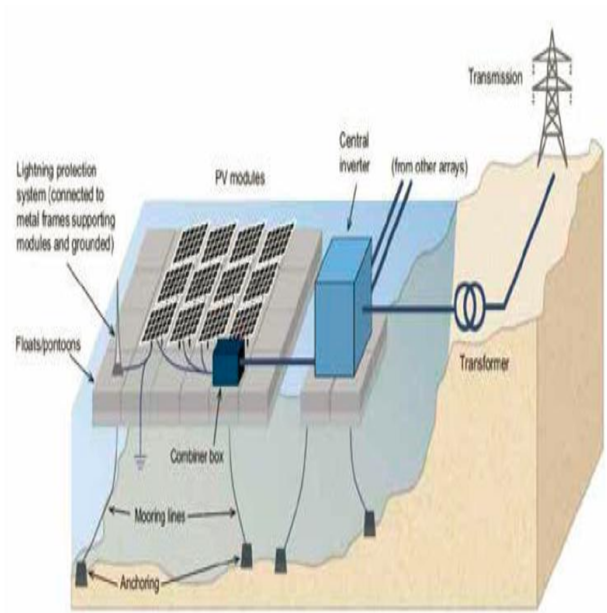


Figure 2: Schematic representation of a typical large-scale floating PV system with its key components.

- **Pontoon/Floating Structure -** A pontoon is floating structure. Pontoon has buoyancy enough to float on water and support a heavy load. The structure is designed such as it can hold number of panels. Floating structure allows installation of PV module
- **Mooring Structure -** A mooring structure is the permanent structure which secures floating structure. The mooring gives forestall free movement of 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. This allows adjusting water level fluctuations while maintaining its position in a southward direction
- **Solar Module -** It is PV Generation equipment, similar to electric junction boxes, which are installed on top of the floating system. 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. As compared with land-based PV systems had been reported in a few studies10,11. However, it is important to note here that this improvement in energy yield closely depends on the design of a floating platform, a gap between the water surface and the PV array, etc.
- **Land neutral:** Since FSPV plants are installed on water surfaces, the land requirement is none or greatly reduced as compared to ground-mounted solar PV plants and hence FSPV is termed as land neutral. This is particularly of importance for developing countries like India, where land is scarce and land acquisition creates hurdles for deployment of solar PV projects.
- **Reduction in water evaporation:** Loss of water resources due to evaporation is a well-known phenomenon, reported as high as 40%12 worldwide, and its effect is more significant particularly in dry and aired regions. As per an estimate by Central Water Commission (CWC) India, the evaporation loss in the country varies from 150-30013cm per km2 per annum. Since FSPV plants are deployed on the water surfaces, they provide shade to the water surfaces, thus reducing the amount of solar radiation reaching the water surface and also limiting the interaction of wind on the water surfaces. The combined benefit of these may results in reduction in the water evaporation losses14,15. However, it is extremely difficult to exactly quantify the net effect on water evaporation loss due to deployment of FSPV plants since in general FSPV plants are installed on some fraction of a total water surface. Hence more studies are needed for quantification of this claim.
- **Possibility of sharing existing electrical infrastructure:** Many inland waterbodies especially reservoirs used for various purposes like irrigation, water supply, reservoirs of hydroelectric plants, etc. have gird connections that are already available. Hence deploying FSPV plants in such cases may save investment cost by utilizing the already existing infrastructure.
- **Complementary operation with hydroelectric power plants :** As of August 2019, India has 45 GW 16 of installed capacity of hydroelectric power plants.Since most of these plants are seasonal, their output decreases particularly during dry seasons when water flow is less and solar radiations are high. Thus deploying FSPV plants in combination with already existing hydroelectric power plants would not only improve power production in lean seasons but also acts as energy storage, using solar power during the day and hydropower during the night. Since the response time of the hydro turbine is fast, the combination of hydroelectric–FSPV plant can be used for supplying power during peak demand. However in some cases, hydroelectric plants having large variations in water level, pose difficulties in designing of anchoring and mooring for supporting the floating platform. Hence it is suggested to conduct a detailed study considering the effect of water level variation on the viability of deploying the FSPV plants at any particular hydroelectric plant.
- **Reduction in algae growth:** Among several other factors the growth in algae mainly depends upon light intensity and temperature of the water. Since FSPV plants provide shade to the water surface, they reduces the amount of sunlight reaching the water surface, which may cause a

reduction in algae growth. However, the effect of deploying the FSPV plants on the local water environment is still not well understood and would require further studies to understand the related issues.

- **FSPV as a new source of revenue:** Deploying FSPV plants can provide an additional source of revenue to a water body owner by–either utilizing the electricity generated via self-consuming, thereby reducing their own consumption or via selling the electricity generated to the grid. In either way, FSPV creates an economic value of a water body. For example, Jinko18 has installed 120-MW FSPV-based plant on a fishing farm at Poyang Lake in China, spread over 2000 acres of water surface and generating 137.70 GWh of electricity. Till now there are very few studies that provide some information on the potential impact of deploying FSPV on local ecology, hence it is suggested to conduct a detailed study before deploying large scale FSPV plants.
- **Less soiling loss:** Since wind blowing over water surfaces contains less dust as compared to wind blow over land, FSPV plants are subjected to less dust as compared to land-mounted solar PV installations.
- **Ease of cleaning:** In case of FSPV plants deployed on inland water bodies, water is readily available for cleaning purposes. However, the quality of the water needs to be checked and should be under the permissible limit as described by PV manufacturers.
- **Easy installation and deployment:** In general, installation of a typical FSPV plant is simpler and easy as compared to land-mounted solar PV plants. This is because of –(a) no civil work is required to prepare the site; (b) floating platform used to float solar PV arrays on a water surface are made in form of a modular individual floats which are prefabricated and are interconnected to form a large section, (c) floating platforms are assembled on land by adding rows of these modular interconnecting floats. Each of these rows is pushed into water as the next row being added to form a large platform. Once completed, the entire platform is towed to the exact location on the Water body with the help of boats. As per discussions with India-based FSPV developer, the typical rate of FSPV plant installation, provided other supply chain is in place, varies from 2.5 kWp/person/h to 3.0 kWp/person/h. However, FSPV has its fair share of challenges like higher capital costs, the potential for contamination of water, limited understanding of the technology, unavailability limited knowhow of appropriate quality standards, technical specifications, etc. These issues are presented in detail in of this report.

III GLOBAL MARKET OVERVIEW

Global Scenario

In 2007, the National Institute of Advanced Industrial Science and Technology (AIST) built the world's first FSPV plant of 20-kWp capacity in Aichi, Japan. Later in 2008, the first commercial-scale installation of capacity 175 kWp came up at Far Niente Winery, California, USA. Most of these early projects are small-scale systems with a purpose of research and demonstration. From early 2013, megawatt scale FSPV plants started to appear in Japan and South Korea. Since then installations have increased many folds from few megawatt-peak (MWp) to more than 1300 MWp by the end of 2018. The technology is currently deployed in more than 24 countries across the entire world with the majority of installations are coming up in Asia, particularly in Japan, China, and South Korea. The FSPV technology has been able to gather a lot of traction in the past 3 years (2016, 2017 and 2018) globally, which is evident from the increase in the installation presented. The total installed capacity now stands at 1314 MWp, which is further going to increase substantially in the years to come and expected to reach 4600 MWp by 2022, thanks to the recent increase in the activities in the sector in countries like China. Majority of installations till date are deployed on man-made water bodies such as irrigation dams, industrial basins, water treatment plants, and unused mining ponds. More information on the current status of the FSPV projects in the top five countries is provided.

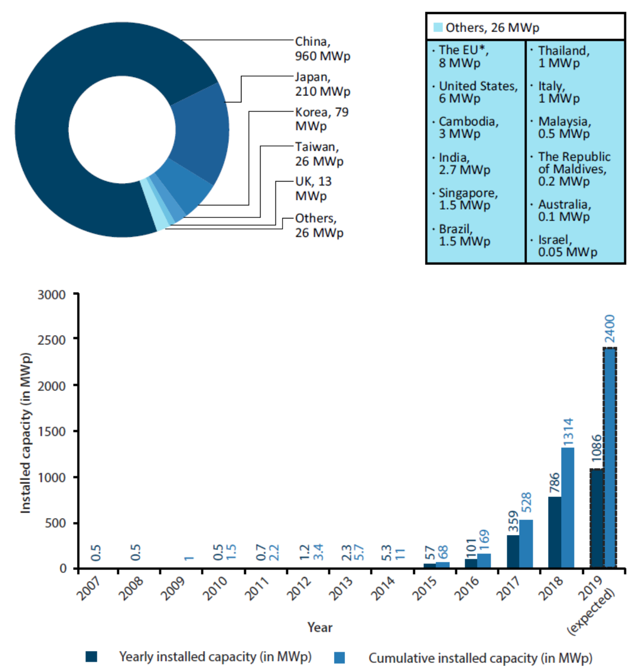


Figure 3: Global installations of Floating Solar PV

China

China is a leading country in terms of highest installation capacity accounting for more than 960 MWp out of global total of 1314 MWp. The country is also home to the worlds largest FSPV plant of 150 MW capacity installed at Huainan, south Anhui province. Most of the FSPV plants in China are installed at unused mining ponds.

Japan

With more than 210 MWp of installed capacity, Japan is a leading country in terms of total numbers of installation and home to 73 of the world's 100 largest FSPV plants. The majority of these plants are installed on man-made waterbodies having main purpose to retain rainwater or irrigation.

The Republic of Korea

Korea was among the early mover to have adopted FSPV. Till date the country has installed more than 79 MWp of FSPV plants and more than 2300 MWp are in pipeline. Korea was the first country to install a tracking-based FSPV plant having a capacity of 465 kW in 2014. Recently, the Ministry of Trade, Industry, and Energy (MOTIE) has announced its plans for developing 2.1 GW of FSPV-based projects at Saemangeum Seawall Dyke located on the southwest coast of the country. The project will be built in two stages . The first stage with a capacity of 1.2 GW is to be completed by 2022 and the remaining 900 MW by 2025 in the second stage. Upon completion, the project will be 14 times larger than the present world's largest 150-MW FSPV-based project of China.

Taiwan, China

With more than 26 MWp of installed capacity and more than 180 MWp in pipeline, Taiwan is among the fastest-growing FSPV markets and the fourth largest country in the world in terms of total installed capacity. The majority of these plants are installed on water retention reservoirs and irrigation dams (Refer Table 1 for more details). The country's largest FSPV plant of 9.9MW capacity is installed at the Agongdian reservoir covering 9.19 hectares of water surface area.

The UK

With more than 13 MWp of installed capacity, the UK is the fifth largest country in terms of FSPV installation. Like many other Asian countries, lack of space for land-mounted PV in the country is the main reason for going towards FSPV plants. The majority of the plants in the UK are installed on irrigation and water treatment ponds. In March 2016, the world's first deep water reservoir (maximum depth of 18.4 m) based FSPV plant of 6.4 MWp was installed at the Queen Elizabeth II reservoir in the UK.

