



Guidelines for Floating Solar PV in India

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Published by:

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Published Under:

Innovative New Solar PV Areas in India

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As at New Delhi, June2025

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On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ)

Acknowledgement: This publication has been prepared under the Indo-German Solar Energy Partnership-Innovative Solar (IGSP IN-Solar) in India. The project has been initiated under the guidance of the Ministry of New and Renewable Energy, Government of India and is funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). The purpose of this study is to develop the necessary guidelines to support the implementation of FPV technologies in the Indian context.

The project team is grateful for the guidance and support received from the Ministry of New and Renewable Energy (MNRE), Deloitte Touche Tohmatsu India LLP (DTTILLP), Indian Institute of Technology (IIT) Madras, Indian Institute of Technology Roorkee and industry players in the space of Floating Solar PV.

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Abbreviation

AC	Alternating Current	kWh	Kilowatt Hour
ADCP	Acoustic Doppler Current Profilers	Mg/l	Milligrams Per Litre
AED	Automated External Defibrillator	LID	Light-Induced Degradation
ALS	Accidental Limit States	MoEFCC	Ministry of Environment, Forest, and Climate Change
BEM	Boundary Element Method	MoP	Ministry of Power
CFD	Computational Fluid Dynamics	MPA	Marine Protected Area
DAF	Dynamic Amplification Factors	MW	Megawatt
DC	Direct Current	MWp	Megawatt Peak
DH	Dynamic Humidity	NHAI	National Highways Authority of India
DO	Dissolved Oxygen	PA	Polyamide
EIA	Environmental Impact Assessment	PE	Polyethylene
EMC	Electromagnetic Compatibility	PERC	Passivated Emitted Rear Cell
EPC	Engineering, Procurement, and Construction	PID	Potential Induced Degradation
FAD	Fish Aggregation Devices	PFD	Personal Floatation Devices
FiTs	Feed-in-Tariffs	PPE	Personal Protective Equipment
FLS	Fatigue Limit States	PP	Polypropylene
FRP	Fiber-Reinforced Plastic	PR	Performance Ratio
FRC	Foul-Release Coatings	RoW	Right of Way
GI	Galvanized Iron	SLDC	State Load Dispatch Centre
GIA	Generator Interconnection Agreement	SLS	Serviceability Limit States
Gol	Government of India	STC	Standard Test Conditions
GW	Gigawatt	STU	State Transmission Utility
ha	Hectare	TDO	Total Dissolved Oxygen
HDPE	High-Density Polyethylene	TOC	Total Organic Carbon
ISTS	Inter-State Transmission System	ULS	Ultimate Limit States
kV	Kilo Volt	UV	Ultraviolet



INTRODUCTION

1 Introduction

Floating Solar Photovoltaic (FPV) technology has emerged as an innovative and promising solution for expanding renewable energy capacity, leveraging water bodies to address land constraints. However, its deployment continues to face challenges, including technical complexities of operating on water, environmental impact uncertainties, and the need for tailored policy frameworks.

In India, where the demand for renewable energy is growing rapidly, the potential for FPV remains untapped. This gap highlighted the need for comprehensive guidelines tailored to India's unique geographical, environmental, and regulatory context. These guidelines aim to bridge this critical gap by offering a structured, actionable framework for all stakeholders involved in FPV development, including developers, policymakers, regulators, and investors. The draft guidelines are built on insights gathered through extensive workshops, one-on-one stakeholder consultations, secondary research, and a deep analysis of global and Indian case studies. They address key aspects of FPV deployment, including technical considerations such as anchoring, mooring, electrical safety, and maintenance, as well as regulatory and commercial challenges, such as permitting processes, water usage rights, and financial viability.

1.1 Overview of Floating PV Technology

The design of a FPV system is similar to traditional solar PV systems, with the primary distinction being the specialized configuration that allows the system to float on water. The Floating Structure acts as the foundation, supporting critical components like PV arrays, inverters, combiner boxes, lightning arresters, and more. These structures are typically constructed from durable materials such as Fiber-Reinforced Plastic (FRP), High-Density Polyethylene (HDPE), or metal. These materials are chosen for their buoyancy, resistance to UV radiation, corrosion, and biofouling, ensuring the long-term stability of the system in aquatic environments.

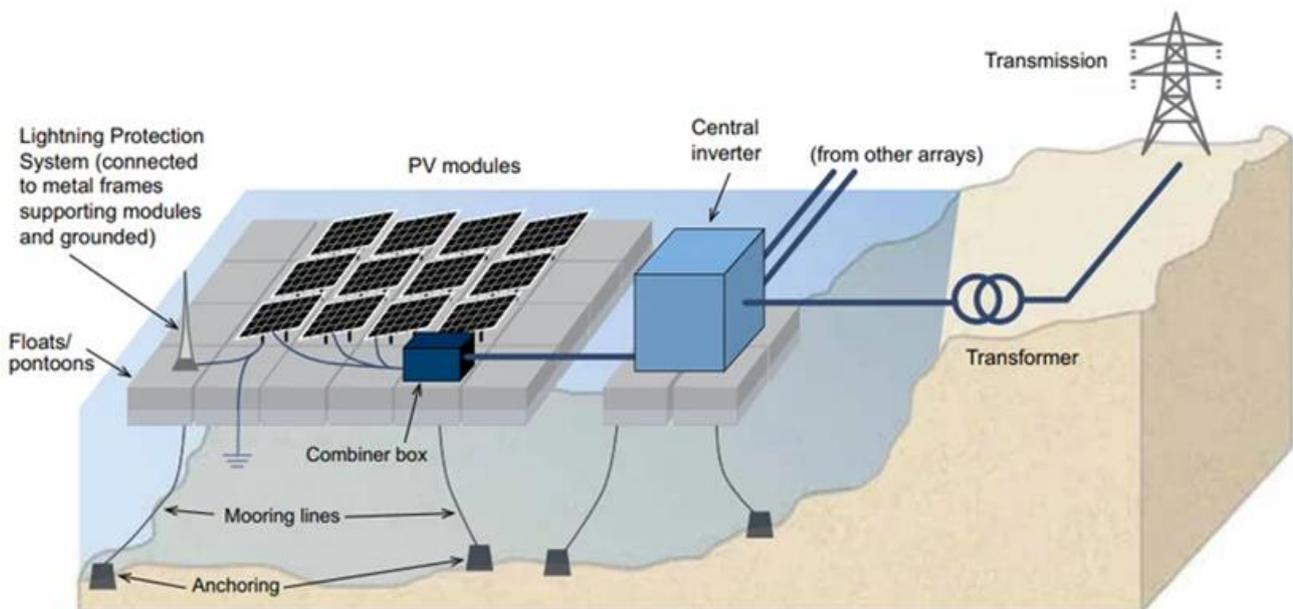


Figure 1: Schematic representation of a FPV system with its key components¹

Some of the key components of an FPV system includes:

- 1. Photovoltaic (PV) Modules:** FPV systems utilize conventional modules that must be highly resistant to humidity, and safeguarded against harsh environmental factors, including Potential-Induced Degradation (PID).
- 2. Floating Structures:** A floating platform is a buoyant structure made up of materials such as HDPE, stainless steel, Aluminum, etc. to support solar panels on water bodies. It ensures stability and durability while withstanding environmental conditions such as wind, waves, and water level variations.
- 3. Inverters and Combiner Boxes:** Inverters convert the DC power generated by the PV modules into AC power suitable for grid use. Combiner boxes aggregate outputs from multiple PV strings for efficient energy transfer.

¹[The World Bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

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4. **Mooring and Anchoring System:** A robust mooring and anchoring system stabilizes the floating structure, preventing drift due to wind, waves, or water current. It is designed to accommodate variations in water levels and bottom conditions.
5. **Cabling and Electrical Connections:** Submersible, water-resistant cables with protective sheaths ensure safe and efficient power transmission while minimizing the risk of water ingress and wear.
6. **Lightning Protection:** Lightning arresters safeguard the system from electrical surges caused by lightning strikes, protecting sensitive components from damage.
7. **Monitoring and Control Systems:** Real-time monitoring systems track energy generation, system performance, and environmental parameters, enabling operators to optimize and maintain the system efficiently.

1.2 Rationale for FPV in India’s Renewable Energy Mix

India's commitment to achieving its renewable energy targets necessitates innovative solutions that maximize resource utilization while overcoming challenges such as land scarcity and environmental sustainability. FPV technology offers a compelling rationale for inclusion in India's renewable energy mix, addressing these challenges and leveraging the country’s vast potential for water-based solar energy projects.

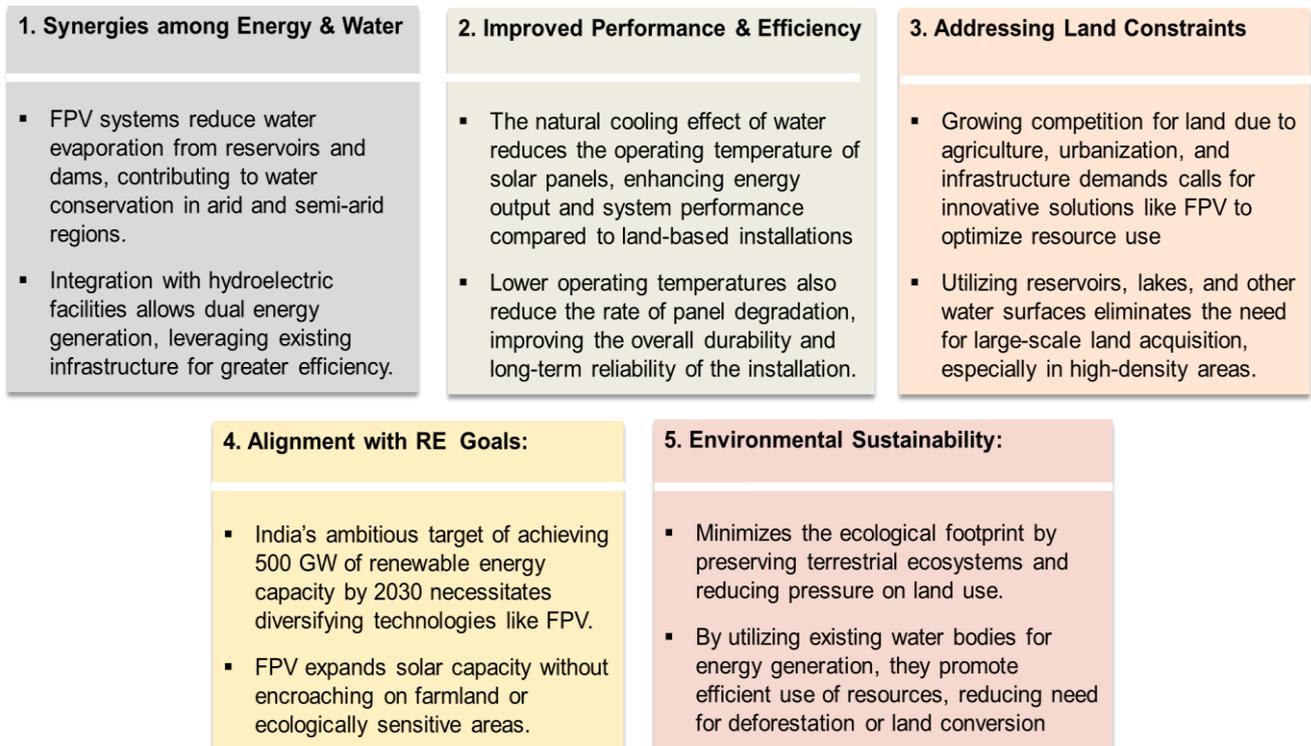


Figure 2: Key Drivers for FPV Adoption in India

Integrating FPV into India’s renewable energy mix addresses critical challenges such as land scarcity, water conservation, and environmental sustainability while contributing to the country’s renewable energy goals. By harnessing the vast potential of FPV, India can strengthen its energy infrastructure, diversify its solar portfolio, and pave the way for a sustainable energy future.

1.3 Overview of FPV Challenges in Indian Context

FPV systems have emerged as a promising solution to harness solar energy while addressing land-use constraints. In India, where land availability is limited due to high population density and agricultural demands, FPV systems offer a sustainable alternative for deploying solar power in water bodies such as reservoirs, lakes, and ponds. However, while FPV holds immense potential, there are several challenges that need to be addressed to ensure its successful implementation in the Indian context.

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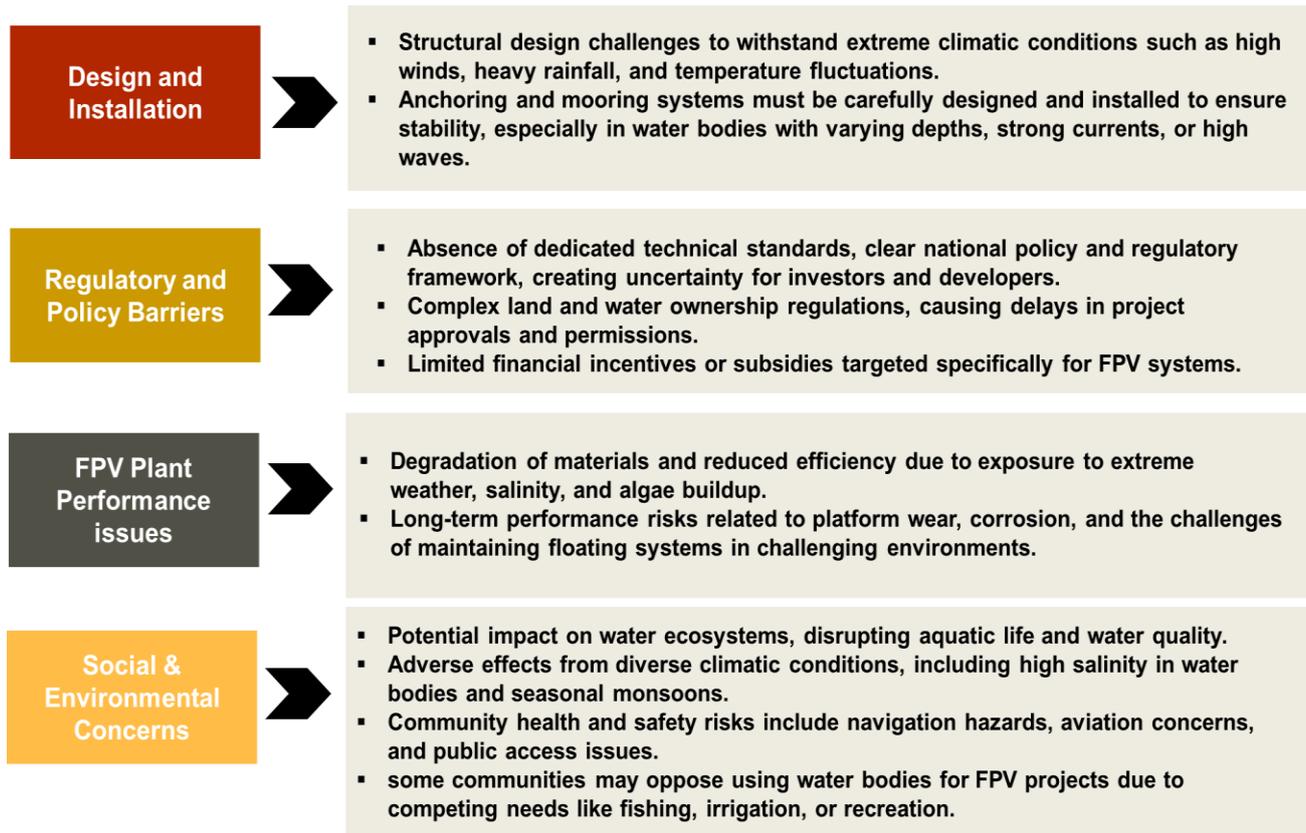


Figure 3: Challenges associated with FPV projects in Indian Context

In addition to the challenges outlined above, several other factors further complicate the deployment of FPV systems in India. A significant hurdle is the absence of standardized guidelines for the planning, investigation, design, installation, and maintenance of FPV systems, which can lead to inconsistencies, inefficiencies, and escalated project costs. Furthermore, the limited domestic manufacturing capacity for FPV-specific components increases dependence on imports, exposing projects to global supply chain vulnerabilities and price fluctuations.

Maintenance of FPV systems poses logistical challenges, particularly in reservoirs with fluctuating water levels or in regions prone to high biological growth, such as algae. These factors complicate operations and may increase operational expenditure. Financing FPV projects remains another critical barrier, as the novelty of the technology in India often leads to apprehension among financial institutions, with perceived risks hindering the flow of capital into this emerging sector.

Despite these challenges, FPV systems offer immense potential to meet India's growing RE needs while preserving valuable land resources. To unlock this potential, it is essential to address the multifaceted barriers that hinder their scalability. Developing & adopting comprehensive guidelines tailored to FPV deployment, coupled with robust policy frameworks & targeted financial incentives, will be critical steps forward.

Additionally, fostering innovation through technological advancements, enhancing local manufacturing capabilities & building technical expertise will be crucial. Collaboration between the government, private sector, and local communities will play a pivotal role in mitigating these challenges and driving the successful implementation of FPV projects across India.

1.4 Objectives of the FPV Guidelines

The objectives of the FPV guidelines are designed to facilitate the efficient, sustainable, and widespread adoption of FPV systems in India. These guidelines aim to support India's renewable energy targets by creating a standardized and structured framework for FPV implementation. Below are the key objectives, explained in detail with clear pointers:

- **Facilitating FPV Adoption:** The guidelines aim to enable the widespread use of FPV technology by providing a clear framework for its development and implementation. By addressing current gaps, these guidelines will help streamline processes and encourage stakeholders to adopt FPV systems across India.
- **Standardizing Approval Processes:** Comprehensive recommendations will be provided for regulatory approvals required to establish FPV plants. These include necessary permits, licenses, and compliance

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requirements at national, state, and local levels. This ensures clarity and uniformity in the approval processes.

- **Ensuring Technical Excellence:** The guidelines will highlight technical standards for FPV systems, covering the design, installation, and operational phases. This ensures high-quality infrastructure that is durable and efficient under varying conditions.
- **Addressing Environmental Impacts:** The guidelines will evaluate the environmental effects of FPV systems on aquatic ecosystems, including biodiversity, water quality, and nutrient cycles. By analyzing existing studies and conducting impact assessments, the guidelines will ensure that FPV adoption aligns with sustainable practices.

1.5 FPV Market Overview

In densely populated areas, the proximity of water bodies to load centers is often an advantage. Traditional land-based PV systems compete for land use with industrial or agricultural activities or may not be economically viable due to high land costs. Japan was one of the early adopters of FPV in 2007 with over two hundred projects.²

In 2023, the Asia-Pacific region continued to lead growth in FPV, driven by large-scale projects such as Indonesia's 192 MW Cirata Floating Power Plant, Thailand's 60 MW installation, and developments in India, Bangladesh (3.2 MW), and China (650 MW). In Europe, several countries celebrated their first FPV projects, including Latvia (2.1 MW) and Albania (2 MW), marking important milestones in their renewable energy journeys. France also expanded its capacity with the 8.7 MW Cintegabelle installation. Notable FPV projects commissioned in 2023 included Israel's 31 MW installation, Ghana's 5 MW Bui Hydro-Solar PV Hybrid, the USA's 8.9 MW Canoe Brook Reservoir project, and Colombia's 1.5 MW Aquasol.²

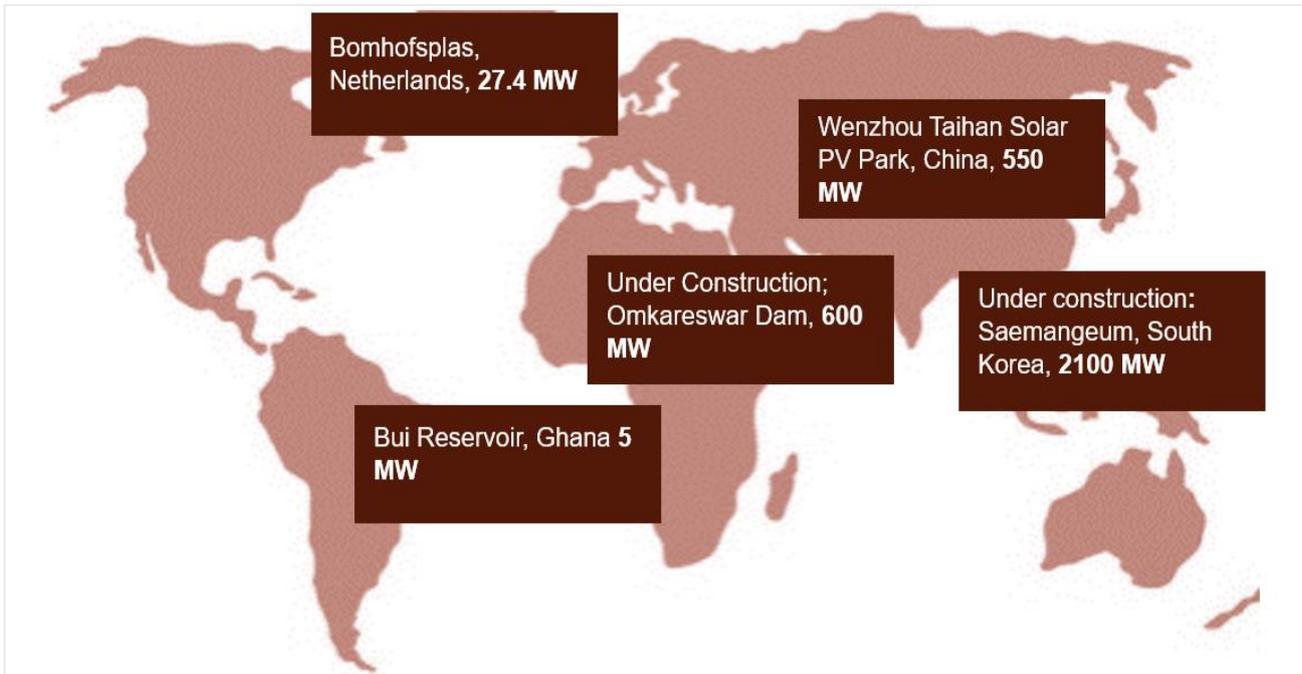


Figure 4: some of the major FPV projects currently under construction or commissioned worldwide

1.5.1 Global FPV Market Trends and Growth

FPV technology has emerged as a promising solution to harness renewable energy, especially in regions with limited land availability or water bodies. This innovative approach involves installing solar panels on floating platforms on bodies of water, such as lakes, reservoirs, or even the ocean. The global scenario for floating solar PV is rapidly evolving, driven by several factors, including increasing energy demand, environmental concerns, and technological advancements.

