Floating Photovoltaics

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Floating photovoltaics (FPV) addresses this issue by installing solar photovoltaics (PV) on bodies of water. Globally, installed FPV is increasing and becoming a viable option for many countries.

Keywords: floating photovoltaics (FPV) ; floating solar ; floatovoltaics ; Water ; Low-cost ; Ecosystem

1. Introduction

As the world population continues to grow, the energy demand is also increasing, causing an increase in use of fossil fuels, which emit greenhouse gases [1]. As climate change continues to worsen, the world is looking at ways to reduce greenhouse gas emissions [2][3]. The world is facing a climate crisis. The International Energy Agency (IEA) reported that in order for the world to reach the goal of net zero emissions by 2050 there will have to be an annual average solar energy generation growth of 24% [4]. In 2020, solar generation increased 23%, resulting in the IEA categorising solar photovoltaics (PV) as 'more effort needed' [4].

Solar PV is expected to be a leading technology to power the world in the future [5]. The price of PV has reduced drastically, reaching a price similar to that of conventional energy sources [6][7]. The IEA stated that PV has become the lowest-cost electricity source in history [4]. While installed PV is set to continue growing, the large scale ground-mounted photovoltaic (GPV) farms are running into issues of finding land to install on [8]. A 1MW PV farm needs approximately 15,000 m^2 of land [9]. With large land requirements and rising land prices it is becoming increasingly difficult to purchase land for a PV farm [10]. Other challenges faced by PV installations are cooling of the panels and keeping them free of dust in order to increase energy efficiency [11]. A solution to this challenge is placing PV on bodies of water such as ponds, lakes, reservoirs, oceans, canals, lagoons, waste water treatment plants, or irrigation ponds [12]. The placing of PV panels on top of bodies of water is called floating photovoltaics (FPV) or floatovoltaics. Countries that are facing challenges with land availability for PV farms are looking towards the potential of FPV [13].

2. Technology

A general FPV system consists of PV panels and system installed atop a floating structure that is anchored to the ground as seen in **Figure 1**.

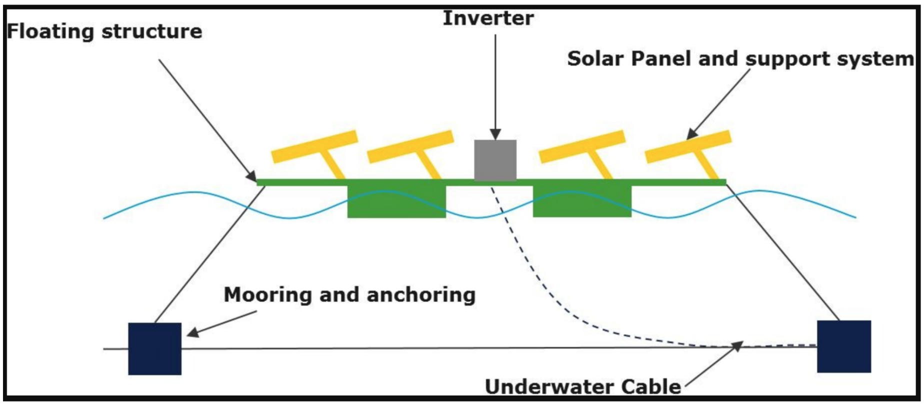

Figure 1. FPV components Reprinted wiht permission from [14]. 2020, Oliveira-Pinto.

2.1. Floating Structure

A pontoon structure is used to keep the system floating in the water [12]. The pontoons are formed by attaching floats together in order to hold the weight of the structure on top of the water [12][14]. The majority of floats used in the industry are made out of high-density polyethylene (HDPE) due to it being UV resistant, corrosion resistant, maintenance free, recyclable and having good tensile strength [12]. Another material used for floats, though less common, is glass fibre reinforced plastic [12]. These systems generally have a set panel inclination that is not easily adjusted once installed [14]. A benefit of the floating structures is that they are easy to decommission compared to a GPV system [15]. Other floating structure options include galvanized steel platforms and one or two axis tracking platforms [14].

2.2. PV Module

The commonly used module type for FPV installations is crystalline silicon [12]. Crystalline modules work well in fresh water environments, but as the sector looks toward marine environments, modules will need to be designed to withstand the salty environment. Therefore, standard metal frames will need to be replaced with an alternative material [12]. There is potential to also use second generation CdTe [16][17][18], a-Si, or CIGS [19], but there has been limited investigation with these technologies. Third-generation PV is not considered yet for FPV due to the lack of maturity [20][21][22][23].

2.3. Mooring

The mooring system of an FPV installation is required to hold the system in place, avoiding overturning or floating away [12]. The system can be moored with anchors on the ground of the body of water, or alternatively, directly to shore [14]. Nylon ropes are often used as the mooring lines and allow movement of the system for changes in water depth and blowing wind [24].