Country	Water body type	Typical range of % of water surface area covered by FSPV plants	Typical range of depth of water body on which FSPV plants are installed (in meters)	Typical range of water level variation (in meters)
China	Irrigation ponds	10%–30%	3.5–14.1	3.5– 8.0
	Industrial ponds	No information	No information	No information
	Large waterbodies	10%–40%	No information	No information
	Mining ponds	10%–20%	3–12.5	4.8
Japan	Irrigation ponds	10%–70%	1.8–15.1	1.8–15.1
	Industrial ponds	No information	No information	No information
	Water storage reservoirs	15%–86%	3.0–5.0	3.0–5.0
Taiwan	Irrigation ponds	11%–28%	3.6–4.6	2.4–4.6
	Industrial ponds	15%	14	5
	Water storage reservoirs	7%–10%	No information	No information
UK	Irrigation Ponds	2% –15%	4.0–18.4	4.0–18.4
	Water treatment plant	48%	10	10

Figure 4: Type of waterbodies on which floating solar PV is installed in top five leading countries

Indian Scenario

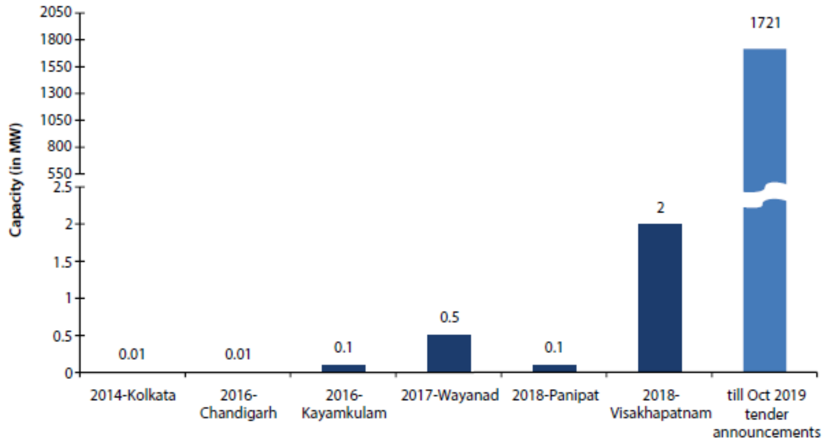


Figure 5: Floating solar PV installations in India

The FSPV as a technology is still in the nascent stages of development in India. The journey started with a 10kW FSPV plant on a pond in Rajarhat, Kolkata in 2015. The project was part of a research activity sponsored by the Ministry of New and Renewable Energy (MNRE). In 2016, NTPC installed country's largest 100kW plant on a reservoir of its combined cycle power plant situated in Kerala's Kayamkulam district. Later in December same year, Kerala State Electricity Board started its operation of 500kW plant at Banasura Sagar reservoir in Wayanad district replacing NTPC's 100kW as a largest FSPV-based plant. The plant is actually a scaled-up version of the 10kW plant commissioned in January 2016 at the same location. The plant was able to bring some confidence to FSPV promoters by successfully surviving the recent flood ravage in the state. The recently commissioned 2MW project at Visakhapatnam, Andhra Pradesh has now the largest FSPV-based plant commissioned in the country till date and with this the total installed capacity of FSPV has becomes 2.7 MW. The FSPV sector is now getting a lot of attention in the country, which can be seen via an increase in the numbers of tenders that are released in the past 2 years. At the moment there is more than 1700 MW worth of projects, which are in various stages of development and more are in pipeline making the outlook very positive for this new segment.

Cost of Floating Solar PV Plants

This section describes the investment cost trends of the recent FSPV projects, which are purely based on the publicly available data. Since FSPV technology has just started getting tractions, accurate data related to project capital and operating cost are not disclosed in the public domain. Hence it is suggested to take the data presented as indicative and not as a generalized cost for the technology. Also atpresent, as there are a few projects that are installed and are in operation, it is very difficult to calculate their operations and maintenance cost. Thus only capital costs are used to showcase the investment cost trends in This is important to note that some amount of approximations 19 is applied on the publicly available data.

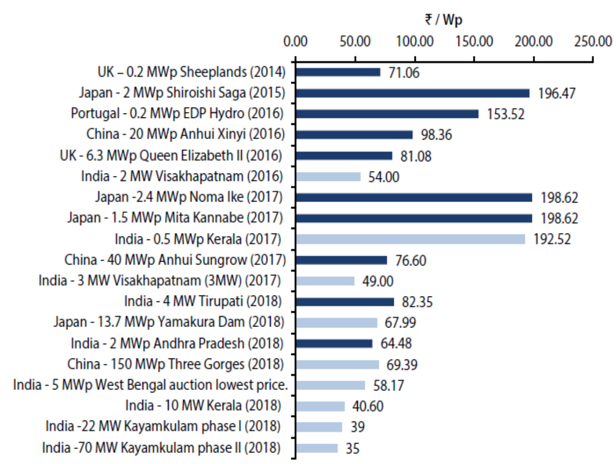


Figure 6: Global investment cost for floating solar PV plants

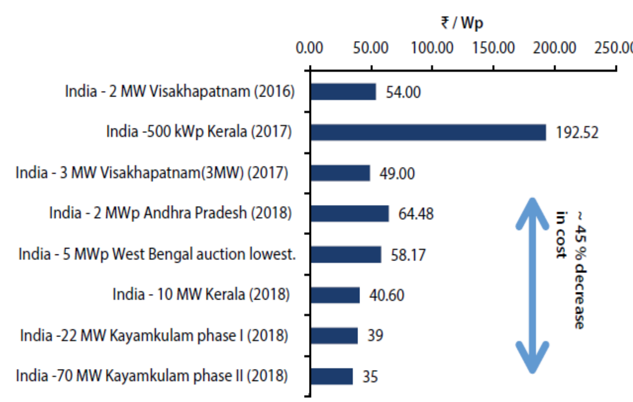


Figure 7: Investment cost for floating solar PV projects in India

Recent bids results indicate a sharp decline in the investment cost for FSPV. In the latest tender result of the country's first large-scale FSPV plant of 70MW capacity, cost as low as INR 35 per Wp has been quoted by developers. This is the lowest cost achieved in the entire world so far. Further considering last year's trends, one can see the 45% reduction in the cost, which is significant. Even though the costs have decreased, it is still very early to come to any generalization, since the FSPV as a technology is still in its early stage of market penetration. The reduction in costs, particularly in India may be linked to many factors like – decrease in the cost of floaters because of improvement in manufacturing process, reduction in the material cost, reduction in thickness of floaters, aggressive biddings by project developers to get some experience in FSPV sector seeing the high growth in national as well international markets etc. However, it is very early to arrive at any conclusion. While falling cost is a welcome trend, it is also important to check whether this is not impacting the overall quality of the projects, since degradation in the quality of FSPV projects has higher potential to impact local biodiversity compared to groundmounted solar PV. Hence it is essential to form proper guidelines/standards to keep the things in check from the initial stage of market development of FSPV technology. In general, the cost for setting megawatt scale FSPV plants depends upon the following :

- Project location
- Depth of waterbody
- Waterlevel variation
- Site conditions – wind speed and its direction, solar irradiations, ambient temperature, humidity levels, etc.
- Size of the plant

Chart presents component-wise cost breakup share of a typical megawatt scale FSPV-based project. Just like groundmounted solar PV plants, the PV module has a major share in overall cost breakup. The main difference lies in the cost of the floating platform and anchoring and mooring system, representing approximately 38% of overall cost.

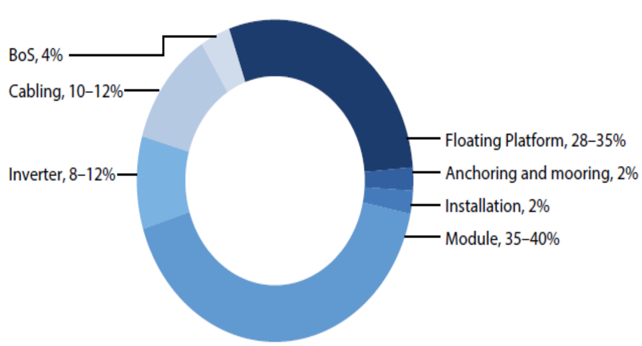


Figure 8: Cost break up for floating solar PV plants

Supporting Frameworks for FSPV

The FSPV sector is becoming popular day by day but still, there are very few countries that are providing any kind of support/incentives exclusively for FSPV. Unlike ground-mounted solar PV, there are no specific standards or policy for FSPV technology as of now. A few Asian countries like Japan, Malaysia, Vietnam, etc., are following preferential feed-in tariffs for FSPV. Till now most of the FSPV projects in these countries are small in size (less than 5 MW) and financed by local/national banks in local currencies. However, large international commercial banks as well as multilateral developments banks which were only supporting small-scale studies, now moving towards financing FSPV projects resulting in the development of large-scale projects. In general, in some countries like China, Japan, Korea, and India existing initiatives like RE targets set under the national policies are driving the demand for development of the new projects (size >2–5 MW) while in some other countries financial support is provided for pilot-scale demonstration projects. For projects having size > 2-5 MW, tenders and auctions are the chief ways which are being used to implement FSPV projects. The analysis of policy and other supporting frameworks are discussed as below:

China

Presently, China is a leading country in terms of total installed capacity in FSPV and accounting for 73% of global installations. The majority of these projects are installed on flooded mines and having a capacity of greater than 5 MW. Most of these large-scale FSPV projects in China are developed under the country's Top Runner Programme, which is targeting 201–270 GWp solar PV installations by the year 2020.

Japan

As highlighted in this report, Japan is the second-largest country accounting for 16% of the total global installations of FSPV. Japan developed the world's first floating pilot project of 20 kWp in 2007. Mostly all solar projects in Japan have been implemented based on preferential feed-in tariffs (FiTs). But 2017 onwards FiTs benefits are not applicable to larger projects (≥2 MWp) and electricity tariff is now calculated by competitive bidding process.

Taiwan, China –

With over 26 MWp of installed capacity and more than 180 MWp worth projects are in various stages of development, Taiwan, China is the fourth largest country in the world. It is among the few countries that are offering a specific FiTs to FSPV projects. As per the Ministry of Economic Affairs, FiTs for FSPV projects in the first half of 2019 vary from NT$4.5016/kWh (for an off-grid project) to NT$4.345/kWh (for grid-connected projects), about 10% higher than the land-based solar PV of the same size.

The Republic of Korea

The Republic of Korea has set an ambitious target of achieving 30.8 GW of installed capacity by 2030 from solar and 35% of energy generation from RE-based sources by 2040. In order to accelerate the country's RE deployment and to create a competitive market environment, in 2012

FiTs was replaced by Renewable Portfolio Standard with an aim to steadily increase RE mix in the total power generation in the period 2012–2024. Under this, power producers having installed capacity greater than 500 MW are required to generate minimum percentage (also know as obligatory renewable service supply ratio) of generation from a new and renewable energy source. Based on the energy generated from RE sources, Renewable Energy Certificates (RECs) are provided to power generators. These RECs are calculated based on the weighing scheme under which weights are applied to various RE sources. A weightage of 1.5 is applied to FSPV as compared to 0.7 for land-based solar PV.