² [International Energy Agency, IEA PVPS \(2024\): Trends in PV Applications 2024](#)

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In 2022, the world’s largest floating solar array was grid-connected in China, with an operating capacity of 320 MW. As of September 2018, that figure had grown more than 100-fold to 1.1 GW, experiencing a nearly doubling of capacity relative to 2017. The majority of this growth in 2023 occurred in the Asia-Pacific region, continuing the trend from previous years, with notable large-scale projects such as the 192 MW Cirata Floating Power Plant in Indonesia, 60 MW in Thailand, and projects in India, Bangladesh (3.2 MW), and China (650 MW). In Europe, 2023 saw several countries, including Latvia (2.1 MW) and Albania (2 MW), launch their first floating solar projects, marking important progress in their renewable energy goals.

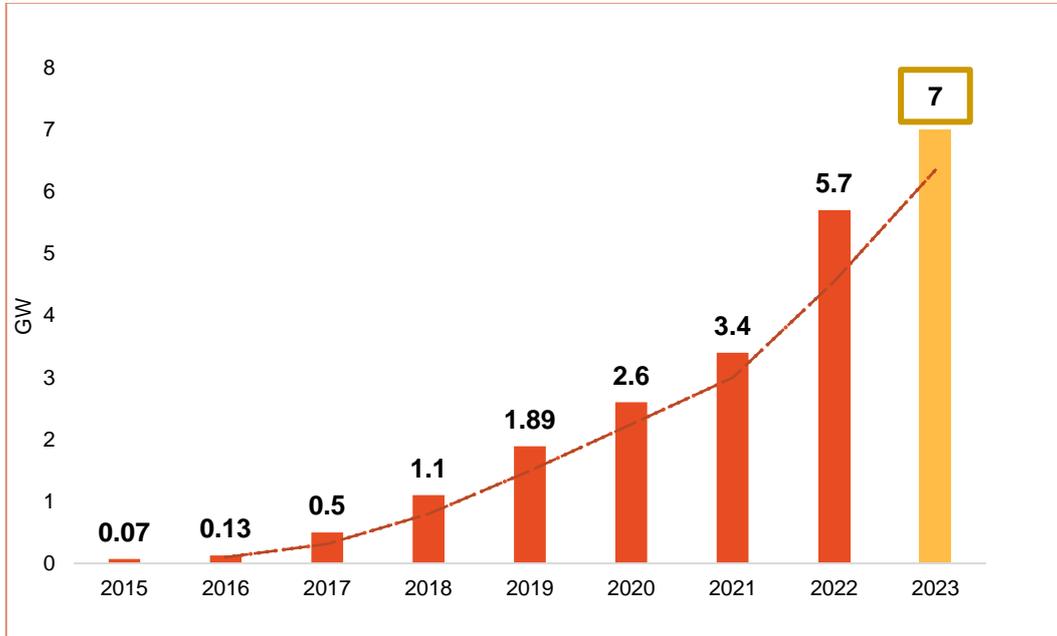


Figure 5: Global Cumulative FPV Installed Capacity (Source: Solar Power Europe, IEA³)

1.5.2 Indian FPV Market Trends and Growth

Floating solar is gaining momentum in India. Over the past two decades, rapid economic growth has driven a significant rise in the country’s electricity demand. To support its sustainable development goals, India has committed to achieving 500 GW of renewable energy capacity by 2030. While only 3 MW of floating solar capacity was installed in 2018, the technology has become a key player in energy production, reaching 434 MW by 2023.⁴

India, with its vast network of water bodies and growing solar energy ambitions, is poised to become a global leader in floating solar adoption. As the country continues to explore and implement floating solar projects, it is harnessing the full potential of this renewable energy technology. By leveraging this innovative approach, India can tap into a significant source of clean energy while minimizing land use requirements and mitigating environmental impacts, contributing to a more sustainable future.

India is home to several large-scale floating solar PV projects, highlighting its commitment to renewable energy innovation. The Omkareshwar Floating Solar Power Project in Madhya Pradesh, with a planned capacity of 600 MW, is poised to become the world’s largest floating solar installation. Other notable projects include the fully operational Ramagundam Floating Solar Project in Telangana, which boasts a capacity of 100 MW, and the Kayamkulam Floating Solar Power Plant in Kerala, with a capacity of 92 MW. Additionally, NTPC Limited has developed a 25 MW floating solar unit at the Simhadri Power Plant in Andhra Pradesh and a 20 MW unit at Auraiya in Uttar Pradesh.

Table 1: Some of the Floating Solar PV Projects Commissioned in India

S. N.	Name of the project	Reservoir	Capacity
1	Omkareswar Dam	Omkareswar Reservoir	278 MW* (600 MW)

³ International Energy Agency IEA PVPS (2024): Trends in PV Applications 2024

⁴ Ciel & terre (2024): Floating solar market trends in India a booming source of energy (Accessed on 24-04-2025)

*Out of the 600 MW, 278 MW commissioned

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S. N.	Name of the project	Reservoir	Capacity
2	NTPC Ramagundam	Ramagundam Reservoir	100 MW
3	NTPC Kayamkulam	Backwater	92 MW
4	Simahadri TPP	Simahadri TPP Reservoir	25 MW
5	NTPC Kawas	NTPC Kawas reservoir area	23 MW
6	NTPC Auraiya	NTPC Auraiya Reservoir	20 MW
7	SPIC Thoothukudi	Water Storage Pond at SPIC	14.8 MW
8	Mudasarlova Vizag	Mudasarlova Reservoir	2 MW
9	Water Works Chandigarh	Dhanas Lake	2 MW
10	Banasura Sagar	Banasura Sagar Reservoir	0.5 MW

1.6 Structure of the Guidelines

The guidelines for FPV in India are designed to serve as a comprehensive resource for stakeholders across the FPV ecosystem, including developers, policymakers, researchers, vendors, and financial institutions. Given the current nascent stage of FPV adoption in India, these guidelines aim to address critical aspects of FPV implementation, drawing from global best practices, ongoing-research, and real-life case studies. The document provides an overview of its structure, outlining the key sections and their contents while explaining the logical flow of information. Each section has been carefully designed to contribute to the overall understanding of FPV technology and its implementation.

Key Sections of the Guidelines

- **Design and Installation criteria:** Outlines the essential design pr and considerations necessary for the effective planning and deployment of FPV systems including robust floating structures, PV modules, electrical equipment and advanced anchoring and mooring systems in ensuring the durability, stability, and safety of FPV installations.
- **Performance Aspects:** Analyzes the factors affecting the performance of FPV systems, including operational efficiency, energy output, and maintenance requirements, to maximize long-term reliability and productivity.
- **Environmental Aspects:** Highlights the environmental considerations critical to sustainable FPV deployment, addressing potential impacts and recommending mitigation measures to balance development with ecological preservation.
- **Regulatory and Approval Compliance:** Details the comprehensive regulatory framework and approval processes for FPV projects in India.

Each section of the document is structured, to begin with a concise introduction that outlines the key aspects of the topic. This is followed by an in-depth exploration of best practices and relevant ongoing research, ensuring a comprehensive understanding. The sections conclude with clear, actionable recommendations and illustrative case studies that highlight real-world applications and provide practical insights.

Case studies from global implementations and Indian projects are incorporated to provide practical examples and lessons learned. Recommendations and best practices are consolidated into a cohesive set of actionable measures. The document concludes with a summary of key takeaways, a discussion on the future trajectory of FPV in India, and encouragement for stakeholders to adopt these guidelines to accelerate FPV deployment. This structured and logical approach ensures that the guidelines are both informative and practical, empowering stakeholders to successfully navigate the complexities of FPV implementation in India.

A flowchart illustrating all the major stages of a FPV project, along with the key stakeholders involved at each phase, is presented below. This flowchart provides a clear and structured overview of the end-to-end project lifecycle, from initial planning to decommissioning. Each stage highlights the specific activities involved and the primary parties responsible, ensuring clarity in roles, responsibilities, and coordination throughout the project.

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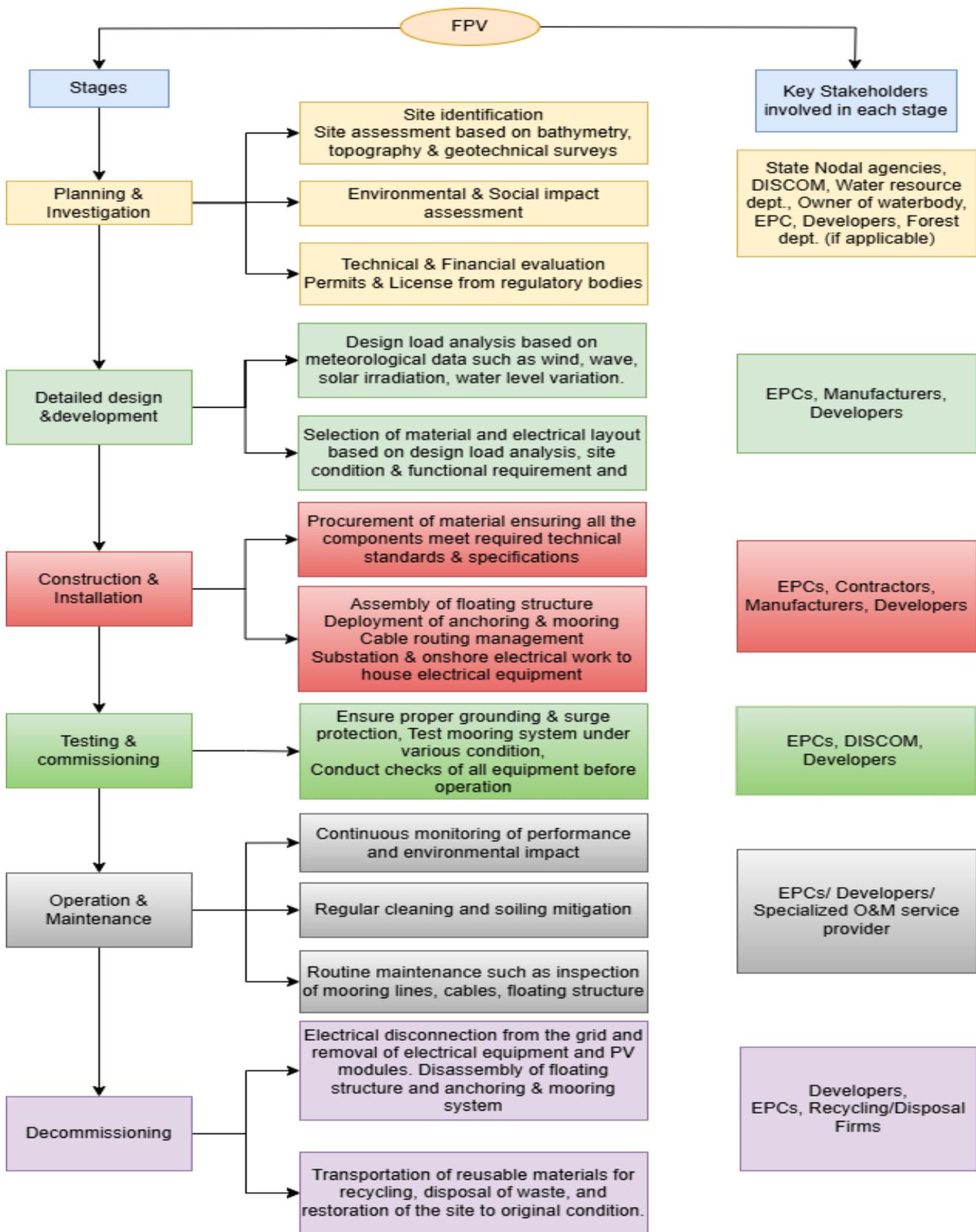
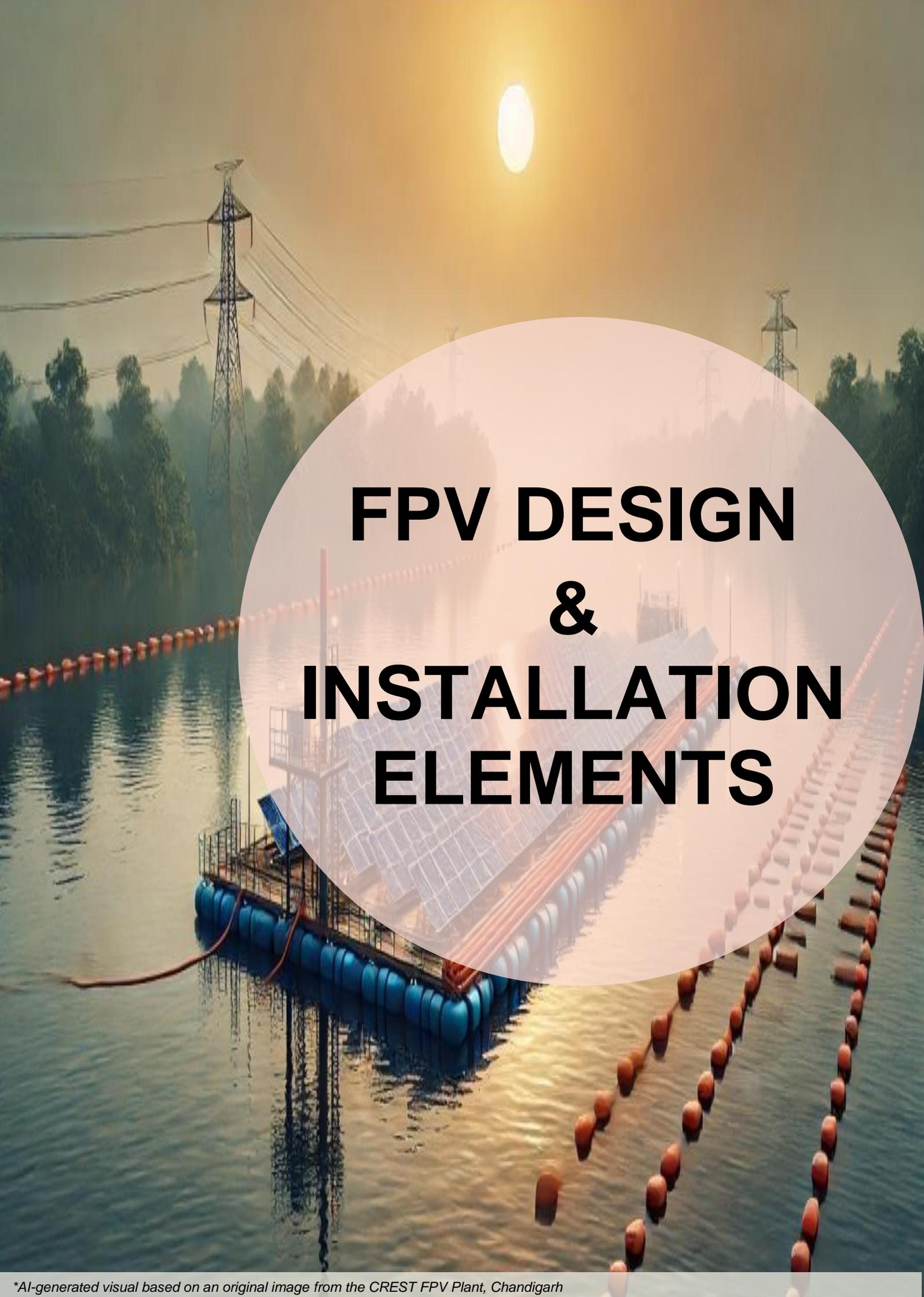


Figure 6: Flowchart of FPV ecosystem

The background image shows a large-scale floating photovoltaic (FPV) plant installation on a body of water. The solar panels are mounted on a platform of blue and red floating buoys. In the distance, there are several high-voltage electrical transmission towers with power lines stretching across the landscape. The scene is captured during a golden hour, with a bright sun low in the sky, creating a warm, hazy atmosphere. The water reflects the sunlight and the structures. A semi-transparent white circle is overlaid on the center of the image, containing the main title text.

FPV DESIGN & INSTALLATION ELEMENTS

2 Design and Installation Elements

The design and installation of a FPV plant involve a series of steps to ensure system stability, efficiency, and longevity. The process begins with a detailed site assessment to analyze the water body characteristics, meteorological conditions, and design load requirements. Based on this evaluation, a customized system is designed to accommodate environmental factors such as wave dynamics, wind loads, and water level variations. Following design approval, the installation phase includes assembling the floating structure, anchoring it securely, and conducting thorough testing. To maintain peak performance and long-term reliability, a maintenance plan is implemented to reduce downtime and address any operational issues.

2.1 Planning & Investigation

Proper site selection is critical for the successful development of a FPV plant and should occur early in the planning phase, before conducting feasibility studies. Early data collection helps project developers assess the project's viability and identify the most suitable or promising locations. It is important to analyze site-specific climatic variations using historical data, as these local conditions play a significant role in the design of the FPV plant. After selecting the site, additional surveys, such as bathymetric studies, geological assessments, and environmental impact evaluations, should be conducted. Securing the necessary licenses, permits, and authorizations for FPV installation can be challenging, especially in areas with complex regulations or limited FPV experience. The permitting process can take anywhere from a few months to several years in some cases. Therefore, it is essential to obtain approval from regulatory bodies before proceeding with the design and installation of the FPV plant. Additionally, proximity to load centers, grid access, and the availability of required permits must be considered. Stages of planning and investigation has been shown below.

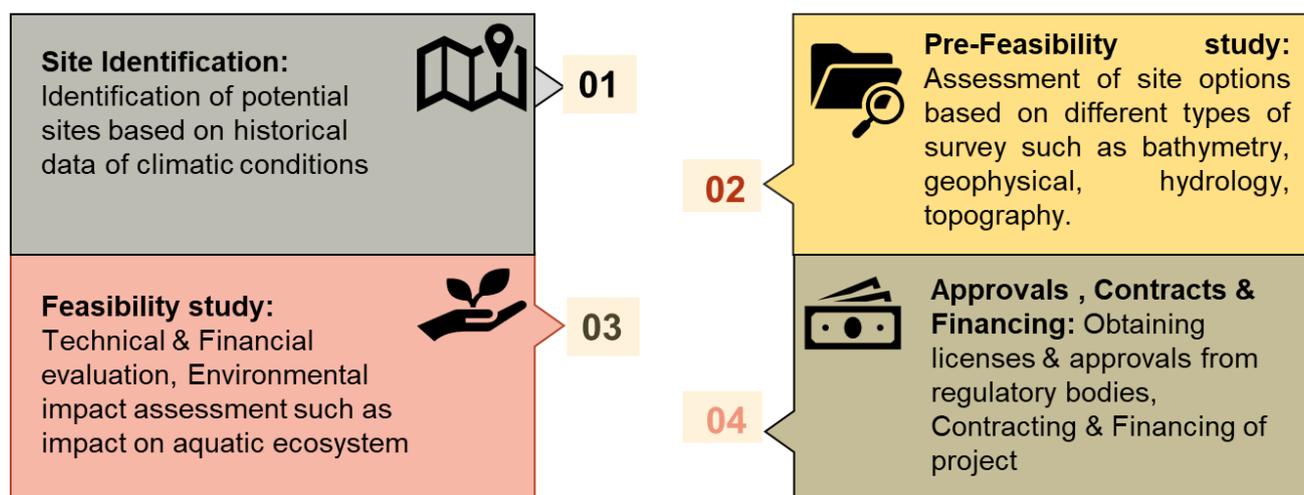


Figure 7: Stages of planning and investigation

2.2 Design Considerations

The design process for FPV systems often involves balancing performance optimization with cost control, with decisions impacting both operational efficiency and financial investment. This section outlines the contribution of site-specific conditions and environmental factors in assessing design loads, along with the techniques employed to measure them. It further discusses the different types of loads that affect the design principles of FPV systems, such as those related to floats, support structures, and station-keeping systems. The design must ensure that the structure:

- Can safely support all expected loads under normal, operating, and damaged conditions.
- Provides safe operation throughout the system's lifespan.
- Protects personnel and the environment.
- Is durable and resistant to deterioration over time.

FPV systems are designed based on their installation environment, which can be either onshore or offshore. Onshore FPV systems are typically placed on calm water bodies like lakes and reservoirs, whereas offshore FPV systems are deployed in coastal or open-sea areas, facing harsher conditions. Differences in water quality, wind speed, wave height, and water depth influence the design, structural requirements, and maintenance of each type. The table below highlights the key differences between onshore and offshore FPV installations.

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Table 2: Comparison of FPV installation in On-shore and Off-shore^{5,6}

Parameter	On-shore FPV Installation	Off-shore FPV installation
Site type	<ul style="list-style-type: none"> Installation of FPV system on water bodies such as industrial ponds, hydropower reservoirs, Lakes 	<ul style="list-style-type: none"> Installation of FPV system in the ocean.
Site condition	<ul style="list-style-type: none"> Generally, experience calmer water conditions with minimal waves and currents. Less exposure to corrosive saltwater, reducing material degradation. 	<ul style="list-style-type: none"> Experience higher waves, stronger currents, and more extreme weather (e.g., storms, typhoons). Exposure to saltwater, which increases corrosion risks of materials.
FPV system design	<ul style="list-style-type: none"> Can use lighter and less robust materials since the environment is less demanding. Anchoring systems are simpler and less expensive. Easier to integrate with existing onshore power grids. 	<ul style="list-style-type: none"> Requires more robust and corrosion-resistant materials to withstand harsh marine conditions. Anchoring and mooring systems must be designed to handle strong waves and currents. May require additional infrastructure to connect to the power grid.
Cost consideration	<ul style="list-style-type: none"> Lower overall costs due to simpler installation, maintenance, and materials. 	<ul style="list-style-type: none"> Higher costs due to need for durable, corrosion-resistant materials and complex installation and maintenance activities.