2.4. Cables

Underwater cables can be used to transport the generated electricity to an onshore substation [14]. It is also common to keep the cables above the water [12].

2.5. Installation

The installation process for FPV is often easier than that for GPV, as long as the anchoring and mooring system is not complicated [25]. The installation does not require heavy equipment and the system is usually assembled on land and then transferred onto the body of water where it can be towed to the site [25][26]. Lightsource, a company in the United Kingdom, used a ramp to roll FPV into the water [27]. The installation can be seen in **Figure 2**.

Figure 2. Array deployment using a ramp. Reprinted with permission from [25]. 2019, World Bank.

2.6. Location

In order to choose a suitable FPV location, there is a list of criteria that must be taken into consideration. **Table 1** breaks down the key criteria that must be analysed before selecting a location to install FPV.

Table 1. Site suitability. Adapted with permission from [25]. 2019, World Bank.

Feature	Criteria
Weather	**High irradiance**
	Limited rain or fog
	Wind speeds below 30 m/s
Location	**No shadowing from mountains or surrounding buildings**

Feature	Criteria
	Convenient transportation
	Convenient installation and maintenance
	Close to electrical connection
Ground conditions	Consistent terrain
	Compact soil for anchoring
Water conditions	Limited waves
	Fresh water
	Low hardness
	Low salinity

3. Application of PV

3.1. Cooling Effect

PV modules are negatively affected by high temperatures as high temperatures decrease the performance, energy output, efficiency, and life span of the modules [11]. The most critical factor affecting a PV module's efficiency is module temperature [28]. An increased surface temperature of a module results in sunlight being converted into heat rather than output power [28]. There has been extensive research into cooling methods for PV modules in order to increase the efficiency when exposed to hot temperatures [29]. When PV modules are placed on bodies of water, they experience a cooling effect that increases their efficiency compared to a GPV system [30]. A paper comparing the cooling effects on FPV in the Netherlands (temperate maritime climate) versus Singapore (tropical climate) found that Singapore had a 6% increase in annual energy yield while the Netherlands had a 3% increase [31]. Another paper investigating the performance of FPV in the tropics found an up to 10% increase in annual energy yield due to the cooling effect [13]. A study in Visakhapatnam, India, found a 1.5–3% increase in energy production for FPV compared to GPV [32]. Another study in India found a 2.5–3% increase between FPV and GPV [33]. Brazillian reservoirs were analysed in a study and found to have a 12.5% increase in efficiency for FPV because of the cooling effect [34]. The World Bank also found increased efficiency varying between 5% and 10% for different climatic regions [25]. The cooling effect due to the cool air flowing under the PV modules is a key advantage of installing an FPV system over a GPV system.

3.2. Humidity

Another effect of installation on water is an increase in humidity for the modules [35]. FPV modules experience higher humidity compared to GPV modules [35]. An increase in humidity around a module can affect the atmosphere and cause the module temperature to increase, thereby decreasing the performance of the module [35].

3.3. Water Evaporation

Studies have shown that FPV is capable of significantly decreasing water evaporation [15][36]. This can be important for coupling FPV with HPP, which will be discussed. It is also increasingly important for countries that are dealing with water shortages [37][38]. Water-scarce regions in central and southern Asia were concluded to benefit greatly when FPV was installed [38][39]. A study found that a 1MW FPV system in Visakhapatnam, India, would reduce water evaporation and save 42-million litres of water [32]. A study looked at the water evaporation reduction, economic feasibility, energy generation, and environmental impact of installing FPV on five main reservoirs lakes in Iran [40]. By covering 10% of the five main reservoir lakes with FPV, enough water would be saved from evaporation to meet the domestic water demands of a city with 1-million inhabitants. The study states that FPV would be beneficial for Iran as it is facing an energy and water crisis [40]. The reduction of water evaporation is a benefit of FPV.

3.4. Impact on Water Quality

FPV is a growing sector that only began to boom recently. As a result, there is minimal research on the impact of FPV on water quality. The impact on water quality is noted to be the greatest threat of FPV. A study conducted by Exley et al. reported that FPV operators stated there was no impact on water quality, but only 15% are monitoring and analysing the water quality while the majority are using only visual inspection [41]. The paper goes on to explain that nine ecosystem services could be affected by the installation of FPV [41]. A study using two adjacent agricultural ponds, one covered with

FPV and one open as a control, found that there were no negative effects on water quality associated with the FPV [36]. The study found improved concentrations of cholorophyll and nitrate, as well as a 60% decrease in water evaporation [36]. Multiple papers concluded that a positive impact FPV has on water quality is the reduction of algae growth [15][42]. The percentage of FPV cover on a body of water will determine the system's impact on algae growth. A study investigating the impact of FPV on water quality found that FPV covering a small amount of a reservoir was not enough to reduce algae blooms [43]. A main concern reported in research around FPV impact on water quality is that there has not been enough studies and modeling to conclude that there will not be negative effects.

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