India

As highlighted in this report, until now the cumulative installed capacity of FSPV-based projects has reached to 2.7 MW. However, it is going to increase many folds by the end of 2019, as projects 1721 MW are in the various stages of development at the moment. The majority of these projects are developed through a tendering process. The Solar Energy Corporation of India (SECI) is the leading organization followed by NTPC Ltd, NHPC, state-level distribution companies (like Kerala State Electricity Board Limited), and city development authorities such as the Greater Visakhapatnam Smart City Corporation Limited (GVSCCL), etc.

The Netherlands

In 2017, the Ministry of Infrastructure and Water Management, Netherlands had created a consortium called 'Zon op Water' to develop 2 GWp of FSPV by 2023. The consortium aims to install many demonstrations of FSPV projects. Under the government subsidies scheme of SDE+, 1.8MWp FSPV plant at Gelderland was financed through a non-recourse loan from ING.

The USA

In some places in the USA, like Massachusetts, special compensation rates (location based) for FSPV projects are given. In 2018, Solar Massachusetts Renewable Target (SMART) programme was launched, which offers compensation rate add-on of $0.03/kWh for FSPV projects.

IV FLOATING SOLAR PV AS TECHNOLOGY OVERVIEW

Major components of floating solar PV

FSPV design is similar to a conventional solar PV system except it requires a special arrangement to float on the water surface. The typical floating structure supports the PV arrays, inverters, combiner boxes, lighting arresters, etc. on a floating bed, which is made of fiber-reinforced plastic (FRP) or high-density poly ethylene (HDPE) or metal structures. The whole floating bed is buoyed with the help of anchoring and mooring systems. The detailed description of floating solar components is given below:

Figure 9: Major components of floating solar PV

PV Modules

The basic integral part of the FSPV plant is solar PV modules and like conventional solar projects generally, poly or monocrystalline or thin film solar panels are used for the installation of the project. Selection of PV modules technology also defers because of space, cost, relative humidity, type of water-bodies, etc. The criteria for selection of PV modules are as follows:

- Solar panel performance – power tolerance, efficiency, temperature coefficient especially in high moisture, and high humidity conditions
- Solar panel quality – certifications such as ISO 9001
- Solar panel durability – conformance to reliability standards such as IEC 61215 (wind loading)
- Quality assurances by solar panel manufacturer – warranty
- IEC 62804 certification for potential-induced degradation (PID) from a solar panel manufacturer
- Solar panel manufacturer's corporate profile and previous experiences

Inverters

Like a conventional solar plant, DC power generated from solar PV modules is taken to the inverter through a series of combiner boxes and finally converted into AC power. A developer may select multiple string inverters or central inverters. Depending upon scale and distance from shore, inverters can be placed either on a separate floating platform or on land. Generally, for smaller capacity FSPV inverter may be located on land near to PV arrays, otherwise for large capacity plants it is advisable to place inverter on a floating platform to avoid excessive resistive losses. Both the types have some inherited advantages and disadvantage and choosing one over another must be done wisely.

Figure 10: (A)Central inverter placed on floating platform at China. (B) String inverter

Floating Platform

This is the most crucial component of FSPV; it supports all necessary components like solar PV during the project time. Hence selection of appropriate materials for the floating platform becomes imperative. HDPE is the most popular material being used in a majority of the FSPV power plants across the globe. Other materials like FRP, medium density polyethylene (MDPE), and ferro-cement are also been utilized as materials for the floating platform. Various designs of a floating platform are described below.

Pure-floats design

It uses a specially designed float that can hold PV panels directly. The entire system is made in a modular fashion and has a provision to join with pins or bolts to make a large platform. Every single unit of such a system typically consists of the main and secondary floats. The main purpose of the secondary float is to provide a walkway for maintenance and additional buoyancy. The design is being used by a few manufacturers, some of them are as follows:

Hydrelio from Ciel & Terre

The Ciel & Terre is a French technology provider, providing innovative floating solar solutions since 2011. In fact, it has the majority of market share in terms of total numbers of installations across 25 countries, accounting for more than 300 MWp of installed capacity. Hydrelio floats are made of HDPE and connection pins are made of polypropylene combined with fiberglass. The floats are manufactured by blow molding and pins are made from injection molding.

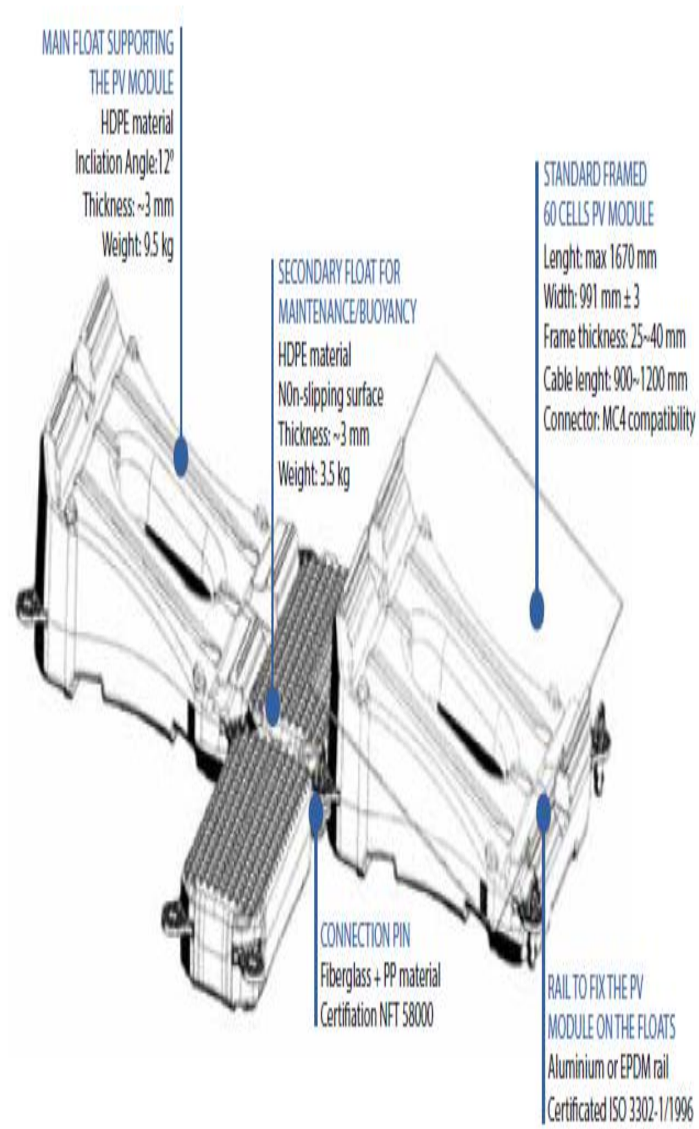


Figure 11: Hydrelio design

Sumitomo Mitsui Construction Co. Ltd.

The design is conceptually similar to Ciel & Terre, with some additional features like more regularly shaped float for denser packing and easy transportation. Additionally, a float is filled with polystyrene foam reducing the risk of sinking even when damaged and there is a usage of binding bands in the connecting part, which reduces the risk of structural failure for floats.

Figure 12: Floating platform

Yellow Tropus Pvt Ltd.

The Yellow Tropus is an India-based design and engineering company focused and specialized in the development of FSPV power plants. The company is offering three types of technology for land-neutral FSPV plants which are as follows: • Seahorse technology – One single unit of this consists of one walkway float and two solar PV panel float for supporting two solar PV panels **Stingray Technology** – It aims to minimize losses due to evaporation by covering more fraction of water surfaces. As per the company's claims the technology is best suitable for large waterbodies that include thermal power plants, steel plants, chemical industries, water tanks that is manmade waterbodies with no aquatic life. One unit of this supports three solar PV panels and has two float sections namely South C-Hex float and North C-Hex float.

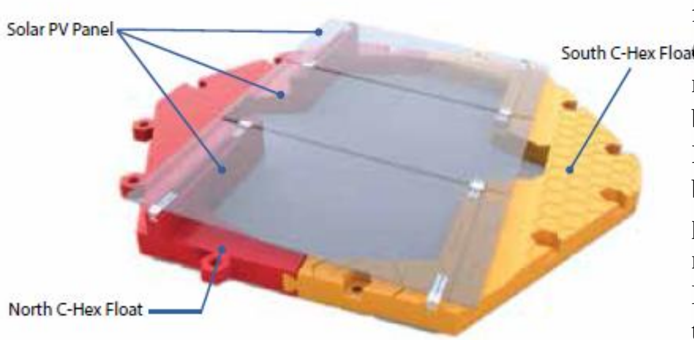


Figure 13: Stingray technology

Pontoon + metal structures design

The other common design which is used by some project developers uses a metal structure similar to land-based system and pontoons to provide buoyancy, hence eliminating the need for specially designed floats. The main advantage of this type of design is, easier to make floats and hence can be manufactured locally. However, access for operation and maintenance is difficult in such designs. The main advantage of this type of design is, easier to make floats and hence can be manufactured locally. However, access for operation and maintenance is difficult in such designs.

Figure 14: Floaters design

Anchoring and Mooring System

Since FSPV plants are installed on water bodies, any variations in water levels induced by monsoon, wind velocity or increase/decrease in water quantity could be problematic for the plants. To avoid this situation, FSPV plants are anchored through mooring systems. The placement of a mooring system must take into account the location, bathymetry, soil conditions, and water-level variations. Mooring systems include quays, wharfs, jetties, piers, anchor buoys, and mooring buoys. Mooring system for a floating platform is generally attached with nylon polyester or nylon nautical ropes that are further tied to bollards on the bank and lashed at each corner. Mooring can be done in the following three ways – bank anchoring, bottom anchoring, and piles.

- **Bank anchoring** – This type of anchoring is particularly suitable for sites, which are shallow, small and where the bottom of the water basin does not allow any kind of anchoring. Bank anchoring is the most cost effective option and its suitability depends on the conditions of the shore. The main disadvantage of this type of mooring is its visibility from outside, impacting the landscape view.

- **Bottom anchoring** – Due to its suitability and flexibility, this type of anchoring is more popular than other types. This can be done in two ways – inserting anchors directly into the bottom of the waterbody and anchoring through concrete block placed at the bottom of the waterbody. The anchors are then connected to a floating platform with the help of mooring cable and chain. The cost of bottom anchoring is generally higher than other types as it requires careful planning while designing and involves divers.
- **Piles** – In this, piles are drilled into the bottom of the waterbody and the floating platform then be moored to the piles. The main advantage of this type of configuration is in their capability to handle water level variations however, the need for heavy equipment and civil work makes it expensive.