2.2.1 Site Conditions

The selection of floater technology, mooring system, and electrical configuration for FPV installations is driven by the specific environmental conditions of the site. These conditions—such as type of water body, wind, waves, currents, snow loads, and soil characteristics—play a pivotal role in the design and safety of the installation. Below is a breakdown of how each factor influences the FPV system:

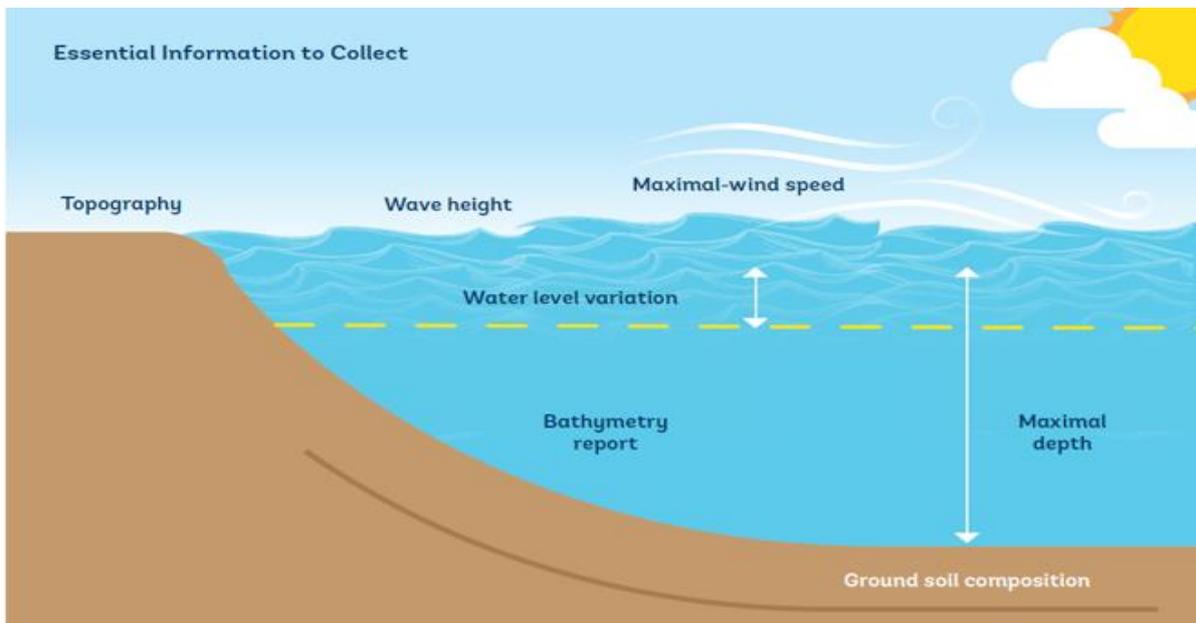


Figure 8: Site conditions affecting design of FPV system

Source: [The World Bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

⁵ [National Renewable Energy Laboratory NREL \(Oct 2021\): Floating Photovoltaic System Cost Benchmark: Q1 2021 Installations on Artificial Water Bodies](#)

⁶ [Energies \(Nov 2022\): Design and Analysis of a Floating Photovoltaic System for Offshore Installation: The Case Study of Lampedusa](#)

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A. Water body characteristics:

Choosing an optimal water body for FPV plant installations involves assessing several key characteristics. Calm waters with **low wave activity and stable water levels** ensure the **stability of floating structures**. Adequate water depth is necessary for proper anchoring, while shallow areas should be avoided due to sedimentation risks. Hydrological conditions and the **size and shape of the water body** are also important for maximizing energy output and minimizing ecological disruption.

FPV plants are typically installed on **artificial water bodies** due to their stable water levels and large surface areas. These include **reservoirs, irrigation ponds, storage ponds, and retention ponds**. For example, in China, many FPV plants are in unused mining ponds. In countries like Japan, South Korea, and the UK, irrigation ponds serve as the primary sites for these plants. In India, the Ramagundam Floating PV plant covers an extensive 500-acre reservoir, while the Omkareshwar FPV plant is set up on a dam.

- **Surface area of Water bodies:**

The surface coverage area of a FPV plant significantly impacts its efficiency, environmental effects, and the usability of the water body. The percentage of coverage is determined based on factors such as the water body type, intended purpose (e.g., irrigation, drinking water, hydropower), and environmental considerations.

In a case study conducted at the **Rapel Reservoir** in central Chile by **J. Haas et al.**, it was observed that for solar module covering **less than 40% of the area**, there is **minimal or no effect** on microalgal growth and hydropower revenue. With **moderate coverage (40–60%)**, solar modules effectively **prevent algal blooms by reducing light penetration**, which limits algal growth, without causing major economic losses in hydropower production. However, excessive coverage can eliminate algal blooms, which may harm the ecosystem and lead to significant financial losses in hydropower generation.⁷

Table 3: Surface area coverage by different types of water bodies

Country	Type of Waterbody	Surface area coverage %
China	Irrigation pond	10-30
	Large water bodies	10-40
	Mining ponds	10-20
Japan	Irrigation ponds	10-70
	Water storage Reservoir	15-86
UK	Lakes	2-15
	Water treatment plant	48

In **Germany**, the current legal limit for surface area coverage by FPV plants on water bodies is **15%**, as stipulated by the **Renewable Energy Sources Act (EEG) and Water Resources Act**. For **freshwater bodies**, the surface coverage percentage for FPV installations can be typically ranges from **10% to 40%**, based on **existing projects**, considering the **water body's type, and intended use**. For **water bodies** like mining ponds which cannot be used for drinking purpose or having very bad quality, up to **70-80%** of the surface can be covered, with a portion left open to facilitate cleaning and maintenance. This range balances energy generation with **ecological preservation, water usability, and operational efficiency**, ensuring sustainable and effective deployment of FPV systems. This should be considered during the site assessment from an **environmental impact perspective**.

- **Water depth and water level fluctuation:**

The water depth at the site, including its variations, should be determined following **ISO 19901-1-2015** guidelines. **Water level fluctuations in shallow areas** should be carefully considered due to their larger impact, such as the risk of **stranding or wave breaking**, compared to their minor effect in deep water.

⁷ [Energy conversion and management \(Feb 2020\): Floating photovoltaic plants: Ecological impacts versus hydropower operation flexibility.](#)

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Water level fluctuation due to natural events in Changbin 192MWp project, Taiwan: the water level on-site varies **twice a day**, implying constant adaptation of the floating solar solution. Between the rise and fall of water in this area, the **maximum observed difference is 5m** when the lowest level requires the power station to lie entirely on the ground. A **specific anchoring design** has been done to withstand this variation⁸.

Table 4: Water depth and water level fluctuation in different FPV plant

FPV plant ¹⁴	Type of Waterbody	Water depth (meters)	Water level fluctuation (meters)
220 kWp Alto Rabagao, Portugal	Hydro dam	50	30
1,005 kWp Sobradinho, Brazil	Hydro dam	29.3	13
192 MWp, Cirata Floating Solar Project, Indonesia	Reservoir	100	18

Based on the table above, there is **no specified maximum water level** for installing FPV systems. However, different suppliers **set minimum water level requirements** for installation. For instance, consultation with selected players indicated **minimum water level is 1 to 2 meters** for the installation of the FPV system. Below this level, the system may come into contact with the ground, leading to potential exposure to debris and dust, which could reduce the efficiency of PV modules and cause damage to both the platform and the modules.

FPV systems are designed to handle **varying water level fluctuations**, with tolerances depending on project requirements and environmental conditions. Stakeholder discussions suggest that **greater water depth or significant fluctuations** necessitate additional space for movement, which may reduce the plant’s effective capacity. Anchoring and mooring system design is critical in managing these fluctuations, requiring careful consideration of site-specific conditions to ensure stability and performance. **Elastic mooring** is preferred for **extreme water level variations** where water level **fluctuation is very high**. This mooring type can stretch up to twice its length, ensuring **balanced load distribution**. However, its **high cost** and reliance on **imports limit** its widespread adoption. For sites with **minimal water level variation**, **taut mooring** is a suitable alternative. In drought conditions, when water levels drop significantly, FPV systems may rest on the ground, emphasizing the need for adaptable designs to maintain efficiency and reduce downtime.

Bathymetry is a critical factor in site selection for floating solar islands and in the design of mooring and anchoring systems. It involves mapping the depth and contours of the waterbed to assess the size, shape, and distribution of underwater features. To optimize the anchoring system design, it is recommended to conduct high-resolution bathymetric surveys with a **grid spacing of 5 meters**.

Rectangular or square water bodies are ideal for maximizing space utilization, whereas irregularly shaped bodies may offer less area for installation. Obstacles like bridges, islands, pipelines, and cables can further reduce available space.

B. Soil conditions:

To design station-keeping systems, such as anchors and mooring lines, for FPV systems, it is crucial to define the soil conditions at the project site. These studies should assess the characteristics of rock or soil formations, which are essential for supporting structures and foundations. The combination of **geological and geophysical**, data should be used to create a ground model that provides all the necessary soil information for detailed geotechnical design, particularly for the **anchoring systems**. The ground model should account for the depth below the waterbed and focus on the soil layers most relevant for the interaction between anchors and the soil.

C. Wind:

For the safe design of FPV systems, it is crucial to specify **both operational and extreme wind conditions**. Wind loads are particularly important for FPV systems, as wind can come from any direction and is difficult to predict. Although the panels have a relatively low profile, their **large surface area interacts with the wind**, generating **lift forces** that can create dangerous moments, potentially causing the **system to overturn**. This makes understanding the effects of wind on FPV systems essential.

⁸ [Ciel & Terre: Water level variations drought how does floating solar meet the challenge \(Accessed on 24-04-2025\)](#)

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Case study: Yamakura Dam, Japan: A recent example of wind-related failure occurred in September 2019, when Typhoon Faxai struck Japan's largest floating solar plant at Yamakura Dam⁹. With a surface area of approximately 18,000 m² and a maximum output of 13.7 MW, the plant **suffered severe damage from 120 mph winds**. The strong winds caused the modular FPV panels to stack on top of each other, leading to **structural collisions that resulted in power system failure**, overheating of about 50 panels, and a fire. This incident highlights the urgent need for more comprehensive wind-structure interaction studies to ensure the safety and stability of FPV systems.

Also, a key finding from the Yamakura incident was the **non-geometrical nature** of the islands, which underscored the need for redesigning floating structures. As a result, the Yamakura FPV was rebuilt with a new design featuring **rectangular islands instead of irregular shapes**. This adjustment helps **reduce stress concentration and deviation**, minimizing the risk of localized failures that could impact the entire system.

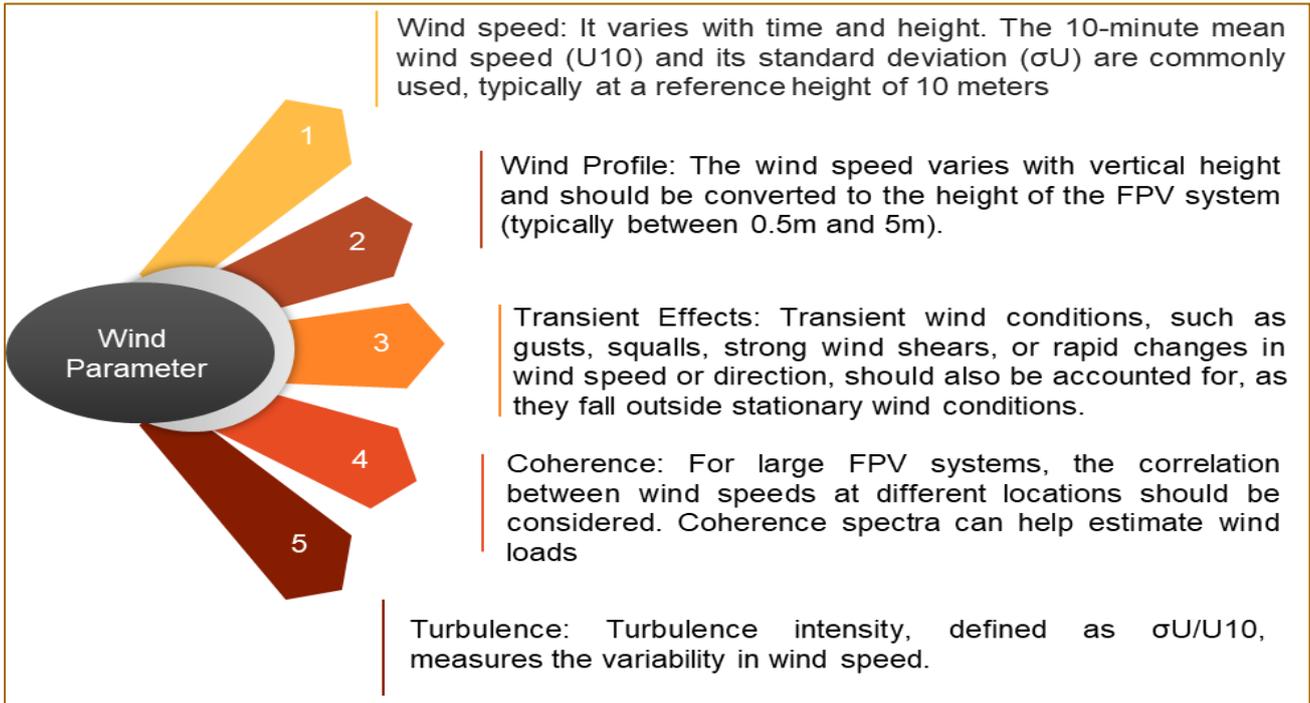


Figure 9: Wind parameters affecting the FPV system

Wind loads are typically measured in two directions: **streamwise**, which corresponds to **drag forces**, and **vertical**, which corresponds to **lift forces**. Drag forces are influenced by the drag coefficient, the projected area of the panels in the wind direction, and the square of the wind speed. In windy environments, large drag forces can cause significant structural drift, increase mooring tensions, and overlap of connected components. Lift forces, on the other hand, are particularly important for floating systems as they affect the balance between buoyancy and gravity, potentially leading to overturning or submersion of the structure. To facilitate the safe design of FPV systems, it is essential to specify extreme wind conditions and apply best practices like [DNVGL-RP-C205 Sec. 2](#), adjusting them to the specific site conditions to ensure accurate assessments.

Table 5: Types of wind load

Load type	Load effects
Global Wind Loads	These affect the mooring system and stress concentration between floats, as well as causing uplift of the floats.
Local Wind Effects	Wind pressure acts normally on surfaces, with frictional drag also considered for large areas. For individual components, time-averaged wind speed is used, but short-duration gusts (e.g., 3-second wind speed) are critical for component checks.

⁹ [PV magazine \(Jan 2021\): Japan largest floating pv plant reconstructed after typhoon impact](#)

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Load type	Load effects
Dynamic Effects	Wind-induced dynamic loads can cause low-frequency resonant motions in moored installations. Wind spectrum should be modelled, accounting for spatial dependency, especially in large systems.
Shielding Effects	For multi-body systems, shielding from neighbouring floats may reduce wind loads. This can be modelled by scaling wind coefficients based on the distance between floats or using wind tunnel tests/CFD calculations. The sheltering between FPV arrays should also be assessed.

To assess wind loads on a floating structure, wind force coefficients for drag, lift, and pressure should be determined. These coefficients, typically given as a load per unit of wind velocity, can be calculated using methods like analytical formulas given in [DNVGL-RP-C205\(2017 edition\)](#), wind tunnel tests, or Computational Fluid Dynamics. The choice of method depends on the required accuracy and complexity of the structure.

Hyung-Joong Joo et al. conducted a study on the **impact of wind load distribution on FPV systems**, using CFD analysis to evaluate variables such as **wind direction and wind speeds** (36.2, 51.7, and 70.7 m/s) on PV modules in floating structures. The study confirmed that **wind load differences** of up to 26% were observed between the **load acting in the rear** and the **load acting in the front**, depending on the wind direction.¹⁰

Chin-Cheng Chou et al. conducted a study to examine the impact of wind loads on solar panels at high tilt angles. In their research, the **tilt angle of a single panel was varied between 10° and 80°**, and the wind incidence angle was adjusted from 0° to 180°, reflecting conditions relevant to offshore photovoltaic panels. The study found that **the most critical wind loads** on a tilted panel occurred **at lower wind incidence angles**, especially when the **panel's tilt angle exceeded 30°**.¹¹

Based on the above case studies, it is observed that when wind speed originates from the front, the wind pressure on the PV module was found to be higher than when the wind comes from the rear. Based on these findings, lower angle of tilt is preferred to withstand wind resistance. Stakeholder discussions further suggest that a lower tilt angle of **5° to 7°** provides **better resistance to high wind speeds compared to steeper angles**. In higher-altitude regions of India, FPV plants have been installed with a **5° tilt angle**. Additionally, the anchoring and mooring system should be designed using historical wind speed data from the specific site over the past **50 years** to ensure stability and durability.

D. Wave

Waves can induce both in-plane and out-of-plane movements in floating structures, with FPV systems typically following the wave motion at low frequencies. However, at higher wave frequencies, increased stiffness may lead to more complex interactions that could compromise the structural integrity of the floats and solar panels. Additionally, high-frequency waves can cause bending in membrane-based FPV platforms, potentially resulting in fatigue over time. The design must incorporate materials and structures capable of flexibly responding to wave movements while maintaining stability and durability. Wave conditions impacting FPV systems can be categorized into regular waves and irregular waves, each requiring distinct analytical approaches:

- **Regular Waves:** Characterized by a consistent shape, wavelength, period, and height, regular waves are useful for modeling specific scenarios such as extreme events (e.g., tsunamis, underwater landslides) or vessel-induced waves. They also help in representing the largest deterministic wave in an irregular wave time series, which is relevant for quasi-static structural analysis. In shallow or steep wave environments, advanced nonlinear wave models are recommended to account for wave asymmetry and its effects on FPV structures.
- **Irregular Waves:** Generated by wind disturbances, irregular waves vary in height, shape, and propagation speed. These waves are described using wave spectra that distribute energy across different frequencies. The key components include:
 - I. **Wind Sea:** Short, wind-driven waves that are particularly relevant for inland water bodies and coastal regions.
 - II. **Swell:** Long-period waves generated by distant storms, which can propagate to coastal areas and impact FPV systems.

¹⁰ [Applied science \(Nov 2023\): Wind Load Distribution in Float Photovoltaic System](#)

¹¹ [Applied science \(April 2019\): Wind Loads on a Solar Panel at High Tilt Angles](#)

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For locations with short fetch distances and low wind speeds, wave impacts may be minimal, reducing the need for detailed analysis. However, for areas with prolonged wind exposure and extended fetch lengths, irregular wave analysis becomes crucial.

FPV systems experience dynamic interactions with wave forces under both normal operational and extreme conditions:

- **Operational Conditions:** Under typical wave conditions, low-frequency waves primarily influence FPV system motion. The system's buoyancy and mooring configurations must accommodate these movements to ensure structural stability. Flexible mooring solutions and durable materials are essential to mitigate fatigue-related issues caused by continuous wave exposure.
- **Extreme Conditions:** In high-frequency wave environments, increased system stiffness can lead to structural stress and potential damage. Extreme wave events, including tsunamis, storm surges, and underwater landslides, pose significant risks, particularly in coastal and reservoir locations. Additionally, breaking waves can exert substantial impact forces, necessitating reinforced structural designs.

Advanced wave spectrum analysis, including JONSWAP and TMA models, is critical for optimizing the structural resilience of FPV systems. This ensures that mooring strategies, buoyancy control, and material selection are aligned with site-specific wave conditions, ultimately enhancing long-term system performance and reliability.

Main wave load contributions include:

- **Wave Drift Loads:** Slowly varying forces from difference-frequency effects in irregular waves, proportional to the square of the wave amplitude, and occurring at lower frequencies.
- **Drag Loads:** Due to the relative velocity between the floating structure and water, caused by viscous effects.

Additionally, moving floating bodies experience added mass and damping from radiating waves. Other loads such as slamming, wave impacts, and green water due to overtopping may also need consideration. Various methods are available to assess wave loads on floating structures such as Morison load formula, Boundary element method and CFD. Drag and inertia coefficients for floating elements should be derived, with reference to [DNVGL-RP-C205 \(2017 edition\)\(Appendices D and E\)](#). For more accurate modelling for FPVs, multibody dynamics with connections using suitable boundary conditions is to be strictly taken in consideration for a holistic reliable transportation analysis, especially when wave loads are critical. Hydrodynamic interaction between floats can also be studied using numerical methods based on potential flow or scaled wave tank models.

Detai zou et. Al. developed a time-domain simulation model to predict the wave-induced motions and loading of FPV units in heading and oblique waves, first without a breakwater and then with one. The model was validated through experiments and showed that **a breakwater could reduce wave-induced motion by up to 56% and loading on the joints between FPV units by up to 55%.**¹²

Omkareshwar floating solar project, India: wave breakers are incorporated to reduce wave energy impacting the floating solar panels. By dissipating wave forces, these structures help maintain the alignment of solar modules, ensuring optimal energy capture and minimizing mechanical stress on the installation¹³.

FPV systems of **Ciel & Terre** are designed to cope with **waves up to 2m high with wave breaker installed.**¹⁴

SolarDuck has developed a unique floating technology called Merganser, in which **a semi-triangular structure with three interconnected floats**¹⁵, designed to endure harsh offshore conditions such as strong winds, waves, and currents. It can withstand **wave height more than 5m.**

Case studies indicate that introducing **wave breakers—especially in large reservoirs**—can help mitigate wave impacts and reduce cyclic loading on floating structures. To support effective design practices, it is recommended that industry standards be established to classify reservoirs as small or large based on factors such as surface area, exposure, and wind velocity. Minimizing wave impact not only enhances energy generation efficiency but also reduces wear on the mechanical components of FPV systems. However, some floating structures, made from a combination of steel and HDPE, are designed to withstand both wind and wave forces, making wave breakers unnecessary in such cases. The decision to use a wave breaker in an FPV system is primarily dependent on the site's conditions. If the wave height at a particular location exceeds the

¹² [Physics of fluids \(Nov 2024\): Effects of a breakwater on a floating solar farm in heading and oblique waves](#)

¹³ [Times of India \(Aug 2024\): World's largest 600 MW floating solar plant to power omkareshwar](#)

¹⁴ [Ciel & Terre: Solutions per site characteristics \(Accessed on 24-04-2025\)](#)

¹⁵ [Solar Duck: Unique solution \(Accessed on 24-04-2025\)](#)

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threshold that the floating structure can handle, a wave breaker is recommended. Otherwise, it may not be necessary.

E. Water Current:

For the design of a FPV system, data on water currents must be collected, and additional measurements should be conducted where necessary. The parameters such as water current directions, water velocity profile, water velocity and probability of exceedance (particularly during flood) should be considered for design.