Cabling

In case of FSPV plants, cable routing and its management requires cautious planning. Unlike ground-based solar PV installations, movement of floating platform on a water surface causes cable length to vary in FSPV plants. The movement of floating platform is due to wind load and variations in water level. This requires extra length in form of slack to be provided for accommodating the movement of the floating platform. Neglecting this, insufficient cable length may result in cables to snap and rupture due to the tension. Apart from the cable length the other parameters upon which cable size depends are voltage and current of the cable and losses from the cable. The cables can be routed in two ways – either via float on water surfaces or via submarine cables, later one being costlier. Cable trays, cable conduits, and cable clip holders are used to keep cables on the water surface. Cables used must be UV-resistant, and uses of wiring trunks are recommended to protect them from direct sunlight. To avoid DC cables/ conduits coming into contact with water, it is recommended to use proper cable ties or clamps. Similarly AC cables can be routed either via separate dedicated floats or via use of submarine cables for the connection to main electrical infrastructure onshore. In a nutshell the following element play vital role while sizing the cable and its routing in case of FSPV plants :

- Plot size
- Distance to shore
- Placement on inverters, transformers
- Quality of water
- Variations in water level

V UNCONVENTIONAL CONCEPTS IN FSPV

Tracking

Like the ground-mounted solar PV panels, floating platforms can also be designed in a way to track the sun in single as well as dual axis, later being slightly difficult to achieve in the of FSPV. Tracking in a single axis (vertical-axis azimuth tracking) is relatively simple as low resistance is offered by water layer as compared to on land. In some of the initial designs of this type, platform (usually of circular shape) is moored around a central pile and motors are used to rotate it around a vertical axis of the central pile, thereby enabling single-axis rotation to track the sun in single axis. In some other designs, central pile is replaced by a fixed outer ring, which surrounds the floating platform.

In a recent development, India-based Yellow Tropus Pvt Ltd claims the world's first dual-axis-tracking (DAT) FSPV plant technology capable of generating 40% higher energy generation as compared to land-based solar power plants. A typical plant based on this technology consists of a toroidal wave attenuator, a Y-shaped flotation device resembling a hexagonal honeycomb shape grid after assembling, and a tracking system to track the sun in the two axes. The main function of toroidal wave attenuator is to balance out the effect of turbulence caused by high winds and waves, hence acting as the first line of defense and providing guidance for azimuthal tracking.

Figure 15: A-200 kWp grid-connected single axis based floating solar PV plant in Suvereto, Italy

Concentrated FSPV

As the name depicted, this uses a reflecting mirror or Fresnel lens to concentrate the sun rays on the solar PV cell/panel. In principle, the technology is similar to groundmounted concentrated solar PV (CSPV), the only difference is an assembly of solar PV cell/panel and reflecting mirror /concentrating lens is mounted on the floating platform instead of attached to the ground. Readily availability of water as a coolant and lower ambient temperature could make this technology more relevant as compared to the ground-mounted one. However, the constant movement of a floating platform on a water surface makes it difficult to track the sun along the two axes, resulting in lower concentration ratio.

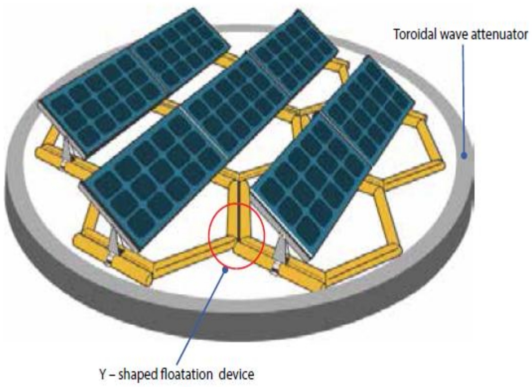


Figure 16: Dual-axis-tracking Technology

Figure 17: Phase I of 4MWp floating solar PV plant at wastewater treatment facility, Jamestown Australia

In another design of its kind in India, a pilot project uses a concentrator made out of plastic also known as liquid solar array (LSA). The lightweight plastic lens rotates to track the sun to achieve the required rotation needed. The PV cells are placed beneath the concentrator in a PV container that sits in the water. This helps in dissipating heat generated due to high concentration and keeping the PV cells cool. The key feature of this technology is its simplicity and minimal use of materials.

Membranes and mats type

In this type of platform, rubber mats are generally used to entirely cover the water surface. These rubber mats now act as a base for solar panel installation. This type is particularly suitable for small manmade waterbodies (size less than 0.2 km2), which are primarily used for water storage and have no aquatic life. Some advantages of this type of platform are simplicity in design, easy installation, and maintenance, the ability to accommodate changes in the level of water, etc. The type is especially suitable for areas prone to water scarcity like a desert and arid areas. In another design by the company name Ocean Sun from Norway, a floating platform is made of rafts, which is 70 m in diameter. Each raft is like a giant inflatable pool made of a plastic ring and a thin membrane.

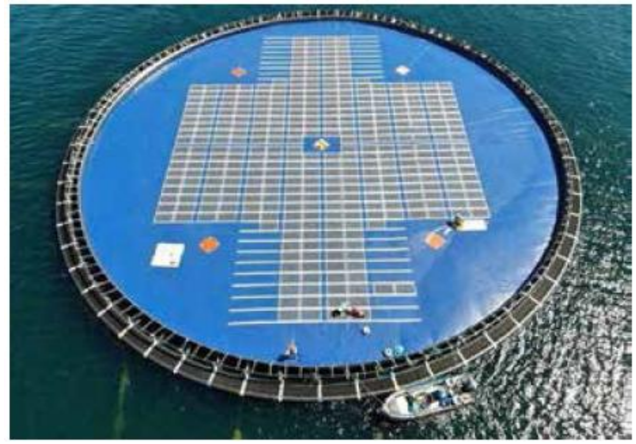


Figure 18: Floating platform

Submerged FSPV

As the name indicates, in this type PV modules are directly placed just beneath the water surface. Apart from achieving the lower module temperatures, one major advantage of this type is its simple mooring requirement due to reducing mechanical loading and lesser internal stress because of the use of flexible modules as compared to conventional PV modules with rigid mounting structure. An increase in the flexibility of the entire system reduces the number of material requirements and also makes transportation easy. However, the technology is in its nascent stage at the moment and has some concerns like long-term reliability of PV modules and electrical safety under submersible conditions. MIRARCO mining innovation had deployed the world's first test system having 0.57 kWp capacity in 2010.

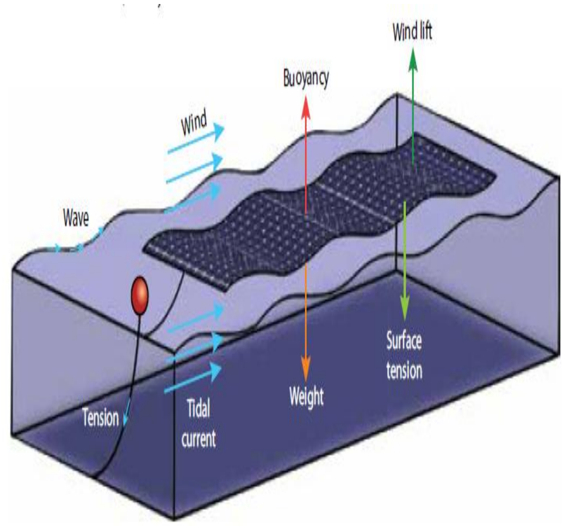


Figure 19: Schematic of forces on submerged FSPV plant

Figure 20: 0.57 kWp submerged floating solar PV based plant

India is known to have a large number of man-made reservoirs20, which are used for a variety of purposes like irrigation, hydroelectric, water supply, navigation, etc. In fact, as on June 2019, share of installed hydroelectric capacity stands at 45 GW21 out of 366 GW of total installed capacity of the country, representing 12.8% share in the total. These reservoirs impound large volumes of water during monsoon for eventual use during lean season. The prevalent high temperatures and arid conditions, however, result in substantial evaporation losses from these reservoirs. CWC22 estimates that average annual evaporation from reservoirs/ waterbodies in India varies from 1.5 m to 3.0 m per km2. Thus FSPV presents a possibility to generate clean energy via a technology that is land neutral and has the potential to conserve water by reducing the evaporation losses.

Potential Assessment Tool

Due to the unavailability of any single point data source, data from several open-source databases like CWC, WRIS, state water resources department, Indian Meteorological Department (IMD), NREL, etc. were gathered. The data collected were cleaned and arranged in a uniform format for further analysis. Each data point was then geo-referenced to find out the information like latitude and longitude. Duplicate data points were removed in the next steps and

additional information like the nearest city, states, purpose, solar radiation, monthly average ambient temperature, reservoir surface area, water depth, reservoir age, etc. were added to each data points. Reservoirs with water depth lesser than 2 m and surface area lesser than 4, 000 m2 were filtered out from the database. Even though only man-made reservoirs were included for assessing the potential of FSPV, covering 100% of the surface area was not feasible due to – (a) most of the reservoirs are more than 20 years old and they may have developed some type of aquatic life during this period. Hence covering 100% of the water surface may have a negative impact on aquatic life and local biodiversity. (b) These reservoirs have also been used for other purposes like irrigation, water supply, navigation, recreational activities, fishing, etc. Thus covering 100% of the surface area is not feasible. (c) Some of the reservoirs are spread across very large areas making it practically unrealistic. Hence a range of percentages was assigned to calculate the useable area, which was further used to calculate the potential. The range is set based on the purpose of the reservoir. For example, for a reservoir with a purpose of irrigation, FSPV plant can be installed on 5%–30% of its surface area, for reservoir with a purpose of generation of electricity, FSPV plant can be installed on 5%–10% and so on. Once the usable area is known, its value I s then used to calculate the potential. Further, historical changes in the water surface of each data.

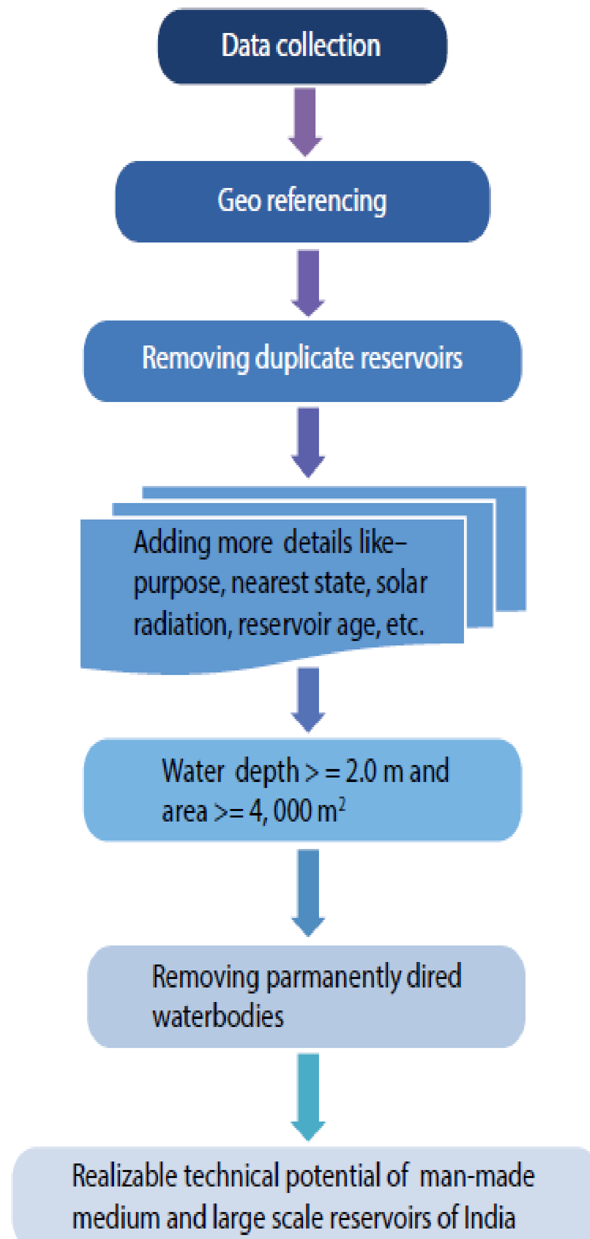


Figure 21: Flow chart of the steps followed for assessing the floating solar PV potential

Sr.No.	Purpose	Scenario I (in %)	Scenario II (in %)
1	Flood control and irrigation	5	10
2	Flood control, hydroelectric, and irrigation	2	5
3	Hydroelectric	5	10
4	Hydroelectric and irrigation	5	10
5	Hydroelectric, irrigation, and recreation	1	2
6	Hydroelectric, irrigation, and water supply	2	5
7	Hydroelectric, irrigation, navigation and, pisciculture	1	2
8	Hydroelectric, irrigation, pisciculture and, water supply	1	2
9	Irrigation	5	30
10	Irrigation and navigation	1	2
11	Irrigation and pisciculture	1	2
12	Irrigation and water supply	2	5
13	Water supply	2	5
14	Hydroelectric and water supply	5	10

Figure 22: Percentage for calculating usable area

The methodology of using these data sets is described in detail byPekel, Andrew, Cottam23 *et al*. Based on this, permanently dried data points were removed and reservoir area value of the remaining data points was adjusted. Google maps were used for removing the reservoirs located in the protected areas like – wildlife sanctuaries, protected forest areas, etc. Two scenarios as presented in TERI's Analysis Table 2 were used for calculating the potential of each data point. Finally, a web-based user interactive tool was developed. The tool highlights the prospective FSPV locations, spreading across the country. Size of the bubble depicts the size of the FSPV plant which can be installed on that particular location. Lastly, state-wise potential numbers were populated. Refer Chart for more details on the state-wise potential for FSPV along with the total number of reservoirs on which FSPV can be installed along with cumulative reservoir area. As indicated above, all the identified reservoirs are attributed with parameters such as– solar radiation, reservoir depth, waterlevel variation, reservoir age, and infrastructure, availability such as site accessibility, vicinity to transmission infrastructures, etc. These parameters play vital role in choosing any particular site for installation of FSPV-based plants. For example, the cost of anchoring and mooring highly depends on the depth24 of the water body on which FSPV plant is installed, therefore, reservoirs with lower depth (<30 m) are generally preferred over the reservoirs with higher depth (>30 m). Thus it is important to identify such reservoirs. All identified reservoirs are further categorized into the following five distinct reservoir depth classes :

- VHD – Very High Depth (depth ≥ 100 m)
- HD – High Depth (30 m ≤ depth < 100 m)
- MD – Medium Depth (15 m ≤ depth < 30 m)
- LD – Low Depth (10 m ≤ depth < 15 m)
- VLD – Very Low depth (3 m ≤ depth < 10 m)

Similarly, reservoir's age is also an important parameter, which provides some indication on a reservoir's capability to hold FSPV plant over its entire life. To include the effect of this, all identified reservoirs were further categorized into the five distinct categories of reservoir age : >200-years old.

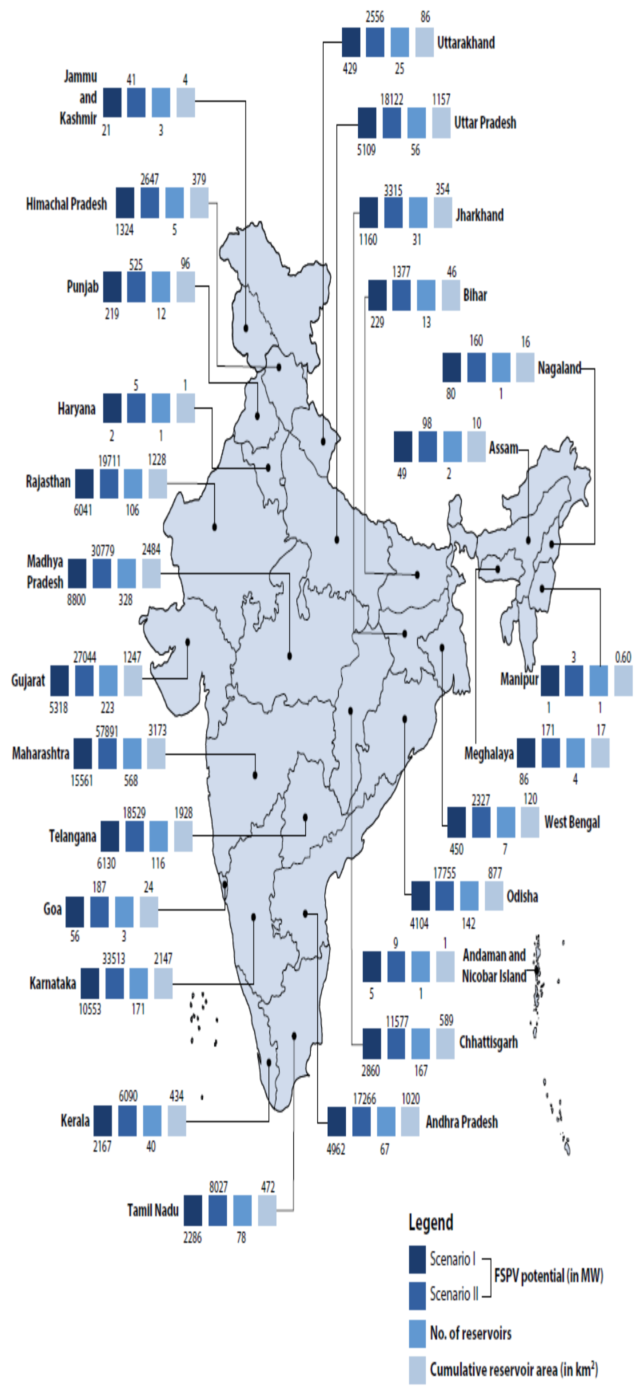
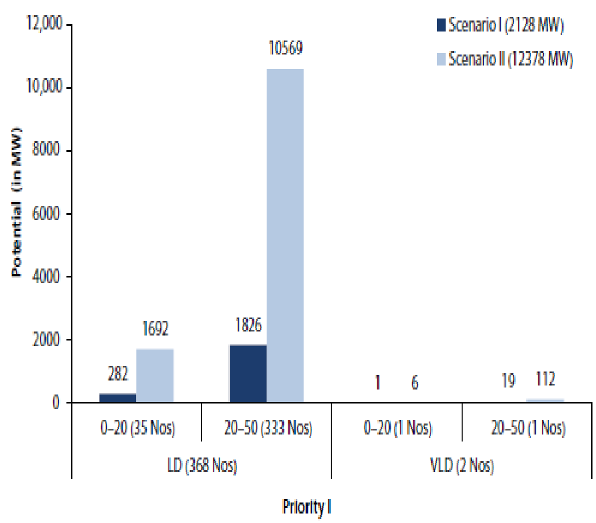
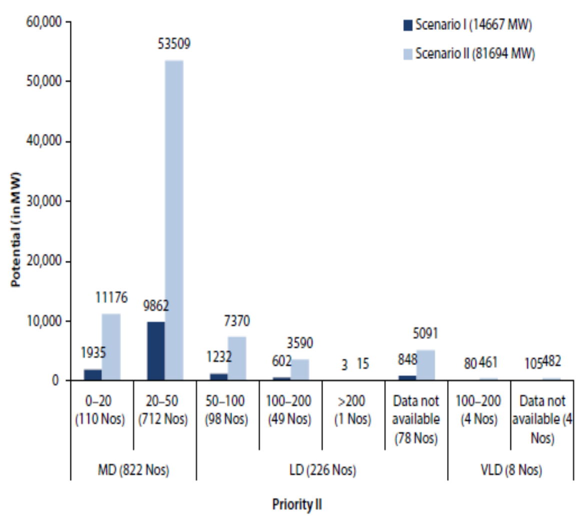


Figure 23: State wise estimated potential of FSPV

Setting Priorities

As presented in this study earlier, even though numbers presented in Chart 15 showcase huge potential of FSPV in the country there is a very limited amount of data available at the moment, raising speculations on the long-term viability of this new technology. Hence in order to reap the benefit of this technology, it is essential to create local knowhow via concentrating more on the long-term impact of technology through proper monitoring of projects. Learning through these initial projects would then be utilized in setting standards and guidelines for further developing such projects. Based on the data gathered, the study tries to identify the difficulty levels in setting up the FSPV-based projects for all the locations and rank them in form of priority, that is, Priority I, Priority II, and Priority III. Locations involved under Priority I are the ones that are considered as 'low-hanging fruit', requiring minimum level of knowhow (which is equivalent to the current technical knowhow for FSPV in the market) available presently and thus easy to install. Refer Chart 16 for more details on the priority-wise potential.





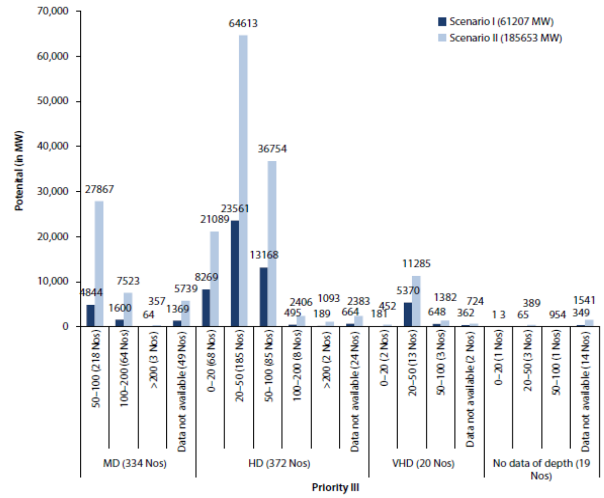


Figure 24: Priority-wise Floating Solar PV potential – Priority I, Priority II, and Priority III

VI FLOATING SOLAR PV – POTENTIAL ENVIRONMENT AND SOCIAL IMPACT

Potential impact of deploying large-scale floating solar PV

FSPV plants are often installed on in-land bodies of water and these waterbodies are used for a variety of purposes such as drinking water, irrigation, recreation, generation of electricity, etc. Frequently these waterbodies are also tagged as 'lifeline', deploying large-scale FSPV plants might have a notable impact on the social development of mankind. Figure 19 tries to depict some of the potential impacts of deploying large-scale FSPV. A few of these potential impacts of deploying large-scale FSPV plants are due to the following:

- Impact on local marine aquaculture due to the reduction in sunlight reaching the water surface
- Impact on the fishing pattern
- Impacts of shading of water surface on temperature stratification and dissolved oxygen levels
- Impact on water quality
- Inhibits the breakdown of chemicals by prompting high dissolved organic carbon concentrations potentially increasing the costs of water treatment
- Impact due to leaching from materials
- Impact due to exposure to electromagnetic fields associated with underwater electrical cables
- Impact on hunting grounds of surface-diving birds
- Impact on migratory birds habitats

Till now there are very limited data available and the long term effects of deploying large-scale FSPV on waterbodies are poorly understood. Also, it is important to note that since waterbody characteristics vary widely, the scale of impact is site-specific in nature and hence it is vital to take all factors into consideration before deploying FSPV plants at large scale for each site.