Key impacts of current on FPV system:

- **Structural stability:** Water currents exert forces on floating structures, potentially causing drift or instability. Effective mooring and anchoring systems must be designed to withstand these forces, ensuring secure positioning of the platforms.
- **Energy efficiency:** Wave-current interactions can create complex motion patterns that affect the stability of the system, leading to misalignment of solar panels and reduced energy efficiency. Currents can also tilt the panels, further decreasing energy production.
- **Maintenance** can be challenging due to strong currents, making access difficult and increasing operational costs.

Current forces acting on the FPV system, particularly on the submerged parts like floats and mooring lines, need to be considered. Current typically results in static loading on the system. Current force coefficients can be determined by analytical formulas, wind tunnel tests, Water basin/towing tank tests and CFD. For multi-body floating systems, shielding effects due to current may also be important, and guidance available in [DNVGL-RP-C205 \(2017 edition\)](#) can be referred.

F. Snow and Ice Accumulation

The impact of snowfall and other forms of precipitation on the FPV system must be evaluated, with particular focus on the effects of ice around and beneath the system. The two main areas of concern are:¹

- The interaction of ice with the FPV system and its components
- The horizontal loads on the structure due to ice

Ice thickness is a critical factor in calculating ice loads. In addition to ice thickness, the ice bulk salinity, ice brine volume, ice porosity, ice temperature, ice density, ice strength and ice flow velocity should be considered for design. Water icing can become a concern when water temperatures drop below -2°C. However, floating ice masses formed in colder areas can persist in warmer waters. When considering ice accumulation on a structure, factors such as wind strength and air temperature are crucial, although icing typically does not occur until water surface temperatures fall below 4°C.

Heilongjiang Province, China: Sungrow Floating has installed a 500-kW floating photovoltaic array on a lake that freezes for about four months each year, with winter temperatures reaching -20°C. During this freezing period, the entire PV array becomes encased in ice. The system is specifically designed to withstand these conditions, with the **array anchored to the ice layer, which can shift in thickness**. The anchorage system is installed before the lake freezes, and special ice-breaking plans are implemented for installation during freezing periods. The anchorage is built to endure frost heave and ice pressure, utilizing **concrete piles or gravity anchors** underwater to resist frost heaving, while **shore anchors account for the impacts of freezing and floating ice**. High snow loads in these regions further require specialized anchoring materials and more time-consuming construction, **leading to higher costs compared to conventional floating PV projects**.¹⁶

To ensure resilience in snow and ice conditions, FPV systems employ durable anchorage designs, specialized installation techniques, enhanced buoyancy-to-weight ratios, extensive testing, and continuous performance monitoring.

G. Earthquakes

The seismic activity of the area where the FPV system is to be installed should be evaluated in accordance with local seismic codes or historical earthquake data, typically including frequency and magnitude details. In India, **IS 1893 (Part 1: 2016)** provides guidance for the earthquake-resistant design of structures. While seismic loads

¹⁶ [PV magazine \(Jan 2021\): What happens to floating PV when the water surface freezes](#)

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may generally be minimal compared to wind and wave loads, they must still be considered for FPV systems in earthquake-prone zones.

2.2.2 Measurement Instrumentation

To reduce uncertainty in FPV projects, it is recommended to deploy a meteorological measurement station for at least 12 months. High data coverage is preferred (85% or higher), though quality and site-specific factors may influence this requirement. The station should record:

Table 6: Measuring instruments

Parameters	Measurement	Standards
Irradiance	Pyranometers measure solar irradiance incident on the PV modules. Pyranometers used should be class A.	ISO 9060 ISO 9846
Wind Speed and Direction	Wind speed and direction should be measured using class 1 anemometers and wind vanes or validated ultrasonic sensors.	IEC 61400-12
Wave	Wave buoys or pressure sensors are used to measure wave height, period, and direction.	ISO 17357
PV Module Temperature	Temperature sensors for PV modules (e.g., PT100/1000 thermocouples or resistance thermometers) should measure between -40°C to 150°C with an accuracy of class B.	IEC 61215
Relative Humidity	Hygrometers or humidity sensors measure the relative humidity in the environment surrounding the FPV system. Relative humidity should be measured with a capacitive sensor, with a range of 0-100% and an accuracy of $\pm 3\%$.	ISO 13788
Water Temperature	Water temperature probes should be used at depths of 1 meter or shallower. Sensors should be suitable for saline environments when applicable, with a measuring range from -5°C to 70°C and an accuracy of $\pm 0.15^\circ\text{C}$.	ISO 5667-3
Current	Currents are measured using current meters, ADCPs (Acoustic Doppler Current Profilers).	ISO 11058
Soiling	Optical sensors are used to assess the level of soiling on PV modules by measuring the amount of reflected light from the panels. A soiling station is recommended for sites with significant dust or bird droppings exposure.	ISO 18434

FPV systems operate in dynamic aquatic environments where waves, wind, and currents significantly impact their stability and efficiency. Unlike land-based solar installations, FPV structures are subject to continuous hydrodynamic forces, making physical modelling essential for evaluating their performance under site-specific conditions. By replicating real-world scenarios in a controlled environment, model testing helps assess structural integrity, stability, and mooring system efficiency.

2.2.3 Design Load

An FPV system and its components must be designed to a **specified design life**, ensuring they provide an acceptable level of safety throughout their operation. The design should consider limit state principles, including Ultimate Limit States (ULS) for maximum load-bearing capacity, Accidental Limit States (ALS) for survival under damage or abnormal conditions, Fatigue Limit States (FLS) for failure due to cyclic loading, and Serviceability Limit States (SLS) for conditions affecting the structure's functionality or comfort. Corrosion and degradation impacts must be incorporated into all limit states, with worst-case scenarios for ULS, ALS, and SLS, while FLS conditions should account for average degradation over time. These considerations ensure the system remains safe, functional, and durable throughout its service life.

During the design and analysis of Floating Photovoltaic (FPV) systems, both static and dynamic load assessments are essential for ensuring stability and performance under various conditions. Static load assessments are useful for local wind pressure loads and determining float dimensions and mooring line quantities, while dynamic effects, including dynamic amplification factors (DAF), should be considered for more complex structures or harsh environmental conditions. In regions with severe conditions, a fully dynamic analysis is recommended.

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- Installation Phase Analysis involves regular and irregular wave analysis, modal analysis for dynamic resonance, and installation tolerance checks. Additionally, a dropped object study is important.
- Operation Stage Analysis focuses on permanent loads, marine growth effects, and extreme case analysis for evaluating system performance in harsh conditions. Fatigue analysis, impact from vessel wake waves, and the potential for green water and slamming effects should be considered. Further analysis includes modelling float interactions, studying vortex-induced motion between floats, and ensuring mooring lines don't interfere with maintenance operations.

Global motions, mooring tensions, and forces at float connections are essential inputs for detailed structural assessments, accounting for flexible modes and vertical relative motions. Stresses and forces should be compared to design reports, and DAF should not exceed limits. The model must accurately represent the FPV system's dimensions, weight, and centre of gravity.

The partial safety factor method ensures a target safety level by applying load and resistance factors to characteristic values of governing variables, which include loads and resistance of the structure. The design criterion is met when the design load effect does not exceed the design resistance (Rd). Sd is calculated by multiplying the characteristic load effect by a load factor, while Rd is derived by dividing the characteristic resistance by a material factor. The characteristic values are determined from probability distributions based on the limit state (e.g., ULS, FLS, SLS, ALS).

This section outlines the loads, load components, and load combinations that must be considered in the comprehensive strength analysis for the design of floating support structures and moorings for FPV systems. The site conditions have an impact on the modelling of design load.

Table 7: Types of Loads to Consider While Designing FPV System¹⁷

Type of Load	Description
Permanent Load	These loads include the weight of the structure. Installed components, such as PV modules, cables, and other equipment, contribute to permanent loads.
Variable Load	These include loads on access walkways, boat impacts from service vessels during normal operations, and additional loads from workers and movable equipment on the structure.
Environmental Load	Environmental loads are those caused by wind, wave (the design conditions to be selected based on the fetch area), current, snow, and ice, and all potential environmental loads must be assessed unless it can be proven that a specific load is insignificant or irrelevant to the location. Extreme events must also be considered, including extreme water levels (such as those caused by storm surges or floods), earthquakes, excessive accumulation of snow and ice, and transient wind loads.
Accidental Load	These loads include impacts from unintended collisions by vessels or debris, loss of buoyancy, loss of mooring line(s), and dropped objects. Such loads are considered during the design process to account for potentially damaging scenarios that may affect the structure's integrity.
Deformation Load	These include temperature-induced loads, which occur due to changes in temperature, creep-related loads that arise over time as materials gradually deform under sustained stress, and settlements of foundations, such as those related to anchor movements.

For detailed modelling of environmental loads, following documents can be referred:

Type of load	Reference documents
Wind load	DNVGL-RP-C205, DNVGL-RP-0584

¹⁷ [DNV GL \(2021\): Design, development, and operation of floating solar photovoltaic systems](#)

Type of load	Reference documents
Wave load	DNVGL-RP-C205 Sec.3, ISO 19901-1 (2015), appendix A.5, Shore Protection Manual volume 1-1 (1984), chapter 3, Coastal Engineering Manual – Part II (2015), IEC TS 62600-2, Section 6.
Current Load	DNVGL-RP-C205, DNVGL-RP-0584

2.3 Design Criteria for Floating Structure

This section presents the design and testing requirements for the materials and subassemblies of floating structure based on their functional requirement. Floats in a floating structure are essential for keeping power-generating equipment afloat and providing access to it. The equipment that may be mounted on these floats includes PV modules, inverters, transformers, cables, combiner boxes (or other cabinets, such as monitoring cabinets), and mounting structures. Additionally, an FPV array will incorporate floats for walkways and may also use floats for mooring purposes. Individual floats or groups of floats can support multiple pieces of equipment or serve different functions within the system.

The design of a floating platform for PV systems is project-specific and depends on several factors, including the scale of the project, water body characteristics, and environmental considerations. Key aspects include the maximum coverage of the water body, the suitability of the waterbed or banks, cable routing for protection, and the desired functions (e.g., maximizing evaporative cooling or minimizing water evaporation). Additionally, compatibility with PV module types and inverters, accessibility for maintenance, deployment speed, and layout configurations all influence the design, cost, and O&M efficiency of the FPV system. PV modules are typically tested to last **20 to 25 years**. Similarly, float structures should be **durable enough to match the lifespan of a PV plant to avoid high maintenance and replacement costs** that could undermine project economics.

2.3.1 Types of Floater Technologies

Floater technologies can be broadly categorized into three types based on structural design.

Table 8: Types of Floater technologies^{18,19}

Type	Pure float	Modular Raft	Membrane
Description	 <p>Characterized by the direct mounting of PV modules onto floats made from HDPE. The floats are typically connected using pins or bolts and are composed of primary and secondary floats.</p>	 <p>Designed such as structural framework is used to support PV modules. Typically use HDPE pipes for buoyancy and steel or aluminum rafts to maintain the optimal tilt angle for PV modules</p>	 <p>PV modules attached to reinforced membrane with tubular ring to provide buoyancy support.</p>
Potential benefits	<ul style="list-style-type: none"> • Low installation cost • Modular design • good buoyancy • corrosion resistant 	<ul style="list-style-type: none"> • High buoyancy • Easy installation • Proven stability (e.g., Suvareto project). 	<ul style="list-style-type: none"> • Easy to transport. • reduction of wave and wind effects on the system

¹⁸ [Taiyangnews \(2024\): Market Survey Floating Solar 2024_V01](#)

¹⁹ [The World bank \(2023\): Unlocking floating solar photovoltaics potential in India](#)

Type	Pure float	Modular Raft	Membrane
Challenges	<ul style="list-style-type: none"> Vulnerable to wind, wave, and storm stresses Difficult to integrate tracking mechanisms. 	<ul style="list-style-type: none"> Does not fully cover the water surface. Limiting evaporation reduction 	<ul style="list-style-type: none"> Biofouling increases the need of maintenance. Expand or contract with temperature changes, causing wear

2.3.2 Functional Requirements for Floating Structure

- Float Performance and Structural Integrity:** The float must remain afloat and stable, providing adequate buoyancy for the entire duration of its designed lifetime. It should be durable, maintaining its structural integrity at the designated location throughout the service life. Additionally, the float must be capable of withstanding hydrodynamic and wind forces specific to the location, ensuring reliable performance under these conditions for its full lifetime.
- Support for Equipment:** The float must have sufficient strength to transfer all applied forces without failure, ensuring the stability of the system. It should also ensure that the PV modules and their frameworks remain securely fixed in place, even under the expected loads.
- Maintenance Accessibility:** All equipment, connections, and joints within the mounting structure must be easily accessible for inspection and maintenance. The float should be designed to allow for the replacement of components without affecting the operation of neighboring floats. Additionally, it must ensure that walkways which are not meant to be submerged, remain above the water level, providing unrestricted access to adjacent floats.

2.3.3 Impact of Loads on Floating Structure

To ensure reliability, these structures must be capable of withstanding the most severe design conditions throughout their entire lifespan without failure or the need for major repairs. In addition to installation and O&M requirements, the selection and design of floaters should take into account key site conditions that contribute to environmental loads, as illustrated in the following figure:



Figure 10: Site conditions affecting floating structure

Case studies demonstrating impact of Loads on FPV system

Omkareshwar Dam, India: At April 2024, the plant experienced significant damage during a storm with **winds reaching 50 km/h**. The storm caused substantial harm to solar panels and equipment. The solar panels are linked to floaters that are strategically placed on the water’s surface. To protect the panels from damage caused by changes in water flow or level, the floaters are firmly fastened together.

SERIS testbed: Effect of loads on Floating platform: In 2016, Solar Energy Research Institute of Singapore (SERIS) designed and installed the world’s largest floating solar PV testbed, with a capacity of 1 MWp at Tengeh Reservoir in Singapore. SERIS conducted comprehensive research, performed in-depth analysis, and monitored over 500 parameters on the testbed. Mechanical stress and fatigue are critical considerations for

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the durability and reliability of floating PV installations. The joints connecting various parts of the floating structure are especially vulnerable due to constant motion caused by water currents, wind, and other environmental factors. Over time, the repetitive movement can lead to wear and tear, potentially resulting in failures at these connection points. The stress/fatigue developed on floating platform from SERIS test bed have resulted in wear and tear as shown below

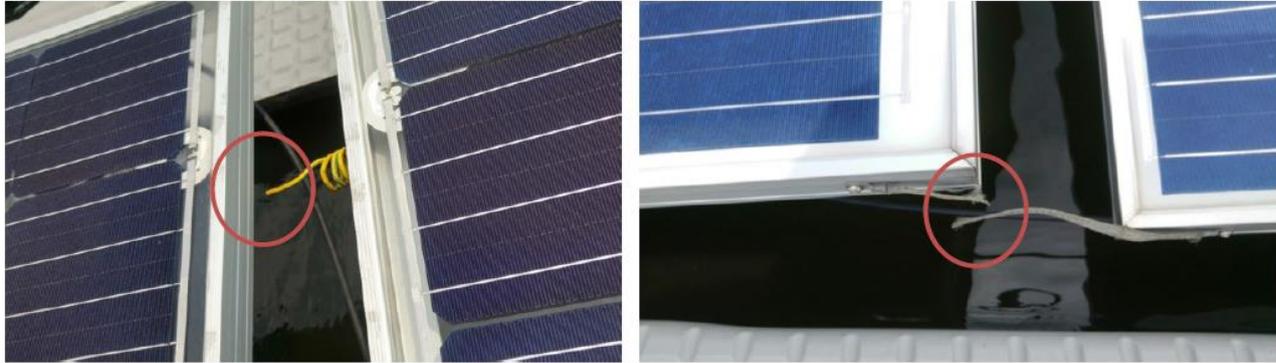


Figure11: Breaking and snapping of connecting wires due to mechanical stress²⁰

As the floats and module mounting structures form the backbone of the entire system, they are designed to serve as permanent components throughout their intended lifespan. Consequently, these structures must be capable of withstanding the most extreme design loads expected during their service life, without failure or the need for major repairs or maintenance. The mounting systems should have flexible joints to absorb wave-induced motions of PV modules. It is critical that the potential degradation or deterioration of the materials is considered during the design phase to ensure long-term performance and reliability.

2.3.4 Material Requirements

Floats can be made from single or combined materials, all of which must meet material requirements. Common materials used in floats include -

- Synthetic Polymers: Lightweight and easy to assemble, especially in modular designs such as HDPE, PE.
- Metals: Provide rigid floating solutions, especially in modular raft FPV array such as Aluminum, Stainless Steel, Carbon Steel (with corrosion-resistant coating).
- Other Materials: Other materials may be used if they meet performance requirements, such as Polyurethane Foam, Fiberglass with epoxy or polyester resin, Ferrocement and composite materials.

The materials selected for the fabrication of the floats must meet the minimum requirements for the following properties under all applicable design conditions.

A. Durability and Impact Resistance:

Ensure material is adequate to withstand the stresses from wave, wind action, operational load, and the weight of the floating PV panels **throughout its design life**. The floats and their interconnections should be capable of resisting impacts or shocks that may arise during installation or operation, including those from floating debris, boats docking, or rocks on the reservoir floor.

14.5 MWp FPV plant in Weperpolder, Netherlands: Floats are connected to a **stainless-steel frame**, ensuring **mechanical strength and corrosion resistance** while keeping **material costs low**. The structure accommodates 12 photovoltaic panels per platform. Additionally, a gangway positioned between two floats along the platform's front side enables easy access for operations and maintenance (O&M) activities. The modular design allows several platforms to be connected, forming continuous walkways that provide convenient access for servicing the array panels. The platform developed by the German company BayWa r.e. aims to maximize structural strength while **minimizing both costs and environmental impact**.²¹

Effect of extreme conditions like harsh wind and wave action on prototype float structure at Büyükçekmece Lake in Istanbul, Turkey: Kaymak et al. conducted an assessment on the structural integrity of **steel-frame type floating photovoltaic (FPV) systems** installed on Büyükçekmece Lake in

²⁰ [The World Bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

²¹ [Energies \(Nov 2022\): Design and Analysis of a Floating Photovoltaic System for Offshore Installation: The Case Study of Lampedusa](#)

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Istanbul, which included three systems of varying capacities: 9 kWp, 30 kWp, and 90 kWp. The fatigue study, spanning 20 months, focused on evaluating the **floaters, frames, and their connections** for potential issues and critical faults. The findings revealed that the integrated design could result in significant bending loads and structural failure due to hydroelastic effects. To mitigate these impacts, an alternative design approach proposes modularizing the entire FPV system. This design incorporates multiple rigid or flexible connections, allowing the system to adapt to wave movements. By moving with wave propagation, this approach helps prevent localized stress peaks, improving both the longevity and performance of the system in rough weather conditions, which makes it more suitable for large-scale applications.²²

When choosing between steel and HDPE floats, strength and durability are crucial factors. **Steel** is known for its robust **strength, able to withstand heavy weight and harsh environmental conditions**. On the other hand, **HDPE** is **resistant to impacts and capable of absorbing shocks without cracking**. It is also resistant to UV rays and chemicals, making it less prone to degradation over time. Based on above case studies, key principles for successful FPV designs are the ability to withstand natural forces and the capacity to move with waves. Steel construction addresses the first principle, while flexible connection elements handle the second, making it possible to create sustainable FPV systems capable of withstanding extreme weather conditions.

Discussions with stakeholders indicate that floaters are available in two types in India: **HDPE and a combined steel-HDPE structure**. While HDPE floaters are **more economical**, the combined steel and HDPE structures are **more robust**, capable of withstanding high wind speeds **without requiring a wave barrier**.

B. Corrosion and UV Resistance:

Material selected must be resistant to chemicals, acids, and UV degradation, with no negative impact on water quality. **HDPE** is inherently resistant to **corrosion from water and UV radiation**. These properties ensure that the floats maintain their structural integrity and buoyancy over long periods, even when exposed to sunlight and harsh weather. The resistance to environmental degradation contributes to a longer lifespan for HDPE floats compared to other materials that may corrode or degrade under similar conditions. **ISO 4892** and **ASTM D2565** standards can be referenced for testing materials' UV resistance.

Effect of the accelerated UV radiations on bimodal HDPE floats: The study by Alok K. Sahu and Kumaraswamy Sudhakar examined the impact of accelerated UV radiation on the mechanical properties of bimodal HDPE floats. After 1000 hours of exposure, tensile strength decreased from 23.22 MPa to 14.64 MPa, but the material still supported a constant load of 637.81 N. Elongation at break remained at 6.24%, and impact resistance showed minimal change. Hardness increased from 61 to 66 (Shore D) due to polymer degradation. Overall, the mechanical properties were largely unaffected, confirming that the material can safely support solar panels and accessories.

According to the case study, HDPE material can endure UV radiation without significant changes in its mechanical properties. However, if necessary, UV inhibitors can be added to HDPE to prevent alterations in appearance and deterioration of impact strength, tensile strength, and elongation due to photodegradation.

Steel floats demand more frequent attention, particularly in saltwater environments, due to the need for regular corrosion inspections. For module mounting structures, galvanized aluminium or stainless steel should be utilized. Conversely, HDPE floats are maintenance-free, as they do not corrode and are resistant to marine growth. To conduct anti-corrosion tests, especially in high-salinity water, ISO 9227-2017 and IS 9844-1999 standards can be referred.

C. Non-toxicity:

Floats should be free from toxic metals such as arsenic and chromium, as well as excessive chlorine, at all stages of an FPV system. When deployed in drinking-water reservoirs, they must undergo testing for turbidity, TDO, and TOC to ensure compliance with drinking-water safety regulations. Floats must adhere to following environmental standards:

- Compliance with IS 10500:2012 is essential for drinking-water reservoirs.
- For environmental compliance testing, refer to IEC 62321-2023 or IS 16197-2014.

Following list of standards can be referred while selecting materials for the floating structure to ensure structural integrity and resistance to degradation caused by UV exposure, corrosion, and other environmental factors.

²² [Sustainable energy technologies & assessments \(Oct 2021\): Problems encountered with floating photovoltaic systems under real conditions: A new FPV concept and novel solutions](#)

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Table 9: List of Technical Standard for Floating structure

Standard	Description
ASTM D1693	Test for Environmental Stress Cracking of HDPE
ASTM D5397	Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
ASTM D790, ISO 178	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics & Electrical Insulating Materials
ASTM D 792 / ASTM D 1505	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement/ Standard Test Method for Density of Plastics by the Density-Gradient Technique
ASTM D638, ISO 527	Standard Test Method for Tensile Properties of Plastics
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D2565, ISO 4892 – 2	Standard Practice for Xenon-Arc Exposure of Plastic intended for outdoor Applications
ASTM D4329, ISO 4892 – 3	Standard Practice for fluorescent ultraviolet (UV) lamp apparatus exposure of plastics
ASTM D1693-15 (or equivalent ISO Standards)	Standard Test Method for Environmental stress cracking of Ethylene plastics
RoHS directive 2002/ 95/EC	Test for Restriction of Hazardous Substances
ISO 12944-2:2017	Corrosion protection of steel structures by protective paint systems
ISO 12944-5: 2019	Paints and varnishes — Corrosion protection of steel structures by protective paint systems
IS 875 (Part 3):2015 (Reviewed in 2020)	Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures-Wind loads), worst-case waves, and water currents prevailing at the proposed installation waterbody.
IS 1893 (Part 1): 2016 (Reviewed in 2021)	Criteria for Earthquake Resistant Design of Structures - Part 1: General Provisions and Buildings
UL 94 or Equivalent IEC/ISO standard	Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances testing
IS 6685: 2009 (Reviewed in 2019)	Life jackets - Specification

2.3.5 Assembly of Floating structure

The construction of each single block includes the following steps: laying up the floating components, assembling and interconnecting the floats (where applicable), assembling the module support structures (either metal or HDPE plastic), and installing the photovoltaic modules. Once the individual units are assembled, they are interconnected, and the first few units are partially floated into the water. Subsequent rows of units are built and launched until the entire floating island is completed. The next steps in the process involve interconnecting the blocks into larger rows, making the electrical connections in accordance with the single-line diagram, sliding or launching the units into the water, towing the floating structure to its designated position, and securing it through mooring and anchoring. Upon completion, the fully assembled floating photovoltaic island is towed to its final location and anchored securely. Assembling and deploying floating structures requires precise coordination and strict adherence to industry standards to ensure the safety and durability of the FPV system.

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Table 10: Challenges and recommended measures associated with assembly of floating structure

Parameters	Description	Recommendation
Launching area	The design of the launching area depends on the type of floaters being used. For lighter floaters, manual pushing is often sufficient. To reduce friction and prevent damage when the floaters slide into the water, covering the area with geotextile can be helpful. A temporary ramp can help facilitate the smooth deployment of floating platforms into the water. A suitable launching area eases deployment efforts and reduce damages during assembly and interconnection works.	The slope of the launching area should be steep enough (greater than 5°) to make launching easier, but not too steep (less than 15°) to ensure the assembly process remains manageable. For larger floating structures, other techniques such as using rails or cranes can be employed, though these methods can have varying impacts on the speed and efficiency of the assembly and launching process.
Structural Integrity During Assembly	Ensure the floating structure is not compromised during assembly and interconnection. Floating structures are usually easier to assemble on land, before launching into the water	Conduct a short integrity test for 5-10 days under environmental conditions expected during operation . Document the survey of interconnections and stress points. Perform completion tests, including visual checks and functional tests before deploying the structure to its operational position to ensure proper function when maintenance loads are applied.

Weather plays a significant role in FPV installation, particularly during deployment. Planning installation activities around favorable weather conditions is required to minimize the risk of damage or delays caused by high winds or waves. Care should be taken to minimize the impact on the local environment. This includes preventing accidental drops of tools and into the water, as well as handling floats, anchors, and mooring system carefully to avoid harm to the water body.

- **SERIS Testbed:** At the SERIS testbed, FPV arrays were pre-assembled on land and then deployed into the water using a launch ramp. This method minimized the need for heavy machinery and reduced the risk of float damage during the deployment process.²³
- **NTPC Kayamkulam FPV:** The FPV arrays were pre-assembled on land and towed to their designated location using boats during favorable weather conditions. Installation was carried out during the summer months when wave activity was minimal, reducing the risk of damage.

Best Practice: Constructing a launch ramp to reduces float, PV modules damage during deployment and allows pushing assembled platforms into the water without heavy machinery. Coordinating multiple teams to assemble floats in parallel with anchors and mooring system for faster installation. Towing floating assembly to final location using boats when weather conditions are suitable for deployment.

²³ [The World Bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

2.4 Design Criteria for Mooring and Anchoring system

The anchoring and mooring system as shown below is critical to ensuring that the FPV system remains stable and secure, even under varying environmental conditions such as changes in water levels, wind, and waves. Securing the floating PV system with a durable and flexible mooring system tailored to site conditions.

Mooring lines, typically made from materials such as fibre ropes, steel wire, chains, or combinations thereof, must be selected based on strength, durability, resistance to environmental degradation and ability to absorb dynamic loads. Elastic mooring lines can accommodate the movement of the platform due to wind and waves, preventing excessive strain on the floating structure.

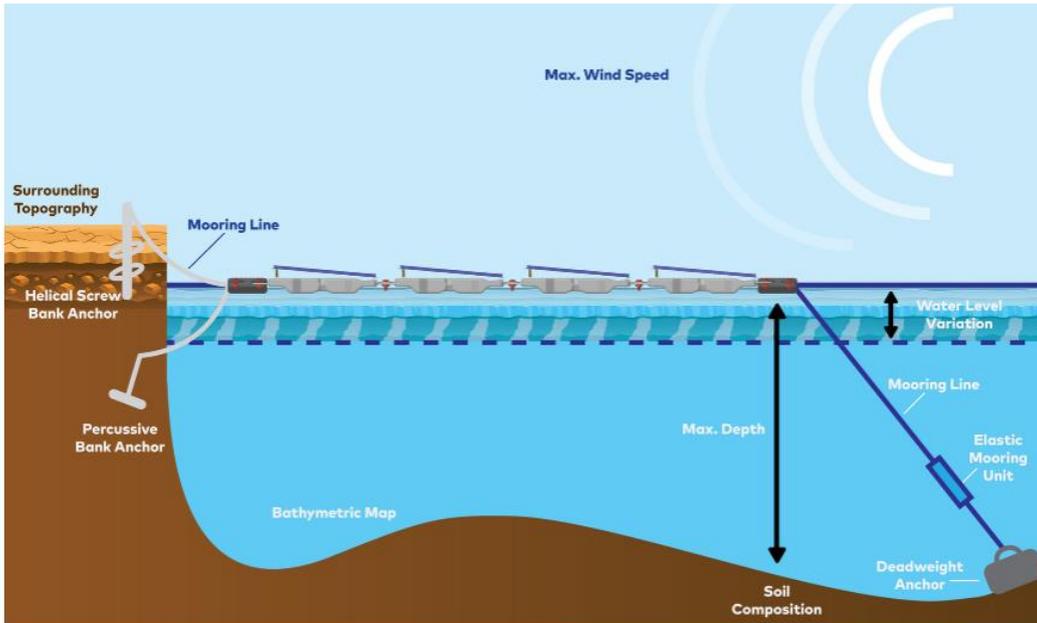


Figure 12: Schematic Diagram showing Anchoring & Mooring in FPV system²⁴

The Anchor system must be capable of withstanding both vertical and lateral loads. Site-specific considerations such as water depth, soil conditions, and environmental forces must be considered when selecting the type of anchors. Environmental impact, particularly the potential for waterbed erosion or sediment movement around anchor points, must also be considered in areas with strong currents or tides. Advanced computational modelling and physical testing can predict the impact of environmental forces and ensure the system resists uplift, sliding, and rotational instability.

2.4.1 Anchor Types & Selection

The anchoring solution and type should be selected on a case-to-case basis depending on the site conditions and other factors such as Water body type (depth width, bed type), Soil & bed type, Environmental Impact Load analysis and maintenance & Bathymetry/topology constraints.

Based on the factors highlighted selection of suitable anchors becomes a critical activity in the FPV deployment. The figure below shows the various types of anchors.

Gravity or Dead weight Anchors: stay in position through their weight, resisting movement caused by external forces like wind or current and are suitable for rocky or hard seabed. They are easy to install and can withstand FPV mooring loads.

Drag Anchors: They usually dig into seabed when pulled and offer drag resistance. They rely on soil holding power and are thus suitable only for horizontal mooring loads.

Screw (Helical) anchors: They are suitable for clay or silt beds with sufficient depth for penetration. They are suitable for shallow water bodies.

²⁴[Temiz Yaratici Teknolojiler \(TYT\) \(April 2021\): Floating-solar-anchoring-and-mooring \(Accessed on 24-04-2025\)](#)

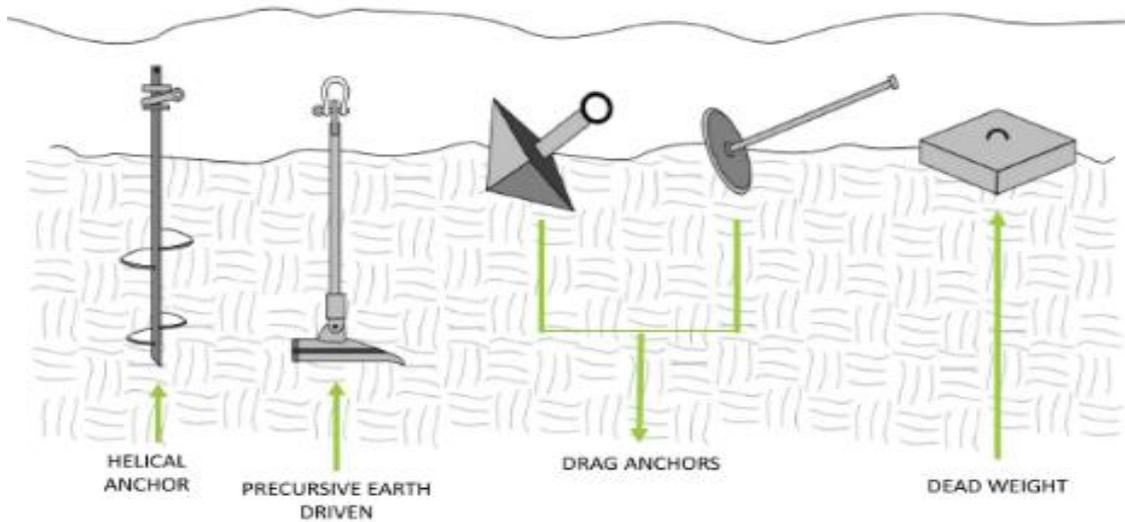


Figure 13: Anchor Types used in FPV²⁵

The selection of appropriate anchoring systems is crucial and depends on site-specific parameters such as water depth, seabed type, and mooring line load. Each factor influences the type of anchor required to ensure structural stability, ease of installation, and minimal environmental impact.

Table 11: Factors affecting selection of anchor type

Parameter	Description	Recommendation
1. Water Depth	Choice of anchor varies with the water depth as tension on mooring lines, environmental & operational risks, and installation changes with depth.	<ul style="list-style-type: none"> • Shallow Depth (<5m): screw type & Gravity anchor • Medium (5-20m): Precursive earth driven anchor • Deep (>20m): Pile & Drag anchor recommended as they absorb the large wind & wave force
2. Seabed Type	Seabed directly affects the anchor holding capacity. (Like for soft clay or silt or rocky beds). It also affects the impact on environment, installation complexity and seabed erosion	<ul style="list-style-type: none"> • Soft Soils: Percussive earth driven anchoring preferred, anchors are firmly embedded, reducing risk of movement due to water currents or wind • Clayey Soils: Propeller (screw) anchors cut through dense material, providing strong, stable hold with increased surface contact. • Firm/Rocky Soils: Gravity anchors ensure stability through weight.
3. Mooring line load	Directly influences the stability and security of the structure	<ul style="list-style-type: none"> • Low to moderate mooring load: Gravity anchors preferred, very large anchors needed for high forces, making them impractical to install. • Moderate to high horizontal and vertical loads: Screw anchor preferred due to high holding capacity. • High horizontal loads with minimal vertical uplift: Drag anchor preferred due to high capacity through dragging and penetration.

²⁵ GIZ (Jan 2024): CSTEP Floating PV in India

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2.4.2 Anchor Design Considerations & Loads

The selection of appropriate anchor types—such as gravity (deadweight) anchors, pile, or helical anchors, and drag embedment anchors—depends heavily on specific site conditions. Key considerations include riverbed and **soil profile, bathymetry data, mooring line loading, and the anchor's performance under continuous stress**. Site-specific environmental factors like **water depth, wave height, wind speed, current velocity, and potential seismic activity must be incorporated into load calculations** to ensure anchoring reliability. Anchors are subjected to a combination of static loads from the hydrostatic pressure of the FPV structure, dynamic loads from wind, waves, and water currents, and lift loads due to variations in water levels. As such, the selected anchor must offer sufficient lateral and vertical holding capacity to maintain the system's stability under all expected conditions. Anchoring system design shall comply to standards mentioned below:

Reference	Description
IS 875 (Part 3):2015 (Reviewed in 2020)	Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice Part 3 Wind Loads
IS 456: 2000 (Reviewed in 2021)	Plain and Reinforced Concrete - Code of Practice [CED 2: Cement and Concrete]
IS 1786: 2008 (Reviewed in 2023)	High Strength Deformed Steel Bars and Wires for Concrete Reinforcement specification
IS 13920: 2016 (Reviewed in 2021)	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice
IS 2502: 1963 (Reviewed in 2023)	Code of Practice for Bending and Fixing of Bars for Concrete Reinforcement
ISO 12944-2:2017	Corrosion protection of steel structures by protective paint systems
IS 800: 2007 (Reviewed in 2022)	General construction in steel - Code of practice
IS 801: 2010 (Reviewed in 2021)	Code of practice for use of cold - Formed light gauge steel structural members in general building construction
IS 802: 2016	Use of structural steel in overhead transmission line towers - Code of practice: Part 1 materials, loads and design strengths
IS 3370: 2021 (Reviewed in 2022)	Concrete Structures for Retaining Aqueous Liquids - Code of Practice: Part 1 General Requirements
IS 2062: 2011 (Reviewed in 2021)	Hot rolled medium and high tensile structural steel - Specification
IS 1079: 2017 (Reviewed in 2022)	Hot rolled carbon steel sheet, plate and strip - Specification
IS 811: 1987 (Reviewed in 2024)	Specification for cold formed light gauge structural steel sections (Second Revision)
IS 1161: 2014 (Reviewed in 2024)	Steel tubes for structural purposes - Specification
IS 4923: 2017 (Reviewed in 2023)	Hollow steel sections for structural use - Specification
IS 513: 2016	Cold reduced carbon steel sheet and strip
IS 1239: 2004	Mild steel tubes, tubulars, and other wrought steel Fittings
IS 808: 2021	Hot Rolled Steel Beam, Column, Channel and Angle Sections - Dimensions and Properties
IS 3502: 2009 (Reviewed in 2021)	Steel chequered plates

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Reference	Description
IS 2629: 1985 (Reviewed in 2021)	Recommended practice for hot dip galvanizing of iron and steel
IS 4759: 1996 (Reviewed in 2021)	Hot - Dip zinc coatings on structural steel and other allied products - Specification
IS 2633: 1986 (Reviewed in 2021)	Method for testing uniformity of coating on zinc coated articles (Second Revision)
IS 6745: 1972 Reviewed In: 2021	Methods for determination of mass of zinc coating on zinc coated iron and steel articles
IS 458: 2021	Precast Concrete Pipes (with and without Reinforcement)
IS 9595: 1996 (Reviewed in 2019)	Metal - Arc welding of carbon and carbon manganese steels - Recommendations
IS 4736: 1986 (Reviewed in 2021)	Specification for hot - Dip zinc coatings on mild steel tubes
IS 5624: 2021	Foundation Bolts Specification
API RP 2SK	Recommended Practice for Design and Analysis of Station Keeping Systems for Floating Structures
API Spec 2F	Specification for Mooring Chain
API RP 2I	In-Service Inspection of Mooring Hardware for Floating Structures
API RP 2MIM	Mooring Integrity Management
BS 6349-6	Maritime Works - Part 6: Code of Practice for Design of Fendering and Mooring Systems
API RP 2A	Floater strength verification, spreader bar design & pad eye design.

Case Study: Anchor Failure

Overview: In 2019 Japan's Yamakura Dam (13.7MW) FPV experienced heavy gusts of wind (more than 200kmph) which resulted in two thirds of the plant being destroyed.

- The plant had 420 anchors & 823 mooring lines out of which 7 anchors came loose in southern end.
- Due to combination of wind loads and water level variation (Due to continuous rain the plant exceeds its maximum level of 37.3 m height) the mooring cables came under heavy tension. This tension from mooring cables was dissipated to anchors besides the wind loads.
- Also, the anchors at southern end (68) were way less compared to other areas indicating a design flaw.
- After the anchor bolts failed, resin bolts started to collapse, and load was distributed unevenly, and modules became mangled resulting in short circuit and fire.

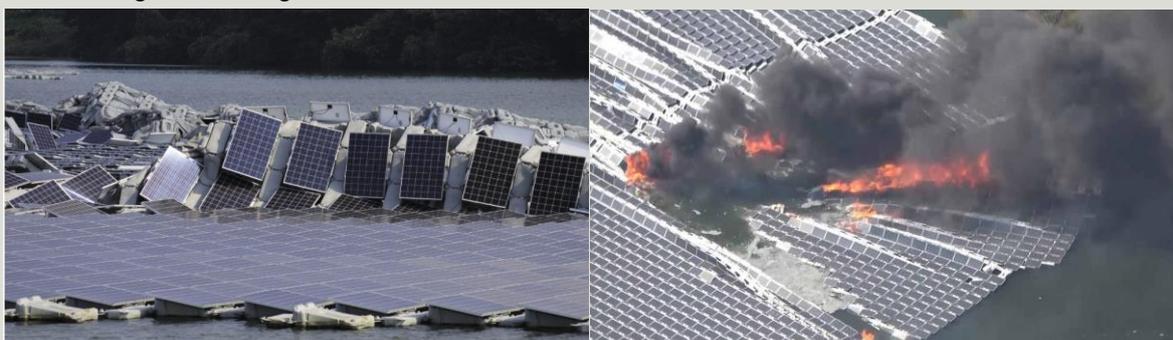


Figure 14: Damaged Yamakura Dam FPV in Japan

Conclusion: The findings from investigation are important for designing floating solar systems that can withstand extreme weather events like typhoons.

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Source: [Don't throw caution to the wind/PV Magazine/2020](#)

Testing for wind resistance and water speed needs to be carried considering extreme scenario, especially in regions prone to climate change and natural disasters. Ensuring robust anchor systems, proper distribution of mooring wire tension, and effective ballast management are essential to enhance the resilience and safety of FSPV installations.

2.4.3 Anchor Installation & Monitoring

The deployment & positioning, orientation and embedding of anchors are crucial aspects during installation of anchors. Both initial pre and post installation activities as per standards should be followed.

Each floating solar project is unique, and designing the anchoring system requires detailed site-specific information such as follows:

- **Meteorological and Hydrological Data:** Local weather patterns, including wind direction, wind speeds, and the likelihood of extreme conditions such as storms or hurricanes, must be factored into the design.
- **Bathymetry:** The depth of the water affects the type of anchors that can be used. For example, shallow waters may favor deadweight anchors, while deeper waters often require pile or drag embedment anchors.
- **Soil Investigation:** Ground investigations, including borehole data or seabed surveys, help assess soil strength and the need for specialized anchors, especially in softer soils or locations with significant sediment movement.
- **Sediment Strength:** Understanding the composition & strength of the seabed material (sand, clay, silt, or rock) is crucial for selecting anchors that will achieve sufficient penetration and holding capacity. Proper sediment analysis ensures the selected anchors will not dislodge or lose their holding strength during operational conditions.

Recommendations	Description
• Installation Monitoring	Both pre-installation and post-installation surveys should be mandatory to verify the integrity and long-term reliability of mooring systems.
• Environmental Considerations	To ensure corrosion and non-toxic materials and minimum sediment disturbance during installation are essential
• Other Essential Parameters	Other important considerations such as need for additional stabilization, seasonal planning, skilled personnel, and post installation survey. DNV-OS-E301, RP-301, RP-C205 and ISO 19901-7 standards ²⁶
• Post Installation Monitoring	DNV ²⁷ require post-installation surveys (also referred to as-laid survey), to record and deviations in positions and depths in relation to the calculations which have been used as the basis for the laying out plan, after-which if such deviations are significant
• Monitoring Techniques	Use of acoustic monitoring techniques, tension & load monitoring an expanded annual survey ²⁸ after the bed-in phase considering that within a year in operation the mooring system, lines have settled in seabed, other deficiencies like component misalignments and twists should be visible.

2.4.4 Mooring Types & Design Considerations

The use of each mooring type depends upon water depth, wave height, wind speed, the type of water body (lake, reservoir, sea). Important Considerations is that Mooring line should balance strength, weight, durability, and fatigue performance based on environmental and installation.

They encompass forces from environmental conditions like wind, waves, currents, and water level variations, as well as operational and transient loads such as thermal expansion and seismic activity. Proper

²⁶ [The World bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

²⁷ [DNV-GL \(2020\): Floating offshore wind turbine installation](#)

²⁸ [The Bureau of Safety and Environmental-BSEE \(2015\): Study on Mooring System integrity management for floating structures](#)

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consideration of these loads ensures that mooring systems can withstand extreme conditions, minimize material fatigue, and maintain platform stability.