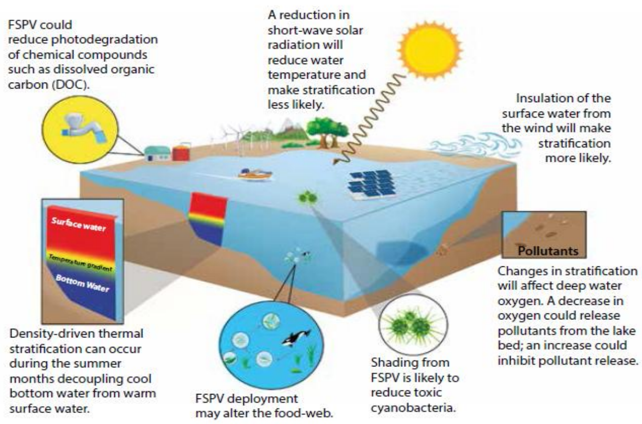


Figure 25: Potential impact of deploying large-scale floating solar PV

VII FLOATING SOLAR PV – PROJECT DESIGN GUIDELINES

A flow chart of floating solar PV project design

FSPV as a technology is still in the developing phase and there are several vital elements including methods/ steps for establishing FSPV plants that are not available publicelly. Hence, developing the best practice guidelines for FSPV sector would help project developers, investors and policymakers in understanding the procedures of FSPV project development. In a nutshell, major steps of developing an FSPV project can be understood through Chart.

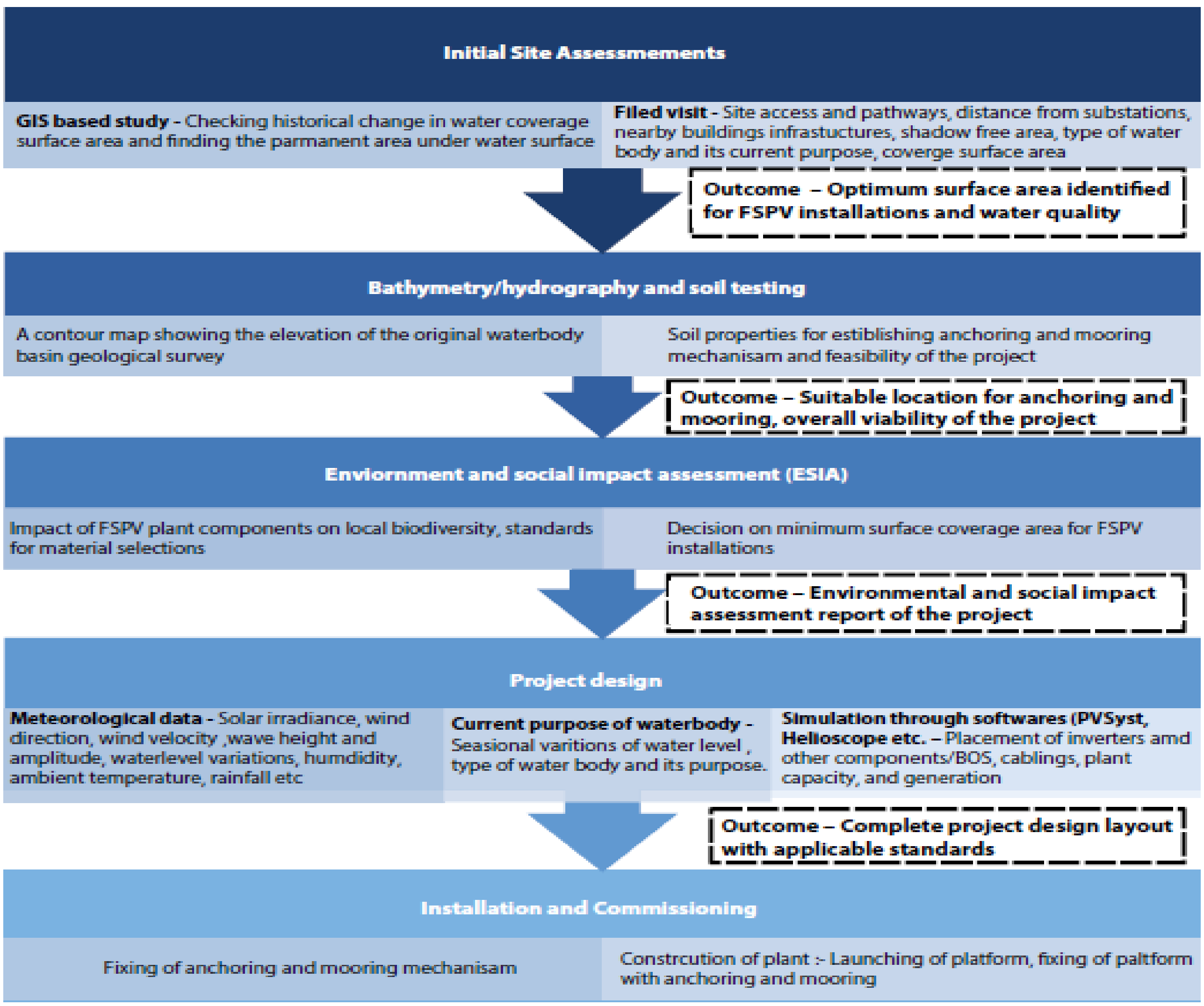


Figure 26: A flow chart of floating solar PV project design

Initial Site Assessments

The initial site assessments of the proposed waterbody should be carried out to understand the feasibility of the site for the FSPV project development. The site assessments can be executed in the two following steps:

- **GIS-based assessment –** Assessments through the GIS tool really help in finding out the site feasibility for an FSPV plant establishment. The GIS tool provides information on water surface variations due to seasonal changes in the past years. The outcome of the analysis gives an approximate surface area of the waterbody which remains permanent irrespective of seasonal water-level deviations.
- **Field assessment –** An initial site visit is essential to understand the ground reality of the site conditions. The visit mainly covers the assessment of type of waterbody and its purpose, accessibility to the site, location of nearest substations, and information on restricted area. In case the waterbody is used for some industrial purposes or in power plants or water treatment plants, etc., details like fire hazard buffer zone, nearby building infrastructure for calculating the shadow-free area, availability of space while installation, space available near shore while placing the floating platform into waterbody, etc., are some of the important points that need to be looked into.Eventually, the initial site assessments assist in estimating a suitable area for FSPV installation and water quality of reservoir/pond/lagoon

Bathymetry/Hydrography and Soil Testing

A bathymetric survey is a method to estimate the depth of a waterbody, and it also helps in understanding the underwater geography of a particular waterbody. There are several methods available for carrying out bathymetric surveys such as multibeam, single beam, sub-bottom profilers, EcoMapper Autonomous Under Vehicle (EAUV), and acoustic doppler current profiler (ADCP). A hydrography survey deals with providing physical features such as understanding of

underwater navigations, accurate positions, depictions of hills, etc., of waterbodies. Both bathymetric and/or hydrographic surveys are useful in understanding the topography of water-bed such as locating any bed-rock outcrops, obstacles at bed level if any, and optimum locations for placing anchors and mooring for the floating platform. The bathymetric and hydrographic surveys that roughly take between 7 and 15 days to conduct, involve the use of precise instruments and methods. The survey gives information on the waterbed in the form of a contour map comprising details related to the depth of the waterbed with reference to datum level. The contour map, as shown in Figure 20, is a decisive factor in identifying the best places of anchoring and mooring, desilting requirements, etc.

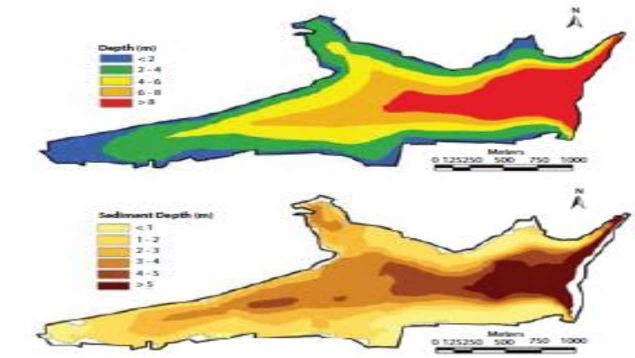


Figure 27: (A) Historical bathymetric map of Bellandur Lake. (B) Sediment accumulation in Bellandur Lake

Figure 28: Impact of improper bathymetry and/or hydrography surveys

This step is vital to judge the overall techno-commercial viability of the projects, and failure in conducting this properly could cause extensive damage to the FSPV plant as shown in Figure 21.

Typically instruments used for bathymetric/hydrographic surveys are shown in Figure 22. Soil testing is also an important step for deciding the type and design of anchoring that would be required. It provides information on soil composition of the banks and waterbody beds, etc. The soil test must be conducted as per IS: 2131-1963 and a testing report must contain information like – natural moisture content, bulk density, dry density, specific gravity, grain size distribution, and atterberg limits along with bore logs with SPT 'N' values.

Figure 29: Instruments for conducting bathymetric/hydrographic surveys

Environmental and Social Impact Assessment detail ESIA

As highlighted in this report, the long-term impacts of deploying large-scale FSPV-based plants on the local environment are poorly known. Also, an FSPV plant includes components like floating platform, anchoring and mooring system, cables, inverters, etc. which are continuously exposed to water. Additionally, these waterbodies are often used for several social usages like fishing, farming, navigation, drinking, etc. and their characteristics vary widely and are site specific. Hence, it is imperative to conduct a detail ESIA for each site to assess the long term impact of deploying an FSPV on a particular waterbody and its suitability.