Table 12: Types of mooring technologies

Types	Description
<ul style="list-style-type: none"> • Catenary Mooring Systems 	Utilizes heavy mooring lines that form a curved (catenary) shape due to their weight, providing stability through tension and gravity. They are relatively simple and cost effective however they face challenges in vertical movements. Suitable for medium depth reservoir with moderate forces.
<ul style="list-style-type: none"> • Taut-Line Mooring Systems 	Mooring lines are under constant tension, connecting the FPV platform directly to anchors. Ideal for deep water bodies or locations with significant water level variations.
<ul style="list-style-type: none"> • Elastic Mooring system 	Designed to allows controlled movement while keeping a floating structure stable. It uses elastic lines, synthetic ropes, or shock absorbers to stretch and absorb energy from waves, currents, and wind. It reduces stress on both the mooring system and the anchored structure, enhancing durability and performance in dynamic environments
<ul style="list-style-type: none"> • Compliant Mooring Using Buoys 	Incorporates floating buoys as part of the mooring line system to absorb and dissipate environmental forces. Ideal for areas with frequent tidal fluctuations, moderate currents, or wave activity

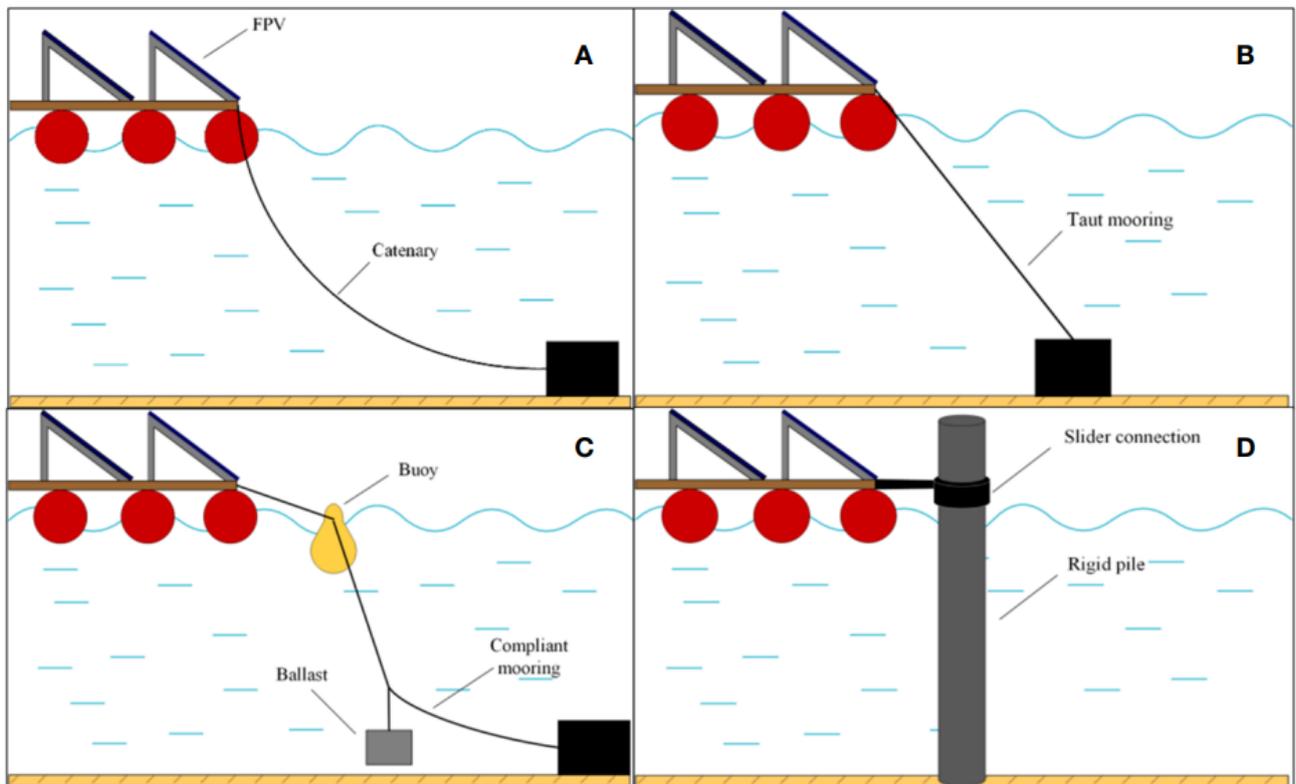


Figure 15: Various Mooring Layouts²⁹

²⁹ ["Frontiers\(2024\): Discussion on the development of offshore floating photovoltaic plants, emphasizing marine environmental protection](#)

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Functional Requirements for the Mooring System

- **Horizontal Excursions:** The system should limit the horizontal motion of the FPV array to prevent drifting, moving too close to the shore or any obstacles, and protect against damage to connected structures.
- **Robustness and Redundancy:** The mooring system should be designed with redundancy to ensure that the failure of one mooring line does not lead to triggering a progressive failure of others. Redundancy enhances the system’s resilience, allowing it to continue functioning even if individual mooring lines fail.
- **Load Distribution:** Loads must be evenly distributed across all mooring lines to prevent overloading any one line, which could lead to failure. Proper load distribution ensures the longevity and safety of the mooring system.
- **Adaptation to Water Level Changes:** In regions where significant variations in water levels occur, the mooring system should be flexible enough to maintain effectiveness under both high and low water conditions. Buoyancy, elastic mooring lines are important considerations to absorb water level variations.

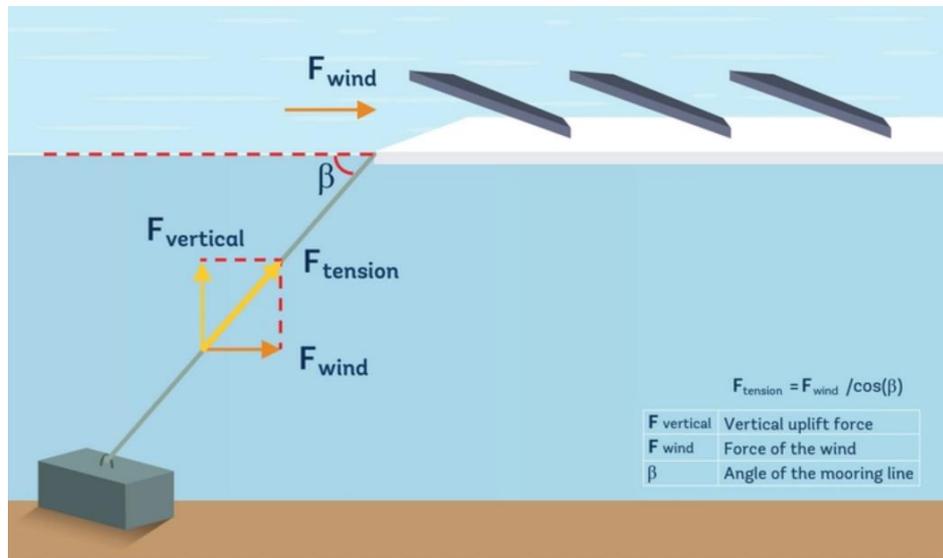


Figure 16: Loads on Mooring Cables³⁰

Parameter	Reference Documents	Details
Slack-Sling Criteria	DNV RP-N103	Conduct mooring studies to satisfy slack-sling criteria i.e. Reversal loads should not less than 0. Ensure cables are not overstressed under all environmental loads, including extreme scenarios.
Fatigue Analysis	DNV RP-C203, API RP 2SK	Perform fatigue analysis of mooring cables using T-N curves. Fatigue life depends upon the design life.
Design Loads and Safety Factors	ISO 19901-7	Address ultimate, fatigue, and accidental limit states. Use appropriate safety factors to ensure reliability.
Dynamic Behaviour Simulations	DNV-GL-ST-0126	Evaluate mooring line dynamics and tension under varying conditions.
Wave & Current Loads	IEC 62600-2 and DNV-RP-H103	Evaluate wave-induced forces for inland water bodies and assess drag and vortex-induced vibrations

³⁰ [Suntara \(Adapted from SERIS\): Anchoring & Mooring system](#)

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2.4.5 Mooring Material Quality & Durability

Material Selection for Mooring Lines

Mooring lines, typically made from materials such as fiber ropes, steel wire, chains, or combinations thereof, must be selected based on strength, durability, resistance to environmental degradation and ability to absorb dynamic loads. Elastic mooring lines can accommodate the movement of the platform due to wind and waves, preventing excessive strain on the floating structure. The inclusion of buoyancy elements helps reduce the vertical load on the floating structure, protecting both the mooring lines and the FPV system. Mooring lines must be designed to handle variable environmental loads over time.

- **Chain Type:** Robust but vulnerable to corrosion & wear.
- **Steel Cable:** Robust & protected from corrosion however over-bending is an issue.
- **Fiber Ropes:** Have good load to weight ratio & fatigue resistance and flexibility, however, have lower tensile strength.

Durability Factors

- **UV Resistance:** Mooring lines are exposed to constant sunlight, so UV degradation is a critical factor. UV exposure can cause materials to become brittle, weaken, and ultimately break or lose their strength over time. Materials such as polyethylene (PE) and polypropylene (PP) are commonly chosen.
- **Saltwater Resistance:** Saltwater accelerates corrosion, especially in materials like steel and metal components. Special coatings and galvanization (for steel cables) can further protect against saltwater corrosion.
- **Wear & Tear Resistance:** Continuous movement caused by wind, waves, and currents can cause abrasion between the mooring lines and the surrounding environment. This is especially problematic for flexible mooring lines, which may rub against the water surface, other components etc.
- **Flexibility:** Mooring lines need to be flexible to accommodate the movement of the floating solar platform. Materials like polyamide (PA) and polyethylene (PE) offer good flexibility, making them suitable for calm and low-stress environments.
- **Corrosion Resistance:** While uniform corrosion is accounted for localized pitting due to Chlorine (in sea/brackish water) and are difficult to detect. Use of corrosion-resistant materials such as high-alloy stainless steel with anti-corrosion coatings (epoxy, polyurethane) for seawater is recommended. Use of zinc/aluminum thermal spray coatings for better long-term protection. ISO 9223, ISO 12944 and DNV-ST-0119 standards.
- **Biofouling/ Marine Growth:** The type and accumulation rate of marine growth at the design site may affect weight, hydrodynamic diameters, Biofouling is accelerated in warm environments with untreated surfaces. Anti-fouling coatings such as Silicone and fluoropolymer-based foul-release coatings (FRCs) are both non-toxic alternatives to biocidal coatings that prevent fouling organisms from attaching to surfaces.

Adjustable chain terminations should be integrated into mooring systems by adding a small chain at the termination points. This facilitates easier modification of the line length after installation, thereby enhancing flexibility and improving mooring performance.

Parameter	Reference	Details
Material Quality	ISO 13628-5 (Petroleum and natural gas industries: Mooring system design)	The quality of mooring cables in floating solar PV systems significantly affects their durability, strength, and resistance to harsh environmental conditions, especially in India's coastal and saline regions.
Corrosion Resistance	DNVGL-ST-0119 (Applies to floating solar) ISO 13628-5 (Mooring system standards)	Corrosion can significantly weaken their strength and lead to failure, disrupting the system. Regular inspections and maintenance should also be conducted to detect and address corrosion early, ensuring long-term durability.
UV Resistance	ISO 4892 (Plastics - Methods of testing)	To enhance UV resistance, it is recommended to use cables with UV-resistant coatings, such as polyurethane, high-grade polyethylene, for the resistance to which protect cables from sun-induced wear.

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Wear Resistance	DNVGL-ST-0119 (Floating structures and mooring systems)	To enhance wear resistance, it is recommended to use cables with abrasion-resistant coatings, such as polyurethane or high-density polyethylene, and materials like stainless steel or aramid fibers.
Dynamic Load Resistance	DNVGL-ST-0119 (Design for dynamic loads on floating systems) ISO 13628-5 (Mooring line design for offshore applications)	To improve dynamic load resistance, it is recommended to use cables with high tensile strength, such as aramid fibers or steel-reinforced materials, Proper cable tensioning and periodic inspections are essential to mitigate the effects.

2.5 Design criteria for PV Modules Selection

This section will outline the selection of type of PV modules for FPV systems. They differ significantly from traditional land-based installations due to their unique marine operating environment. While the main components such as solar modules, inverters, and mounting structures are similar, FPV systems have to deal with additional challenges such as waterborne conditions, higher humidity, temperature variations, and structural stresses caused by waves and wind. Selecting suitable PV components for FPV is critical to ensure long-term performance and reliability for FPV system.

2.5.1 Types of PV Module Technologies

PV module type	Description
Monocrystalline	Made from single-crystal silicon. Monocrystalline modules are favoured in FPV installations due to their high efficiency, which is beneficial when space is limited on floating platforms. Their durability ensures sustained performance in aquatic environments.
Polycrystalline	Composed of multiple silicon crystals, these modules offer a balance between cost and efficiency. Polycrystalline modules are commonly used in FPV projects because of their cost-effectiveness and adequate efficiency. They provide a practical solution for large-scale installations where budget constraints are a consideration.
Thin-Film	These modules are made by depositing thin layers of photovoltaic material onto a substrate, resulting in lightweight and flexible panels. Thin-film modules are less commonly used in FPV due to their lower efficiency compared to crystalline silicon modules. However, their lightweight nature can be advantageous in certain floating applications where weight is a critical factor.
Additional technologies	
PERC Modules	PERC (Passivated Emitter and Rear Contract) technology significantly enhances the efficiency by adding a special layer to the rear of the cell. This layer reflects light back into the cell for improved absorption and facilitates better electron movement, resulting in higher efficiency. As a result, it generates more power from the same sunlight exposure compared to traditional Monocrystalline or Poly solar panels.
Bifacial Modules	Bifacial modules have the potential to boost energy yield in FPV systems by capturing sunlight reflected off the water surface. However, because water has a relatively low albedo—around 5%—the actual performance gains may be limited.
Dual-glass module	In dual glass module, the rear glass replaces the traditional white EVA (plastic) back sheet and creates a glass-glass sandwich that is considered superior as glass is very stable, non-reactive and does not deteriorate over time or suffer from UV degradation.

2.5.2 PV Modules - Conventional PV Plant vs Floating PV: Unique Challenges

- **Environmental Exposure:** Modules are exposed to high humid, misty, and saline environments, increasing their susceptibility to corrosion and water ingress. These conditions accelerate aging and degradation of materials.

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- **Mechanical Stress:** Modules undergo dynamic loading due to wind, waves, and water currents, depending on the support system. This constant mechanical stress can lead to structural fatigue, microcracks, and potential failure of the PV modules.
- **Water Splashing, condensation:** Water splashing, condensation, and water collection at the bottom edge of modules can occur due to wind and site conditions. High mineral content in the water may alter the optical properties of the glass and reducing efficiency.
- **Electrical and Connector Issues:** Connectors and grounding components are prone to corrosion, water ingress, and mechanical forces due to the movement of the floaters.
- **Potential Induced Degradation (PID) and Installation Challenges:** High humidity levels in the FPV environment increase the risk of PID in modules. Additionally, assembling floating plants onshore and launching them into the water can cause microcracks or physical damage to the modules, affecting their long-term performance.

Recommendation:

The glass-glass modules which have glass on both sides compared to traditional modules offer better resistance to environmental conditions and ensure enhanced protection. These with robust frames to resist dynamic and static loads should be used. Module frame should be tested for corrosion resistance in saline water environment as per the applicable standards for extended cycles. Accelerated aging test should be done to ensure the effectiveness of panel for highly humid and saline environment for solar panel, frame, and mounting structures. The mounting systems should have flexible joints/vibration damping measures to absorb wave-induced motions of PV modules for maximum amplitude and frequency that could occur in water body based on the historical study. Use of corrosion resistant materials like anodized aluminum or coated materials should be used. PID resistant modules should be used to resist PID effects. This should be followed by regular inspections and monitoring. IEC 61701 and IEC 61215 can be referred.

Standards	Description
IS 14286 (Part 1): 2023/ IEC 61215-1: 2021	Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval Part 1 – Test Requirements
IS 14286 (Part 1/Sec 1): 2023/IEC 61215-1-1:2021/ IEC 61215-1-4:2021	Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval Part 1 – Test Requirements Section 1- Special requirements for testing of crystalline silicon photovoltaic (PV) modules
IS 14286 (Part 2): 2023 IEC 61215-2: 2021	Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval Part 2 – Test Procedures
IS/IEC 61730 -1: 2016 (Reviewed in 2020)	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction
IS/IEC 61730 -2: 2016	Photovoltaic (PV) module safety qualification - Part 2: requirements for testing
IS/ IEC 61701: 2011 (Reviewed in 2019)	Salt mist corrosion testing of photovoltaic (PV) modules. (Applicable for coastal and marine environment)
IS 16664: 2018 IEC 62716: 2013 (Reviewed in 2024)	Photovoltaic (PV) Modules- Ammonia Corrosion Testing (if applicable)
IS 17210 (Part 1): 2019 IEC TS 62804-1: 2015	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon
IS 14286 (Part 1/Sec 2/3/4)- 2019 (as applicable)	Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval Part 1 – Test Requirements Section 2/3/4- Special requirements for testing of thin-film Cadmium Telluride (CdTe) /amorphous/ Cu (In, GA) (S, Se) based photovoltaic (PV) modules
ASTM D257	Test method to measure surface and volume resistivity of insulating materials

2.5.3 PV Modules Degradation

PV modules in FPV are exposed to additional wind, wave and buoyancy induced loads. Modules experience repeated loading and unloading cycles from water movement, leading to material fatigue and potential failure.

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Besides this module might face torsional loads due to twisting of floaters mounting system and this can compromise the structural integrity of the system.

The marine setting introduces high humidity, corrosive conditions, loads from waves and wind, varying water levels, and temperature variations.

PV Degradation Studies	Studies Referenced	Findings
<ul style="list-style-type: none">• <i>A Review of Photovoltaic Module Failure and Degradation Mechanisms: Causes and Detection Techniques</i>	(Al Mahdi, Leahy, and Morrison, 2024)	<p>Degradation Trends: PV module degradation rates are influenced by material properties, environmental stress, installation quality, system design, and whether the system is grid-connected or standalone.</p> <p>Regional Impact: Higher degradation rates (over 1% per annum) have been observed in regions like India and northern Ghana, attributed to high temperatures and moderate humidity levels, which are comparable to Indian weather conditions</p>
<ul style="list-style-type: none">• <i>Floating Photovoltaic System Cost benchmark, Installations on Artificial Water Bodies</i>	(Ramasamy, Vignesh and Robert Margolis. 2021., NREL)	<p>NREL in its cost benchmarking for FPV systems has assumed an annual PV degradation factor of 0.7% for both lands based and FPV system. They have cited findings from Goswami and Sadhu; however, they note that study was only for 17 months with a single module test system. Given the lack of long-term field data from they have assumed a similar figure for both types of PV systems.</p>

Case study SERIS Testbed³¹

Ambient temperature and Humidity

The Solar Energy Research Institute of Singapore (SERIS) designed and installed the world's largest floating solar PV testbed (1 MWp) at Tengeh Reservoir in Singapore. The testbed provides valuable insights into the environmental challenges faced by FPV systems. The ambient air temperature on water was consistently lower than those on land due to the cooling effect of the water body (Onshore-Rooftop). Higher relative humidity levels at the module surface compared to reference rooftop systems. This increased humidity can contribute to the accelerated degradation of PV modules, particularly through corrosion.

³¹ [National Renewable Energy Laboratory, NREL \(2020\): Hybrid Floating Solar Photovoltaics-Hydropower Systems: Benefits and Global Assessment of Technical Potential](#)

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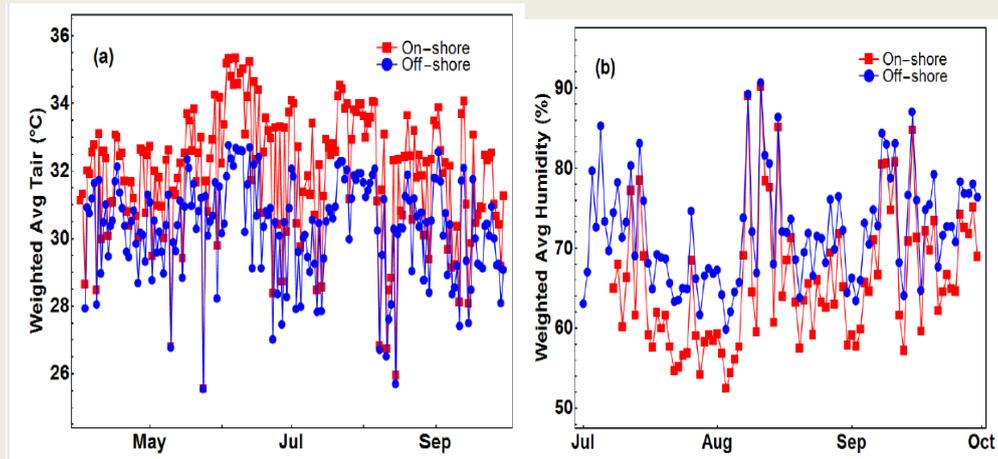


Figure 17: Temperature & Humidity Comparison³²

Source: SERIS & Lee et al. (2020): Hybrid floating solar photovoltaics-hydropower systems: Benefits and global assessment of technical potential

The degradation rate of PV modules in FPV systems remains a subject of ongoing research, with existing studies presenting varied findings. While some reports indicate higher degradation rates due to elevated humidity levels, others attribute these conclusions to the insufficient testing period (e.g., 17 months), which is inadequate to provide a long-term performance outlook.

Given the diverse climatic conditions across Indian states and the growing interest in deploying FPV systems, it is imperative to conduct long-term, region-specific studies to comprehensively understand the degradation mechanisms.

Recommendations to Reduce PV Module Degradation:

- The frame of modules is generally made of anodized aluminum, which is resistant to corrosion. For floating applications, depending upon the type of water body (inland lake or marine water bodies), the anodization thickness needs to be revisited.
- Use of corrosion resistant materials like anodized aluminum or coated materials should be used. **Grounding the DC negative pole of the inverter** can help mitigate PID issues in PV systems. Modules should be tested for **IEC TS 62804-1:2015**. This should be followed by regular inspections and monitoring.
- Modules can be compliant with IEC 61701³³ standards for salt mist corrosion and IEC 62716 for ammonia resistance extended cycle (let say by 50%) to simulate continuous slay and humid condition. Modules should be able to handle additional load due to wind and water movement. Modules can have coatings against protection from prolonged UV exposure.

2.6 Design Criteria for Electrical Equipment Selection

This section outlines the selection of type of electrical equipment, such as inverters and cables, and its configuration in FPV system, with a focus on minimizing power losses and mitigating risks. Electrical components must be designed for wet environments and dynamic motions. Cabling should be arranged to minimize friction and avoid tight groupings, with durable cables and ample space in cable trays. Equipment must be secured to prevent falling into the water, except for submerged export cables, which should be dynamic and have a dedicated mooring system.

2.6.1 Inverters

Central inverters and string inverters are most used for FPV systems, in some cases micro-inverters might be considered. For larger FPV systems, or PV systems with considerable distance to shore, it is recommended to locate the inverters, as well as the transformers, on a floating structure in proximity to the rest of the FPV array(s), with cable(s) to the onshore switching facilities and grid interconnection point. For smaller FPV systems with short distance to shore, it can be considered to locate inverters and transformers on land. This section will

³² [The World Bank \(2019\): Where Sun Meets Water Floating Solar Handbook for Practitioners](#)

³³ [International Electrotechnical Commission-IEC 61701 \(Accessed on 24-04-2025\)](#)

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outline the key challenges faced by inverters in FPV systems and provide recommendations to address and mitigate these issues.

Table 13: Major issues and recommendations with Inverter in FPV

Parameters	Description	Recommendation
Mechanical stress and Water Ingress	Inverters are subjected to constant mechanical stress due to the movement of the floating platform on the water surface. Additionally, there is a risk of water ingress, especially in central inverters.	It is best to have IP68 protection for inverter in floating PV system If inverter system is installed with the water body. In case inverter is installed on land, ensure IP rating of minimum IP65 for enclosures, install raised platforms to avoid water splashing, and consider barriers like metallic sheets.
Water condensation	Inverters used in FPV may face condensation inside enclosures due to humid/moist air especially in marine environment.	Use corrosion-resistant materials for enclosures, install space heaters, dehumidifiers, and RH sensors inside inverters.
UV exposure	Exposure to UV radiation may degrade the material and components of inverter over time.	Conduct UV exposure test and ensure UV-resistant coatings are applied to inverters.
Fault Susceptibility	Inverters used in FPV are susceptible to insulation resistance faults, ground faults and arc faults due to moist and conductive environment. These faults can lead to operational issues and potential safety hazards, if not properly mitigated.	Ensure inverters are equipped with residual current monitoring devices, insulation resistance monitoring, arc fault protection, and anti-PID kits.
Damp heat	Inverters in FPV are exposed to damp heat conditions which can cause long term humidity penetration.	Ensure inverter enclosures are equipped with proper sealing, corrosion-resistant materials, and adequate ventilation or dehumidification systems to prevent moisture accumulation
Cable Termination	Input and output termination	IP68 rating should be ensured. Or correspondingly one should ensure to limit the dust, humidity ingress.

Inverter shall comply to standards mentioned below:

Standard	Description
IS/IEC 61683: 1999 (Reviewed in 2020)	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
IEC 61000	Emission/ Immunity requirement
IEEE 519	Recommended practices and requirements for harmonic control in electrical power systems.
IS/IEC 60068-1: 2013 IEC 60068-1:2013 (Reviewed in 2025)	Environmental testing General and guidance
IS/ IEC 60068-2-1:2007	Environmental testing - Part 2-1: Tests - Test A: Cold
IS/ IEC 60068-2-2:2007	Environmental testing - Part 2-2: Tests - Test B: Dry heat
IS/IEC 60068-2-14:2023	Environmental testing - Part 2-14: Tests - Test N: Change of temperature
IS/IEC 60068-2-30:2005	Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)

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Standard	Description
IS 9000 (Part 4): 2020 IEC 60068-2-78: 2012 (Reviewed In: 2023)	Environmental Testing Part 4 Tests - Test Cab: Damp Heat, Steady State (Second Revision)
IS 16169: 2019/ IEC 62116: 2014	Testing procedure—Islanding prevention measures for power conditioners used in grid connected photovoltaic (PV) power generation systems
IS 16221 (Part 1): 2016 / IEC 62109-1: 2010	Safety of Power Converters for use in Photovoltaic Power Systems Part 1 General Requirements
IS 16221 (Part 2): 2015 /IEC 62109-2: 2011 (Reviewed in 2020)	Safety of power converters for use in photovoltaic power systems: Part 2 particular requirements for inverters
EN 50530	Overall efficiency of grid connected photovoltaic inverters.
IS/IEC 61727: 2004	Standard for interfacing solar PV plant with utility grid.
IS/ IEC 60529: 2011 (Reviewed in 2019)	Degrees of protection provided by enclosures
Grid Connectivity	Relevant CEA regulations and Indian grid code as amended and revised from time to time
ISO 12944	Selection of material based on site specific parameters for corrosion
IS/IEC 60529	IP rating selection based on site specific parameters for IP rating requirements (IP 68 / 69)

2.6.2 Cables & Accessories

This section outlines the requirements for cables and components used in FPV systems. Cables between PV modules and combiner boxes must be copper and dual-insulated, with connectors complying with IEC 62852 and having a minimum IP 68 rating. Cable trays and conduits must be UV-protected and durable, made from materials like PVC, HDPE, or fiberglass. Cables on floating platforms are categorized into static cables, which experience low mechanical stress, and dynamic cables, which must handle movement and mechanical forces. These cables can be floating or submerged, with XLPE/XLPO insulation and Copper/Aluminum conductors preferred. Cables must also be UV-resistant, hydrolysis-resistant, and able to withstand harsh marine conditions.

SERIS testbed: Cables may be snapped because of mechanical stress and fatigue. Factors contributing are constant movement from water currents and wind, as well as inadequate support and protection of the cables. Cable sheath may also be damaged from abrasion, exposure to water, and other environmental factors. Water contact of cable can lead to electrical leakage and reduced insulation resistance, posing a safety hazard and reducing system efficiency. Prolonged exposure to water, especially in saline environments, accelerates the corrosion and degradation of cable materials affecting the functionality.³⁴



Figure 18: Mechanical stress/fatigue

³⁴ [The World Bank \(2023\): Unlocking Floating solar photovoltaics in India](#)

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Ramagundam floating Solar Power Plant, Telangana, India (100 MW): These 100 MW floating solar installation features advanced cable management systems to address the unique challenges of floating solar technology. Electrical Safety: Harsh environmental conditions, including high humidity and potential flooding, require strict safety measures for electrical components, including proper grounding and insulation to prevent hazards. Submersion Risks: Submerged cables are vulnerable to degradation from prolonged exposure to moisture and biofouling, necessitating regular inspections to maintain cable integrity.

O'Mega 1 Floating PV Plant, France: At the end of January 2022, the body of water where the installation was located experienced intense winds, with gusts reaching up to 80 km/h. These strong winds, combined with the swell and continuous friction, caused the cables connecting the modules to the junction boxes to become exposed. This led to a short circuit on one of the three-panel floaters of the power plant. As a result, the affected inverters were shut off, but three of the floats caught fire.³⁵

Above mentioned case studies have highlighted common risks linked to FPV systems such as:

- Floating solar systems are susceptible to extreme weather conditions, which can result in structural damage and electrical malfunctions.
- The interaction between water and electrical equipment poses significant risks, including potential electrocution and fire hazards.
- The incidents listed above underscore the importance of robust design and maintenance strategies to mitigate risks associated with environmental factors.

Table 14: Major issues and recommendations with cables in FPV

Parameters	Description	Recommendation
Cable Placement	When managing cables, it's important to avoid cables touching the water, as this could lead to corrosion and degradation of cable properties. To maintain cable longevity, they should be protected from direct sunlight using UV-resistant materials and wiring trunks	Use cable ties or clamps to fasten AC and DC cables, ensuring they always stay above water to stay protected from mechanical damage and UV exposure. They should be securely fastened to prevent unintended contact with water and, where applicable, installed in cable trays, ladders, or conduits.
Cable movement	Cables that are too taut may snap or wear out over time	Allow sufficient slack in cables to accommodate the natural movement of floating platforms.
Cable Joints	Cable that needs to join either on DC side of AC side using connectors or otherwise	Once should ensure to have IP68/69 connectors and wherever it has to joined with connector, sufficient protection should be taken to make it Marine grade joints.

- Protection Measures: To prevent water ingress in case of insulation damage or faults, water-blocking tapes should be applied. Floating cables should be protected with flexible conduits or covered cable trays to minimize exposure to external elements.
- Cable Insulation: The insulation must be UV-stabilized, hydrolysis-resistant, and flame-retardant to withstand harsh environmental conditions.
- Cable Management: Provide sufficient slack in cables to minimize mechanical stress. Evaluate mechanical stress testing conditions and apply appropriate safety factors for cable accessories to ensure system reliability. Using high-standard MC4 connectors and cable trays, ensuring proper cable management, and maintaining high-quality crimping in combiner box connections are crucial steps to prevent failures and enhance overall system performance.
- Connectors and Lugs: Use IP68-rated connectors for waterproof and dustproof protection. Ensure compatibility between cable lugs and conductor materials and prefer tin-plated copper lugs for corrosion resistance.
- Maintenance: Conduct regular checks for connection tightness during maintenance to prevent potential issues.
- Anti-Fouling Measures: Use copper cables with anti-fouling properties to minimize the growth of organisms. Additionally, apply an anti-fouling coating to cables to prevent the attachment of marine life to the surfaces.

³⁵ [PV magazine \(Mar 2022\): Fire accident at its 17MW floating PV plant in France](#)

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Cables shall comply to standards mentioned below:

Standard	Description
EN 50618:2014/ IS 17293:2020/ IEC 62930: 2017	Electric Cables for Photovoltaic Systems for Rated Voltage 1500 V dc
IS 7098 (Part 1): 1988 (Reviewed in 2020)	Specification for crosslinked polyethylene insulated PVC sheathed cables: Part 1 for working voltages up to and including 1100 volts (First Revision)
IS 7098 (Part 2): 2011 (Reviewed in 2021)	Crosslinked polyethylene insulated thermoplastic sheathed cables - Specification: Part 2 for working voltages from 3.3 kV up to and including 33 kV (Second Revision)
IS 8130: 2013 (Reviewed in 2024)	Conductors for insulated electrical cables and flexible cords - Specification (Second Revision)
IS 1554 (Part 1): 1988 (Reviewed in 2020)	Specification for PVC insulated (Heavy Duty) electric cables: Part 1 for working voltages up to and including 1 100 V (Third Revision)
IS 3961: 2016	Recommended Current Ratings for Cables Part 6 Crosslinked Polyethylene Insulated PVC Sheathed Cables
IS 3975: 1999 (Reviewed in 2021)	Low carbon galvanized steel wires, formed wires and tapes for armoring of cables - Specification (Third Revision)
IS 5831: 1984 (Reviewed in 2021)	Specification for PVC insulation and sheath of electric cables (First Revision)
ASTM-D-2843	Standard test method for density of smoke from the burning or decomposition of plastics
ASTM-D-2863	Standard method for measuring the minimum oxygen concentration to support candle like combustion of plastics.
IS 10810: 1984 (Reviewed in 2021)	Methods of tests for cables
IS 10810 (Part 59): 1988 (Reviewed in 2020) /IEC 60754 (Part-I)	Tests on gases evolved during combustion of electric cables
IS 1255 (Reviewed in 2016)	Code of practice for installation and maintenance of power cables up to and including 33 kV rating (Second Revision)
IS:9537: 1981 (Reviewed in 2017)	Specification for conduits for electrical installations
IS 8309: 1993 (Reviewed in 2019)	Compression type tubular terminal ends for aluminium conductors of insulated cables - Specification
IS:13573: 2011 (Reviewed in 2024)	Cable accessories for extruded power cables
IS 3809: 1979 (Reviewed in 2017)	Fire resistance test for structures
DIN 46329	Cable lugs for compression connections, ring type, for Aluminium conductors
IS 694: 2010 (Reviewed in 2020)	Polyvinyl chloride insulated unsheathed-and sheathed cables/ cords with rigid and flexible conductor for rated voltages - up to and including 450/750V
IS 16781: 2018 IEC 62852: 2014 (Reviewed in 2023)	Connectors for dc Application in Photovoltaic Systems Safety Requirements and Tests

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Standard	Description
IS 10810 (Part 62): 1993 (Reviewed in 2019) /IEC 60332 Part-3	Method of tests for cables: Part 62 flame retardance test for bunched cables
IEEE-383	Standard for type test of Class IE Electric Cables
IS 4905: 2015/ ISO 24153: 2009 (Reviewed in 2020)	Random sampling and randomization procedures (First Revision)
IS 10418: 2024	Drums for Electric Cables - Specification (First Revision)

Heat dissipation in floating solar installations differs markedly from that of ground-mounted systems, as cables are laid on high-density polyethylene (HDPE) floats, which are susceptible to heat buildup and potential melting. This makes high-quality electrical connections essential to maintain system integrity.

Consequently, cabling standards for FPV systems should be more rigorous than those for ground-mounted setups, ensuring that all electrical connections meet the highest quality standards to prevent heat-induced failures.

2.6.3 Combiner Box

Depending on the project design, either AC or DC combiner boxes may be utilized. In both cases, considering their proximity to water bodies, the combiner boxes must be specifically designed to operate effectively in a humid environment. Enclosures for combiner boxes are typically made from materials such as FRP, polycarbonate, polyamide, and galvanized iron (GI) sheet metals. Among these, polycarbonate offers superior durability for outdoor applications, providing better fire and chemical resistance compared to other polymer and metal-based materials. This section highlights the challenges associated with combiner boxes in FPV and proposes potential mitigation measures.

Table 15: Major issues and recommendations with combiner box in FPV

Parameters	Description	Recommendation
Material quality	String combiner boxes are not specifically designed for marine environments like lakes or reservoirs, where they may face more intense humidity and dynamic humidity (DH).	Polycarbonate-based enclosures are ideal for marine environments, offering good durability. Protective covers or small canopies can be used to reduce direct UV and solar irradiation exposure.
Water ingress	Combiner boxes in FPV are exposed to water splashes or partial immersion, leading to potential water ingress.	Use combiner boxes with a bottom-entry cable design to prevent water stagnation. Ensure the installation height is sufficient and above the minimum bending radius of the cables. Enclosures should be at least IP65 rated.
Insulation protection	combiner boxes in FPV are installed on HDPE floats near PV modules or walkways, which may stress the cables.	Cables should be installed through cable trays or conduit pipes, allowing enough slack to avoid stress on the combiner box.
Fire resistance	Floating solar plants contain flammable components like HDPE floats and cables, making combiner boxes susceptible to fire incidents.	Combiner boxes must be fire-resistant and should not contribute to the spread of fire, both horizontally and vertically.
Aging	Design age of the plant	As this material tend loose its structural ability over the time due to prolonged exposure of UV, salt corrosion and humidity, it should be replaced periodically based on the manufacture recommendation.

Combiner boxes (AC/DC) shall comply to standards mentioned below.

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Standards	Description
UL 94V	Fire Resistant/ flammability for Enclosure
UL 746C	UV Resistant for Enclosure
IS 17050: 2023/ IEC 62262: 2021	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts
IS/IEC 60529: 2001 (Reviewed in 2019)	Degrees of protection provided by enclosures (IP Code)
IEC 60269: 2024	Low-voltage fuses
IEC 61643 (Part 11): 2016/ IEC 61643-11: 2011 (Reviewed in 2021)	Low - Voltage surge protective devices: Part 11 surge protective devices connected to low - Voltage power systems - Requirements and test methods
IS 16463 (Part 12): 2017/ IEC 61643-12: 2008	Low - Voltage surge protective devices: Part 12 surge protective devices connected to low - Voltage power distribution systems
IEC 62208	Enclosure for low voltage Switchgear and control gear assemblies
IS/IEC 60695-2-11: 2021	Fire hazard testing
IS / IEC 61439-3(2012) reviewed in 2024	Low voltage switchgear and control gear assemblies / enclosure requirements
IS/IEC 60068-2-5:2018 (Reviewed in 2025)	Environmental Testing Part 2 Tests Section 5 Test S: Simulated solar radiation at ground level and guidance for solar radiation testing and weathering

Consideration should be given to additional mechanical stresses and load combinations when installing on the floating platform. The boxes should be shielded from direct sunlight with secondary roofing. Information such as maximum voltage, operating voltage, current, short-circuit rating, and safety warnings in both English and the local language should be labeled on the combiner boxes. Whenever possible, combiner boxes should be pre-installed on land and transported to the FPV system on the water.

2.6.4 Transformers

In FPV systems, transformers can be supplied as independent units or as part of a compact substation, with the need for proper ventilation and minimum IP ratings. When selecting a transformer, considerations include the risk of oil spillage, the site's conditions, potential effects on water bodies (especially if used for drinking water or fishing), and the transformer's susceptibility to corrosion. Dry-type transformers are preferred in areas with high wave, wind, or movement conditions. Special attention should be given to the transformer's protective materials, coatings, and mechanical design to withstand prolonged exposure to vibration and movement. For electrical safety, an IT system is optimal, providing better fault protection and higher availability. This section highlights the challenges associated with transformers in FPV and proposes potential mitigation measures.

Table 16: Major issues with Transformer in FPV

Parameters	Description	Recommendation
Design	Offshore transformers face additional stress due to the movement of floats.	Ensure transformers are mechanically designed to withstand hydrodynamic forces. Increase mooring and anchoring to reduce float movement. Add dampeners to minimize vibration stress. Install nitrogen injection fire protection systems (NIFPS) as needed. Implement SCADA systems for monitoring transformer parameters.
Breakdown voltage of bushing	In offshore environments, salt deposition can increase the risk of phase-to-ground faults.	Increase the breakdown voltage of the bushing and ensure proper creepage distance. For MV transformers, use cable boxes with IP65 or higher ratings to prevent salt deposition on bushings.

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Protection	Oil seepage into the waterbody may harm marine life and water quality.	Use hermetically sealed, oil-filled transformers with natural, environment-friendly oils. In specific cases, consider dry-type transformers with special construction.
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Transformer shall comply to the standards mentioned below.

Standard	Title
IS 2026: 2011 (Reviewed in 2021)	Comprehensive guidelines for power transformers including design specifications, testing procedures, performance criteria
IS 2026 (Part 1): 2011 (Reviewed in 2021) / IEC 60076-1	Power transformers: Measurement of Voltage Ratio & phase displacement; Measurement of winding resistance on all the taps
IS 2026 (Part 3): 2018 IEC 60076-3: 2000 (Reviewed in 2023)	Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air
IS/IEC 60076-4: 2002	Power Transformers Part 4 Guide to the Lightning Impulse and Switching Impulse Testing ½ Power Transformers and Reactors
IS 2026 (Part 5): 2011 /IEC 60076-5	Power transformers – Part 5: Ability to withstand short circuit
IS 2026 (Part 7): 2009 (Reviewed in 2019) /IEC60076-7	Guide for loading of oil immersed transformers
IS 2026 (Part 11): 2021/ IEC 60076-11: 2018	Power transformers – Part 11: Dry-type transformers
IS 11333: 1985 (Reviewed in 2021)	Specification for flameproof dry type transformers for use in mines
IS 3637: 1966 (Reviewed in 2016)	Specification for gas - Operated relays
IS 9434: 2019 IEC 60567: 2011	Oil-Filled Electrical Equipment — Sampling of Gases and Analysis of Free and Dissolved Gases — Guidance (Second Revision)
IS 10593: 2023 IEC 60599:2022	Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis
IS 3639: 1966 (Reviewed in 2021)	Specification for fittings and accessories for power transformers
IS 2099: 1986 (Reviewed in 2018)	Bushings for alternating voltages above 1000 Volts
IS/ IEC 60137: 2017 (Reviewed in 2024)	Insulated Bushings for Alternating Voltages above 1000 V
IS 3347: 1988 (Reviewed in 2019)	Dimensions for porcelain transformer bushings for use in lightly polluted atmospheres: Part 3 -17.5 kV bushings: Sec 1 porcelain parts (Second Revision)
IS 12676: 1989 (Reviewed in 2021)	Oil impregnated paper insulated condenser bushings - Dimensions and requirements
IS 2705: 2017/ IEC 60185	Current transformers - Specification: Part 1 general requirements (Second Revision)
IS 335: 2018/ IEC 60296	Standards for mineral insulating oils used in electrical equipment
IS 16081: 2013 IEC 61099: 2010	Insulating liquids - Specifications for unused synthetic organic esters for electrical purposes

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Standard	Title
(Reviewed in 2024)	
IS 16659: 2017 IEC 62770: 2013 (Reviewed in 2024)	Fluids for electrotechnical applications - Unused natural esters for transformers and similar electrical equipment
IEC 61869/ IS 16227 series	Instrument transformers
IS 17050: 2023/ IEC 62262: 2021	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts
IS 10028/ IS 1646	Selection, installation, and maintenance of transformers

When installed on a floating platform, considerations for system movements due to waves, wind, and current should be considered to avoid damaging the inverter and transformer or affecting their performance. Inverters and transformers can be housed in protective structures to ensure long-term reliability and prevent exposure to environmental conditions. Installing inverters and transformers with secure, vibration-resistant mountings to accommodate the platform's movement. After installation, all spare parts, tools, and loose items must be removed from the enclosure. Unused terminals should be sealed, and durable warning signs and labels should be affixed. If oil-based transformers are used, measures to mitigate oil leaks should be taken. Inverters and transformers should be transported to the installation location on the water using appropriate methods, following standard industry practices.

2.6.5 Electrical Safety

A. Grounding:

The grounding of a solar plant is crucial for safeguarding the equipment and ensuring operational safety. In comparison to ground-mounted installations, the earthing and lightning protection for floating solar systems are more complex and still evolving as the industry works to establish best practices. Currently, three techniques³⁶ are being utilized, as outlined below.

- **Shore-based Protection:** The earthing connections of various equipment from the floating island are extended to the shore and grounded following conventional practices.
- **Waterbed-based Earth Pits:** Earthing connections are extended underwater to dedicated earth pits located on waterbed.
- **Using earth electrodes suspended in water at certain depths:** Utilizes the water body as the grounding path, with earth electrodes suspended in the water to dissipate leakage currents. This method poses risks to personnel and marine life and requires precise data on water conductivity, which varies with depth and temperature.

All exposed conductive parts must be interconnected and terminated either into the water at a suitable depth or to the waterbody floor using earthing rods and connected to the electrical system's earthing. In some cases, such as for IT systems, termination to the electrical system may not be necessary if justified by the risk assessment.