Project Design

Upon receiving the clearance from ESIA, designing of FSPV plants can begin. For the sake of simplicity, the entire project design needs the following three components –

- **Meteorological data** – Meteorological or met data are essential to understand the local resources pertaining to FSPV. The met data comprise solar radiation, wind direction, wind velocity, wave height and amplitude, humidity, ambient temperature, rainfall, etc.
- **Water quality information** – Water quality information is really crucial in selecting the material of anchoring and mooring system, floating platform, cables and understating the long-term effects it may cause on the life of FSPV plant components. Hence it is essential
  to have a thorough investigation on water quality of the waterbody while taking the sample from multiple points. A typical water quality report should contain information such as physical and chemical properties of water (PH, turbidity, salinity, dissolved oxygen (DO), total dissolved solids (TDS) level, temperature of water, etc., and must follow IS:10500 2012.
- **Simulation** – Simulation softwares like PVsyst, HelioScope, ANSYS, OrcaFlex, CFD, etc., can be used in designing the layout, angle of tilt, plot size, designing of anchoring and mooring lines, placement of inverters, plant capacity, balance of system (BOS), estimates of energy generations for the entire project life, etc. The general steps for designing the FSPV plants are explained in Chart

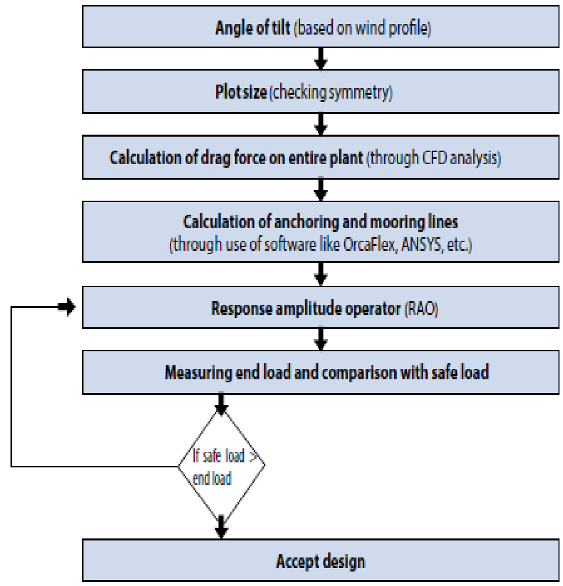


Figure 30: A flow chart of steps in floating solar PV project design

Angle of tilt

Dependencies of PV modules angle of tilt on the location of the plant and wind speeds are well known. In fact, the wind load plays a vital role in deciding the quantum of drag force being induced on the mounting structure. In case of FSPV plants, this is even of much importance, as an incorrect angle of tilt can induce higher drag forces causing severe damage to the entire plant structure. Typically, wind loads are measured as per the Indian Standards IS 875 (Part 3). The standard provides details of the wind speed for every Indian city. Based on multiple discussions with various expert groups, angle of tilt in case of FSPV projects can be kept as per the details given in Table

Mean wind speed (m/s)	Angle of tilt (°)
>35	5
25–35	10
<25	15

Figure 31: Angle of tilt with respect to wind speed

Plot size

Generally, in ground-mounted solar PV plant, drag force is induced on the individual row of the panels and is irrespective of the plot size as shown in Figure 23. However, with respect to FSPV plants, since each row is connected to a single outer frame resembling a single plot, drag forces are induced on the entire plot as indicated in Figure 24. This makes the plot size, in the case of FSPV much more important in comparison to ground-mounted plants. To understand this let us take an example of a recent fire incident due to typhoon that happened in Japan’s 13.7MWp FSPV plant. The entire 13.7MWp plant, covering a total area of 137,326 m2 was assembled in a large single outer frame. Due to its large plot size, the high drag force developed during the typhoon tore the plant from the middle section while anchoring lines remained intact, as depicted in Figure 25. Hence, in order to minimize the drag force, it is recommended to keep a single plot size small and symmetrical (not more than 3–4 MWp).

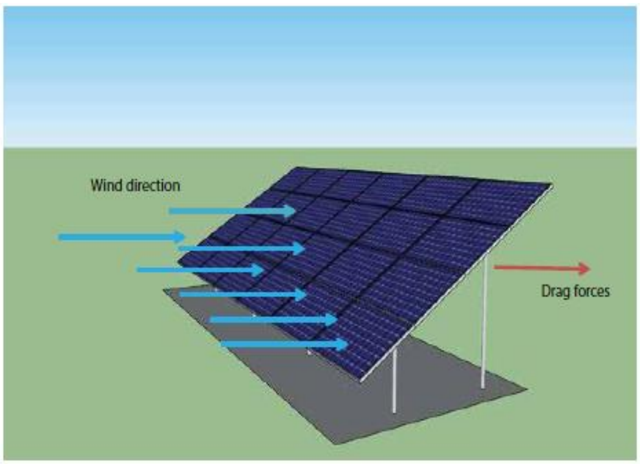


Figure 32: Drag forces in ground-mounted solar PV

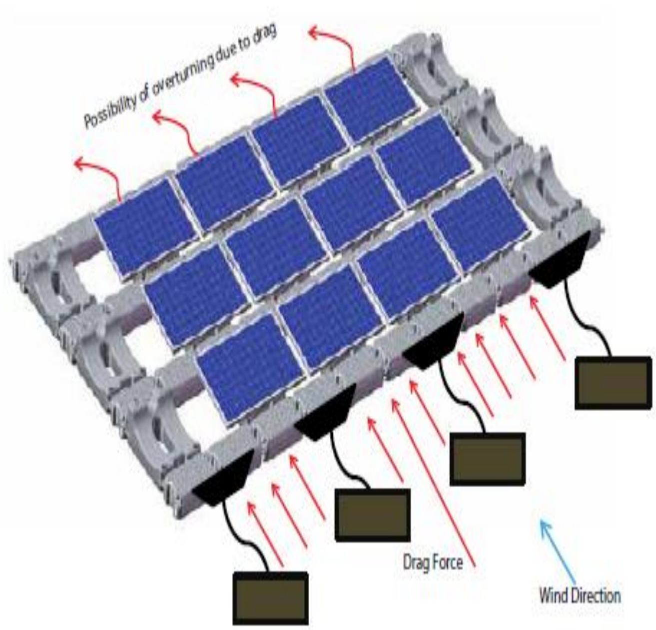


Figure 33: Schematic of drag forces developed in floating solar PV plant

Figure 34: Japan’s 13.7MWp floating solar PV plant before (A) and after (B). The red circle indicates that the anchoring Calculation of drag forces

Once the angle of tilt and plot size are decided, the detailed analysis of drag forces over the entire plant must be investigated. CFD simulations are performed to calculate the value of drag force and its points of action over entire plot, as explained in the Figure

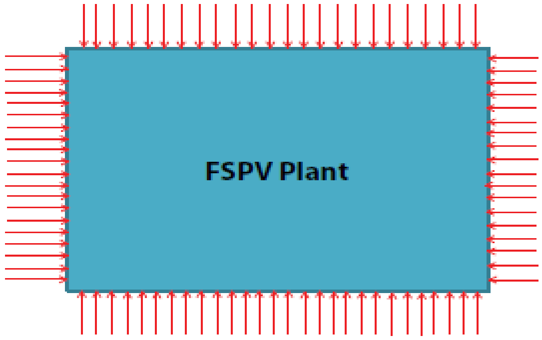


Figure 35: Drag forces on floating solar PV plant

Calculation of anchoring and mooring lines

After drag force and its points of action get simulated, forces induced on the anchoring and mooring lines can be calculated through softwares like OrcaFlex, ANSYS, etc. The results of the software are used in calculating the forces on individual points of the anchoring and mooring lines.

Response amplitude operator

A response amplitude operator (RAO) is a method that is used to find the floating structure’s characteristic response created by wave action. The results obtained from this study help in choosing mooring wire ropes, which can sustain sufficient tensions in extreme conditions. The calculations of tensions (in kN) on different ropes are calculated in RAO

Measuring end load and its comparison with the safe load

Once the tensions in different loads are identified, the next step is to calculate end loads on each of these points and this should be performed under permissible limits. Further this calculation should be compared with safe load. The designs considered as safe if the end load is lesser than the safe load, otherwise the process has to be repeated till the value of end load becomes lesser than safe load.

Installation and Commissioning

In comparison to ground-based solar PV plants, FSPV plants are easy to install and may not require heavy civil construction in most cases. The entire process of installation and commissioning can be divided into three steps:- a) site preparation and construction; b) installation and c) commissioning. As in any solar PV-based plant development, the first step is to prepare the site. This involves civil works for grading and leveling, excavating the foundation for mooring and anchoring, fabricating a dedicated launching platform for launching the floating platform into the water surface (this depends upon access to the water surface at the site), fabricating inverter housing, building embankment for foundation protection, etc. Installation begins after the initial site preparation is completed. It includes connecting the rows of floats to form a floating platform, mounting PV panels on the floating platform, connecting cables, inverters, transmission lines, etc. Since FSPV plants are installed on waterbodies and are often subjected to harsh environmental conditions like high humidity, high winds, etc., it is recommended that the solar PV panels, supporting structure and other balance of systems such as inverters, cables, etc., are chosen wisely. Some activities involved under installation and commissioning are likely to generate air and noise emissions. Such emissions and wastes generated could have an adverse impact on local bio-diversity. Therefore, it is essential to follow the recommendations provided in the ESIA report while adhering to the specific standards; some of them are also explained in the subsequent section.

Technical Specification and Standards

As discussed in this report, FSPV plants are deployed in waterbodies and often subjected to harsh environments. Hence it is important to consider relevant standards to ensure the quality of the FSPV plant components while being cautions of not degrading the quality of water as well as local bio-diversity. It is recommended to adhere to the following technical standards of the major components used in grid-connected FSPV-based plants

Sr No	Component	Standard	Description
I.	Solar PV module		
	1	IEC 61215-1 Ed. 1.0	Terrestrial photovoltaic modules – Design qualification and type approval - Part 1: Test requirements
	2	IEC 61215-1-1 Ed. 1.0	Terrestrial photovoltaic modules – Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic modules
	3	IEC 61730-1Ed. 2.0	Photovoltaic module safety qualification Part 1: Requirements for construction
	4	IEC 61730-2 Ed.2	Photovoltaic module safety qualification Part 2: Requirements for testing
	5	IEC 61701 Ed.2	Salt mist corrosion testing of photovoltaic modules (applicable for coastal and marine environment)
	6	IEC 62716 Ed.1	Photovoltaic modules – Ammonia corrosion testing
	7	IEC TS 62804-1 Ed.1	Photovoltaic modules – Test methods for the detection of potential-induced degradation Part 1: Crystalline silicon
II.	Floating platform / floaters		
	1	ASTM D1693 (or equivalent ISO Standards)	Test for environmental stress cracking of HDPE
	2	ISO16770	Stress cracking resistance of HDPE
	3	IS 15410:2003 or equivalent BS 6920:2014	Test for drinking water compatibility, material safe for drinking water
	4	RoHS directive 2002/ 95/EC	Test for restriction of hazardous substances
	5	ASTM D790 (or equivalent ISO Standards)	Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials
	6	ISO 178	Plastics – Determination of flexural properties
	7	ASTM D638, ISO 527	Standard test method for tensile properties of plastics
	8	ASTM D695, ISO 604	Standard test method for compressive strength properties of plastics
	9	ISO 16770	Full notch creep test (FNCT)
	10	ASTM D2565 (or equivalent ISO Standards)	Standard practice for xenon-arc exposure of plastic intended for outdoor applications
	11	ASTM D4329(or equivalent ISO Standards)	Standard practice for fluorescent ultraviolet (UV) lamp apparatus exposure of plastics
	12	ASTM D1693-15 (or equivalent ISO Standards)	Standard test method for environmental stress cracking of ethylene plastics
	13	ASTM D5397-07(2012)	Standard test method for environmental stress crack resistance of polyolefin geo-membrane
	14	IS 15410:2003 or equivalent BS6920	Containers for packaging of natural mineral water and packaged drinking water

III.	**Inverters/power conditioners**		
	1	IEC 61683	Efficiency measurements
	2	IEC 60068-2/ IEC 62093	Environmental testing
	3	IEC 61000-6-2, IEC 61000-6-4 & othe relevant parts of IEC 61000	Electromagnetic compatibility (EMC)
	4	IEC 62103/ 62109-1&2	Electrical safety
	5	IEEE1547/IEC 62116/ UL1741 or equivalent BIS standards	Protection against islanding of grid
	6	LVRT compliance	As per the latest CERC guidelines/order/ regulations
	7	Grid connectivity	Relevant CERC regulations (including LVRT compliance) and grid code as amended and revised from time to time.
	8	Rated capacity	Nominal/rated output power of the inverter (if different power ratings are mentioned at different temperatures, then power rating at 50°C shall be considered) in kilowatt will be considered as inverter rated capacity
IV.	**Cables**		
	1	BS/ EN 50618 / TUV 2pfg 1169/08.2007	Solar-grade cables for outdoor installation
	2	IEC 60227 / IS 694 IEC 60502 / IS 1554 (Pt. I & II)	General test and measuring method of PVC-insulated cables for working voltage upto and including 1100 V and UV resistant for outdoor installation
V.	**Earthing**		
	1	IS 3043	Code of practice for earthing
	2	IEEE 80	IEEE guide for safety in AC substation surrounding
	3	IEEE 142	IEEE recommended practice for grounding of industrial and commercial power systems
VI.	**Others**		
1	Switches/ circuit breakers /connectors	IEC 60947 part I,II,III / IS 60947 Part I,II,III EN 50521	General requirements connectors – safety AC/DC
2	Junction boxes / enclosures for inverters /charge controllers / luminaries	IP 65/66(for outdoor) IP 54(for indoor)	General requirements

Figure 36: Technical standards for various components of floating solar PV plants

Apart from the aforementioned technical standards, it is also important to consider the following points before deploying the FSPV-based plants:

- The material used for the floating platform must be UV stabilized (UV20) and should be manufactured from appropriate thermoplastic having good environmental stress crack resistance (ESCR) such that the floating platform can withstand a minimum operational period of 25 years without any discolouration. Also, materials used for floating platforms should be chemically resistant to acid, lye, petrol, mineral oil, and most importantly, should not contaminate the waterbody in any condition in its lifetime. Additionally, a floating platform, when deployed in waterbodies, containing raw water, should be designed in a manner such that it does not restrict the process of gas exchange across the air–water interface. This is why voids of appropriate size must be provided and should be made an integral part of floating platform design.
- The floating platform, module-mounting structure, and anchoring and mooring system must be designed while considering the worst-case scenario and must be able to withstand variation in ambient temperature in the range of +50°C to -10°C.
- In order to perform PV module cleaning and regular operation and maintenance, appropriate measures must be incorporated in the floating platform design.
- The floating platform must re-processable and recyclable at the end of its useful life.
- The anchoring and mooring system must be designed while considering the variation in water level and prevailing wind speed. It should also restrict any lateral movement of the plant as well as not cause any negative impact on local biodiversity of the waterbody.

- All cables and connectors used in FSPV plants are of solar grade and able to withstand harsh environmental conditions for 25 years.

VIII ADVANTAGES

- No land acquisition required
- Protects ecologically sensitive areas and very friendly to environment
- Drastically reduced installation time and associated cost
- Water for cleaning and cooling the panels is readily available

  Efficiency is improved

IX CONCLUSION

With the rate of capacity additions growing almost 3.5 folds, and reaching 84.4 GW within the last 5–6 years, the journey of renewable energy capacity additions in India is being phenomenal so far. With scheme like Saubhagya, providing last mile connectivity, the regulatory structure in place is geared towards creating the demand for clean energy while making electricity affordable for all. With focus given to transforming the energy sector from fossil-based to zero carbon globally, the Government of India is also playing its role in creating a favourable environment by introducing the relevant policy interventions that are needed. In fact being among the world's fastest growing emerging economies and world's second most populous country, make the country a key player in the global energy transitions. There are many ways to contribute in this transition, FSPV being one of them. The report investigates the possible ways of utilizing the vast potential trapped in the country's inland waterbodies (medium and large reservoirs) through installation of FSPV. FSPV looks promising to become a third pillar of the solar PV sector and its market share is likely to accelerateas the technology gets mature. It provides some inherent advantages like improvement in energy yield due toevaporative cooling effect because of vicinity to the water surface, alternate to land use (land neutrality), potentialto use the existing power infrastructures, potential to savewater evaporation loss, etc. However, FSPV is in nascent

stage of its development in India and there are lots of questions particularly regarding its long-term impact on the local environment and bio-diversity which require answers before rushing into large scale deployment. Formulation of FSPV-specific standards and project development guidelines is the need of the hour and is of vital importance to reap the actual benefit of this technology without causing any negative impact on the local environment. In this initial stage, focus must be on the viability of FSPV as a technology and not on the tariff and hence monitoring of its performance and bringing it to public domain must be encouraged. This can be achieved via following the priorities presented in this report and sharing the learnings among the stakeholders.

REFERENCES

[1] P. Sharma, B. Muni, and D. Sen, "Design parameters of 10 kW floating solar power plant," Int. Adv. Res. J. Sci., Eng. Technol., vol. 2, pp. 85– 89, May 2015.

[2] Z. A. A. Majid, M. H. Ruslan, K. Sopian, M. Y. Othman, and M. S. M Azmi, "Study on performance of 80 Watt floating photovoltaic panel," J. Mech. Eng. Sci., vol. 7, pp. 1150–1156, Dec. 2014.

[3] A. Holm. (2017, Jan 27). Floating solar photovoltaics gaining ground.

[4] A. Sahu, N. Yadav, and K. Sudhakar, "Floating photovoltaic power plant: A review," Renew. Sustain. Energy Rev., vol. 66, pp. 815–824, Aug. 2016.

[5] Y. Choi, N. Lee, A. Lee, and K. Kim, "A study on major design elements of tracking-type floating photovoltaic systems," Int. J. Smart Grid Clean Energy., vol. 3, no. 1, pp. 70–74, Jul. 2013.

[6] JET Float International. (2017, Jan 29). Floating solar plants photovoltaic

[7] Y. K. Choi and Y. G. Lee, "A study on development of rotary structure for tracking-type floating photovoltaic system," Int. J. Precis. Eng. Manuf., vol. 15, no. 11, pp. 2453–2460, Nov. 2014.

[8] Y. Ueda, T. Sakurai, S. Tatebe, A. Itoh and K. Kurokawa, "Performance analysis of PV systems on the water," 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, pp. 2670– 2673, Sep. 2008.

[9] R. Cazzaniga, M. R. Clot, P. R. Clot, and G. M. Tina,"Floating Tracking Cooling Concentrating (FTCC) systems", Photovoltaic Specialists Conference (PVSC), Austin, USA, pp. 514–519, 2011.

[10] S. Vorrath. (2017, Jan 27). Australia's first floating solar plant opened in South Australia

[11] NRG Energia. (2017, Jan 27). Floating photovoltaic systems.

[12] K. Trapani and D. L. Millar, "The thin film flexible floating PV (T3FPV) array: The concept and development of the prototype," Renew. Energy, vol. 71, pp. 43–50, May 2014.

[13] K. Trapani and M. R. Santafe, "A review of floating photovoltaic installations: 2007 – 2013," Prog. Phtovolt: Res. Appl., pp. 1–9, Dec. 2014.

[14] G. M. Tina, M. Rosa-clot, P. Rosa-clot, and P. F. Scandura, "Optical and thermal behavior of submerged

photovoltaic solar panel: SP2," Energy, vol. 39, no. 1, pp. 17–26, Oct. 2012.

[15] M. Rosa-clot, P. Rosa-clot, G. M. Tina, and P. F. Scandura, "Submerged photovoltaic solar panel: SP2," Renew. Energy, vol. 35, no. 8, pp. 1862– 1865, Nov. 2010.

[16] R. Lanzafame, S. Nachtmann, M. Rosa-Clot, P. Rosa-Clot, P. F. Scandura, S. Taddei, and G. M. Tina, "Field experience with performances evaluation of a single-crystalline photovoltaic panel in an underwater environment," IEEE Trans. Industrl. Electrncs., vol. 57, no. 7, pp. 2492–2498, Jul. 2010.

[17] M. R. Santafé, J. B. T. Soler, F. J. S. Romero, P. S. F. Gisbert, J. J. F. Gozálvez, and C. M. F. Gisbert, "Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs," Energy, vol. 67, pp. 246–255, Feb. 2014.

[18] J. J. Gozalvez, P. S. F. Gisbert, C. M. F. Gisbert, M. R. Santafe, F. J. S. Romero, J. B. T. Soler, and E. P. Puig, "Covering reservoirs with a system of floating solar panels: Technical and financial analysis," 16th International Conference on Project Engineering, pp. 177–187, Jul. 2012.

[19] C. F. Gisbert, J. J. F. Gozálvez, M. R. Santafé, P. F. Gisbert, F. J. S. Romero, and J. B. T Soler, "A new photovoltaic floating cover system for water reservoirs," Renew. Energy, vol. 60, pp. 63–70, May 2013.

[20] Y. G. Lee, H. J. Joo, and S. J. Yoon, "Design and installation of floating type photovoltaic energy generation system using FRP members," Sol. Energy, vol. 108, pp. 13–27, Jun. 2014.

[21] Y. Choi, "A case study on suitable area and resource for development of floating photovoltaic system," Int. J. Electr. Comput. Electron. Commun. Eng., vol. 8, no. 5, pp. 828–832, 2014.

[22] G. M. Tina, M. R. Clot, P. R. Clot, "Electrical behavior and optimization of panels and reflector of a photovoltaic floating plant," 26th European Photovoltaic Solar Energy Conference and Exhibition, pp. 4371–4375, 2012.

[23] Y. Choi, N. Lee, and K. Kim, "Empirical research on the efficiency of floating PV systems compared with overland PV systems," The 3rd International Conference On Circuits, Control, Communication, Electricity, Electronics, Energy, System, Signal and Simulation, vol. 25, pp. 284–289, 2013.

[24] Y. Choi, "A study on power generation analysis of floating PV system considering environmental impact," Int. J. Soft. Eng. Appl., vol. 8, no. 1, pp. 75–84, 2014.

[25] C. J. Ho, W. L. Chou, and C. M. Lai, "Thermal and electrical performance of a water-surface floating PV integrated with a watersaturated MEPCM layer," Energy Convers. Manag., vol. 89, pp. 862– 872, Oct. 2015.

[26] C. J. Ho, W. L. Chou, and C. M. Lai, "Thermal and electrical performances of a water-surface floating PV integrated with double water-saturated MEPCM layers," Appl. Therm. Eng., vol. 94, pp. 122– 132, Oct. 2016.

[27] A. K. Sharma and D. P. Kothari, "Floating solar PV potential in large reservoirs in India," Int. J. Inv. Res. Sci. Technol., vol. 2, no. 11, pp. 97– 101, Apr. 2016.