The earthing design should consider various floating technologies, particularly for non-conductive materials, where equipotential bonding may not be required if justified. The system must ensure no potential difference exists between the water and exposed parts of the solar installation that could harm humans or animals. Additionally, earthing design should incorporate site-specific earth resistance measurements and consider the functional earthing of the DC side of the system for PID prevention.³⁷

Earthing shall comply to the below mentioned standards:

Standards	Description
IS 3043: 2018	Code of practice for earthing
IEEE: 80	IEEE guide for safety in AC substation grounding

³⁶ [The World bank \(2023\): Unlocking floating solar photovoltaic potential in India](#)

³⁷ [DNV \(2021\): design-development-and-operation-of-floating-solar-photovoltaic-systems](#)

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IEEE: 837	Standard for qualifying permanent connections used in substation grounding
IS 17978: 2022/ IEC TR 63227: 2020	Lightning and Surge Voltage Protection for Photovoltaic (PV) Power Supply Systems
UL-467	Grounding and Bonding Equipment
CEA Regulations	CEA regulations for electrical safety-2010 / Indian Electricity Rules/ Indian Electricity Act.
ESE type lightning	ESE type lightning system must be installed at all the places covering entire PV plant as per detailed system design.

B. Lightning protection system

It plays a critical role in safeguarding PV installations from the destructive effects of direct lightning strikes and the potential fires caused by lightning-induced currents. The implementation of an LPS is essential, particularly at FPV sites, where such risks are more pronounced. This protection extends to the onshore substation rooms responsible for off-taking FPV power, which must also adhere to local building regulations and be equipped with an LPS.

Additionally, developers are advised to conduct a thorough risk analysis to evaluate the specific lightning risks at each location. By consulting local meteorological service records, developers can better understand the frequency and intensity of lightning strikes in the area, enabling them to deploy the appropriate protection systems for the site.

- **External Lightning Protection System (LPS):** It intercepts direct lightning strikes and safely discharges lightning currents to the ground, preventing thermal or mechanical damage and minimizing fire or explosion risks. It consists of an air-termination system, down-conductor system, earth-termination system, and lightning equipotential bonding. The system is commonly used in ground-mounted or rooftop PV installations, with methods like rolling sphere and protective-angle to determine the protected volume. Adequate separation between the LPS and the PV system is essential to avoid flashovers to adjacent metal parts³⁸.
- **Internal Lightning Protection System (LPS):** It protects equipment using surge protection devices and equipotential bonding, along with smart cabling design. Type II surge protection devices are recommended for both DC and AC sides of the system. Long cables extending over water should have minimized wiring loops to reduce the risk of lightning-induced currents. Equipotential bonding elements are routed close to DC and AC cables, ensuring the safe discharge of lightning currents to the earth, with attention to flexibility and secure attachment to avoid damage from movement or fatigue.

Additional Considerations for Floating Solar PV Installations:

Unlike ground-mounted systems, FPV installations operate above water bodies, where aquatic ecosystems exist directly beneath. This unique context necessitates a heightened focus on two critical safety areas: **lightning protection and grounding. Floating PV systems are particularly susceptible to lightning strikes**, which are more frequent over open water bodies. Therefore, a **robust and site-specific lightning protection system** is vital to ensure operational safety and equipment protection.

Grounding also presents unique challenges for FPV. Ground-mounted systems benefit from direct contact with the earth for effective dissipation of electrical surges. In contrast, floating systems **lack a direct ground reference**, and if not properly grounded, may pose **safety hazards to both equipment and aquatic life**. If grounding is extended to the shoreline, the long distance may reduce its effectiveness, necessitating specially designed grounding approaches for floating systems.

2.6.6 Electrical Layout of FPV Plant

The key components of the electrical layout include the PV modules and arrays, inverters, transformers, and the cabling system. The PV modules generate DC power, which is then converted into AC power by inverters. These inverters can either be **central inverters**, which handle a large amount of power at a single point, or **string inverters**, which are smaller and more distributed across the system for redundancy and flexibility. Transformers are used to step up the voltage to minimize losses during transmission over longer distances.

³⁸ [The World bank \(2019\): Where-Sun-Meets-Water-Floating-Solar-Handbook-for-Practitioners](#)

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The optimal configuration of inverters and transformers directly impacts the **overall efficiency** and **operational performance** of the FPV system. The following scenarios illustrate the different combinations of inverter and transformer placements:

- **Scenario A:** This configuration is suitable for smaller FPV systems where both inverters and transformers are placed onshore. The proximity of the electrical equipment to the shore minimizes transmission losses but may require additional considerations for flood protection.
- **Scenario B:** This setup places both the inverters and the transformer on floating platforms. It minimizes power losses in long-distance transmission and is preferred for large systems located far from shore.

For larger FPV systems located far from shore, floating inverters and transformers are preferred to minimize transmission losses. For smaller systems, onshore configurations are more practical due to their lower installation complexity and ease of maintenance. Based on Stakeholder consultation the choice of type of inverter and configuration of inverter and transformer should **strike a balance between minimizing electrical losses, ensuring redundancy, and optimizing long-term performance and maintenance accessibility**.

The choice of cabling solution is another crucial consideration in the electrical layout. The cabling system is composed of **static cables**, which are used within the platform, and **dynamic cables**, which connect the floating units to the shore, accommodating the movement of the floating structure. Dynamic cables are supported by floaters and arranged in an "S" shape to allow for the movement of the floating platform. This design helps prevent tension in the cables and ensures that they can accommodate the dynamic motions of the floating system.

2.6.7 Connection of FPV to grid

The power evacuation process for a FPV system involves transferring the electricity generated by the solar modules to a substation for further distribution. Key components in the FPV substation include PV modules, which convert sunlight into DC electricity, and inverters, which transform DC into AC for grid compatibility. Step-up transformers are employed to increase the voltage levels for efficient transmission. The mooring system ensures the stability of the floating structures during operation, while underwater or floating cables are used to carry electricity from the FPV system to the substation. These cables must be durable and leakage-proof to ensure safe transmission. Additionally, protection and control equipment, such as circuit breakers, relays, and metering systems, are installed to monitor the system and ensure the safety and reliability of the power evacuation process. The following outlines the process on-grid and off-grid scenarios.

- **On-Grid Connection:** This scenario is the most common, where FPV plants are connected to existing electrical infrastructure or nearby substations.
 1. **No Grid Upgrade:** The FPV plant connects directly to existing electrical lines, limited by the current infrastructure's capacity and usage. For example, a small-scale FPV plant might connect to a local distribution network without the need for additional substations or transformers.
 2. **With Grid Upgrade:** New infrastructure, such as transmission lines or substations, is constructed to accommodate the additional power supply from the FPV plant. Large-scale FPV plants, for example, may require high-capacity transformers and new transmission lines for seamless integration into the grid.
- **Off-Grid Connection:** In off-grid scenarios, FPV systems are often deployed in rural areas with water reservoirs where grid access is unavailable such as excess energy generated during peak sunlight hours is stored in batteries for use during low-sunlight periods. Lithium-ion batteries are commonly used due to their efficiency and long lifespan. Off-grid FPV systems can power remote communities near water reservoirs or support irrigation and water treatment systems in rural areas.

FPV plants must meet grid requirements for safe and reliable operation, including power quality standards for voltage, frequency, and harmonic distortion. Safety features such as overcurrent protection, grounding, and equipotential bonding are essential. Additionally, compliance with N-1 contingency ensures the system remains operational even if a component fails, maintaining reliability.

2.7 Installation Considerations

The successful installation of FPV systems is crucial for ensuring the long-term performance, safety, and durability of the project over its lifecycle. Proper planning, precise execution, and adherence to best practices throughout the installation process are essential. The following sections provides an overview of key best practices for installing FPV systems, from pre-installation activities to final testing and commissioning. The major processes involved in FPV projects are:

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2.7.1 Pre-Installation Activities

Before starting the installation of an FPV system, several preparatory activities are crucial to minimize risks, delays, and unforeseen challenges and ensure that the project complies with regulatory, environmental, and technical aspects of the FPV project. The successful deployment of FPV plants requires carefully selected land sites for critical infrastructure, including pooling stations, assembly sites, and substations.

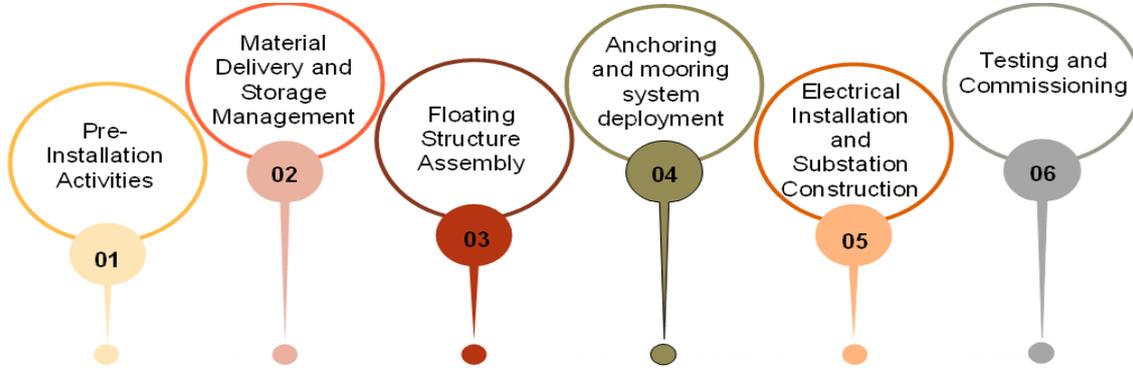


Figure 19: Major processes involved in FPV projects

Pooling stations should be strategically located **near the FPV installation** to reduce transmission losses and facilitate efficient maintenance. These sites must have reliable road access to ensure smooth transportation of equipment and personnel, with secure fencing to protect infrastructure from unauthorized access. Additionally, pooling stations should be positioned away from ecologically sensitive areas and comply with environmental regulations to minimize disruptions to local ecosystems and biodiversity.

Assembly sites play a crucial role in FPV deployment, requiring sufficient space for assembling floating solar modules and storing essential components and tools. Proximity to manufacturing hubs, ports, or load centers can streamline logistics, reduce transportation costs, and enhance overall project efficiency. A well-developed infrastructure, including roads and utilities, is necessary to support construction activities, ensuring the smooth movement of materials and workforce. Additionally, these sites should be located in areas where land availability does not conflict with agricultural or residential land use, avoiding potential disruptions to local communities.

Substations should be strategically placed near existing electrical infrastructure to facilitate seamless grid integration and minimize the costs associated with new transmission lines. Ensuring regulatory compliance is essential, as substations must adhere to local guidelines governing electrical installations and land use. Apart from land-based infrastructure, general considerations for FPV deployment include assessing water surface characteristics such as wave amplitudes, wind impact, and water level fluctuations to ensure system stability. Conducting environmental impact assessments is also critical to mitigate potential ecological risks, protect aquatic ecosystems, and support long-term sustainability. By carefully selecting and planning land sites for FPV infrastructure, projects can optimize energy production, enhance operational efficiency, and minimize environmental and logistical challenges.

Best Practices: Detailed site assessments to evaluate environmental and technical aspects are crucial to mitigate risks early. Early and proactive engagement with regulatory bodies can prevent delays and streamline the permitting process.

2.7.2 Material Delivery and Storage

Effective material delivery and storage management are important to minimize delays and ensure smooth execution during installation. Floats, typically made from high-density polyethylene (HDPE) or similar materials, are lightweight but bulky, making transportation a challenge. Coordinating for just-in-time delivery of floats can reduce the need for large storage spaces. In some cases, manufacturing floats locally or near the project site can reduce logistical costs and timely delivery.

Sufficient storage capacity near the installation site is critical, especially for large-scale FPV systems. A proper storage area is necessary to safely house floats, PV modules, electrical equipment, and other components. Electrical components such as inverters and transformers should be stored in covered areas to protect them from environmental exposure until, they are ready to be installed.

Case study: NTPC Kayamkulam FPV (92 MW): Extensive planning was undertaken for the unloading and storage of modules, with all modules delivered within a month through roadways. An appropriate storage area near the site was identified due to the large space required for FPV components. Additionally, the float

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manufacturer, Ciel & Terre, set up a production facility near the project site, reducing transportation costs and enabling just-in-time delivery.

Best Practice: Establishing local production facilities for components like floats, anchors, and mooring system where possible to reduce transportation costs and improve logistical efficiency. Designating an organized storage area near the project site for proper storage of equipment.

2.7.3 Installation

The installation of a FPV system involves a multi-step process that includes assembly, launching of floating structure, electrical interconnection, deployment of anchoring, and mooring. Below is a structured overview of the key stages for installing a floating PV system, based on the construction and procurement practices described.

1. Assembly of Floating Structures

Once the materials arrive on-site, the assembly of the floating structures begins. Floating structures are typically made up of smaller modular units, which are assembled by multiple teams of workers.

- **Layout of Components:** Floating base components—such as pipes, metal frames, or plastic floats, depending on the design—are laid out on the ground or a prepared ramp area.
- **Unit Assembly and Launching:** Each assembled unit is connected to the next, forming continuous rows. As the rows are completed, they are gradually launched into the water. This process is repeated until the entire floating platform is assembled on the water surface.

2. Interconnection and Launching

Once individual units are assembled, they are interlinked to form longer rows. The interconnection process includes:

- **Electrical Interconnection:** Interconnection of modules according to the single-line diagram (SLD) to form strings. This includes connecting modules, junction boxes, and string inverters.
- **Launching the Units:** After the units are assembled and electrically interconnected, they are gently pushed into the water using the launch ramp or similar infrastructure.
- **Towing to Position:** Once the units are launched, they are towed to their designated final location in the water using motorized boats.

3. Deployment of Mooring and Anchoring

Mooring and anchoring are critical steps to ensure the floating PV system remains in place once deployed in the water. The method chosen depends on the bathymetry and site-specific conditions.

Floating structures can be anchored to the bank or to the bottom of the water body using mooring lines (ropes, chains, wires, etc.). This can involve the use of specialized barges and, if necessary, professional divers to secure the system. Buoys are employed to keep mooring connections afloat, and these are later connected to the floating structures for stability.

4. Cable Routing Management

Proper management of cable routing is crucial to ensure the longevity and efficiency of the FPV system. DC cables are routed as follows:

DC Cable Connections: Interconnections between solar modules, from the modules to the junction box, and from the junction box to the inverter are made on land, typically while the system is on the launch ramp.

Cable Placement: All DC cables should be secured with cable ties or clamps, ensuring they stay above the water to avoid corrosion. It is also important to leave slack in the cables to avoid strain and potential rupture. Proper protection, such as wiring trunks, should be used to guard against UV exposure.

Main Cable Trunk: The main cable trunk from combiner boxes to central inverters is routed on floats or in protective conduits. This ensures that the cables do not rub against fasteners or other sharp objects, which could cause damage.

5. Substation and Onshore Electrical Works

In FPV projects, substations are constructed to house inverters and electrical equipment such as transformers and switchgears. These substations are usually located onshore and are linked to the FPV system.

Civil works for substations are conducted according to national electrical standards, like those for ground-mounted PV systems.

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Electrical connections are made from the inverters to the grid infrastructure. These connections are made using submarine cables or additional floats depending on the system design.

2.7.4 Testing and Commissioning

The critical step in FPV installation is the testing and commissioning phase to verify that the system functions as designed. Thorough inspections and tests ensure that the system is ready for operation and can perform efficiently over the long term.

- **Electrical Testing:** All electrical components must be tested to ensure proper grounding, voltage regulation, and surge protection. This is critical to avoid electrical faults or damage to the system after commissioning.
- **Mooring and Structural Integrity:** The mooring system should be tested under various weather and water conditions to ensure that it remains secure. Additionally, anchors should be inspected regularly to detect any signs of wear or movement.
- **Final Inspections:** A comprehensive inspection of all system components, including, floats, anchors, electrical systems, and safety equipment, is essential to identify any potential issues before the system is declared commercially.

2.8 Combination of Floating PV Plants with Other Energy Systems

Integrating a floating photovoltaic plant with other energy systems, such as hydropower, energy storage, and wind power, creates a hybrid system that harnesses the complementary strengths of each source. This approach enhances energy reliability and stability while optimizing the use of existing water bodies, such as reservoirs, for FPV deployment. Additionally, it maximizes land use efficiency and helps reduce water evaporation.³⁹

2.8.1 FPV and Hydropower

- **Increased Energy Production:** Combining FPV with hydropower allows for higher total energy output, especially during the day when solar energy generation is at its peak. Hydropower can then provide baseload power, ensuring a continuous supply.
- **Infrastructure Synergy:** FPV systems can leverage existing hydropower infrastructure, including transmission lines and grid connections, reducing additional investment costs.
- **Optimized Water Resource Utilization:** Floating solar panels can reduce evaporation by covering water surfaces, preserving water levels essential for hydropower generation. Studies suggest that FPV can reduce water evaporation by over 80%.
- **Grid Stability:** The combination of hydropower and FPV creates a more stable energy supply by reducing PV curtailment and allowing for flexible power dispatch.

FPV can be deployed on the water basins of **pumped-storage hydropower plants**. In such systems, during periods of excess solar energy production, hydropower reservoirs can store energy by pumping water to higher elevations, ensuring energy availability during peak demand hours. This stored energy can later be released to generate electricity when solar power generation is low, making the reservoir function as a natural battery. Wind turbines can also be incorporated to pump water into reservoirs, further enhancing energy storage capabilities.

2.8.2 FPV and Wind Power

- **Complementary Generation Profiles:** Solar power generation peaks during the day, while wind power is often more abundant at night or in different seasons, ensuring a continuous power supply.
- **Cost Efficiency:** Hybrid systems utilizing both wind and solar can share grid infrastructure, reducing the cost of power electronics, inverters, and transmission systems. For instance, a study in Minnesota demonstrated that integrating 500 kW of solar with a 2 MW wind turbine reduced operational costs by \$150,000 per year.
- **Enhanced Grid Reliability:** Since wind and solar energy sources are typically anti-correlated, combining them results in a more balanced power output, reducing grid fluctuations.

2.8.3 FPV and Energy Storage

- **Peak Shaving & Load Balancing:** Excess energy generated by FPV during the day can be stored in batteries or other energy storage systems and discharged during peak demand periods, reducing strain on the grid.

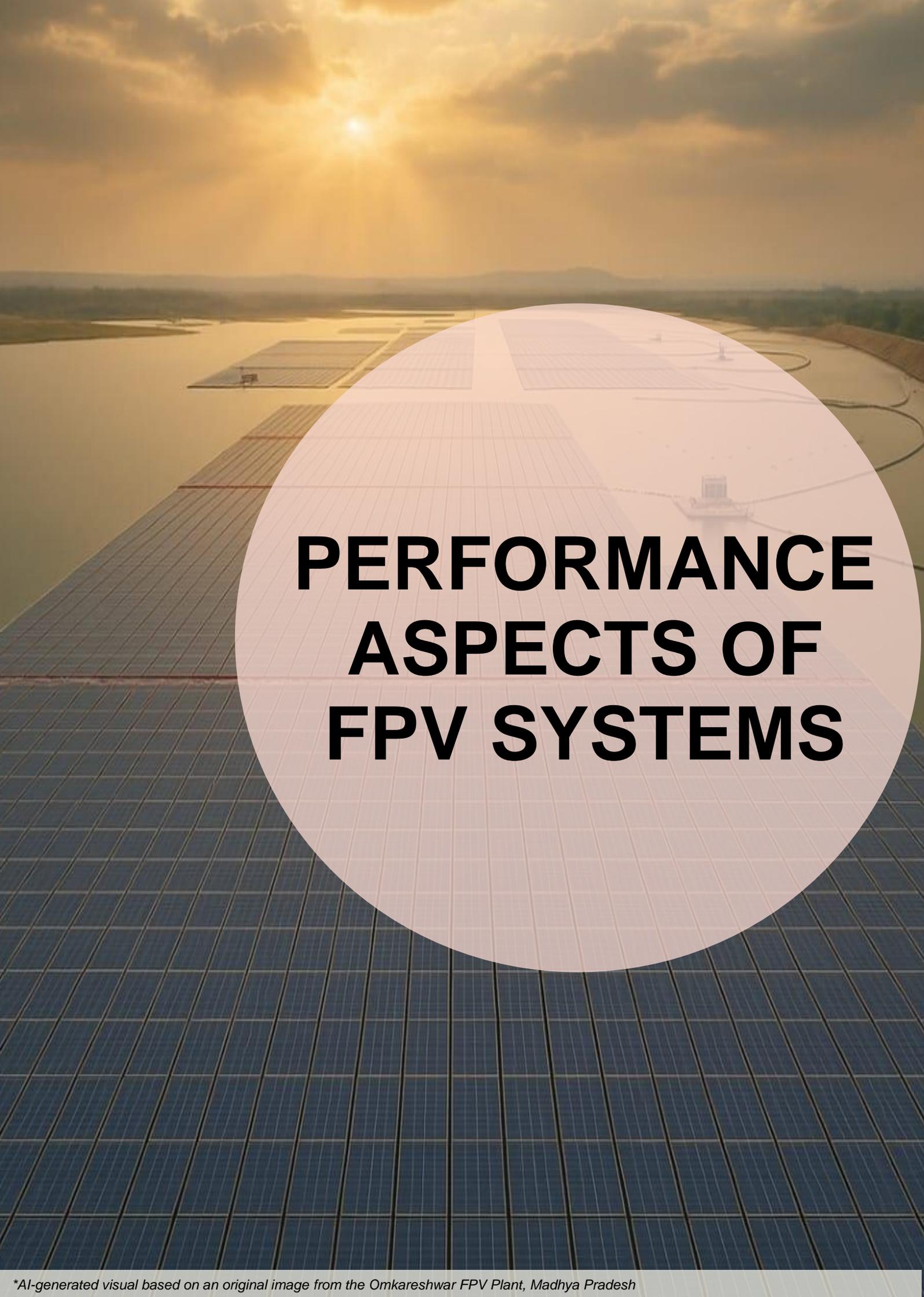
³⁹ [Enel Green Power \(Sept 2024\): Renewable Hybrid Power Plant \(Accessed on 24-04-2025\)](#)

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- **Grid Resilience & Backup Power:** Battery storage can provide backup power during outages or periods of low renewable generation, ensuring uninterrupted energy supply.
- **Compressed Air Energy Storage (CAES):** FPV systems can be integrated with compressed air storage, where excess solar energy powers water pumps to pressurize air in storage tanks. The stored air can later drive hydro turbines to generate electricity when needed, further enhancing energy reliability.

2.8.4 Design Considerations for Hybrid FPV Systems

Effective implementation of hybrid floating PV systems requires thorough **site evaluation**, including resource assessment of solar radiation, wind speed, and hydropower availability to optimize energy generation. Waterbody characteristics such as depth, water level variations, sedimentation, and wave conditions must be analyzed to ensure FPV system stability. Additionally, assessing grid connectivity, including proximity to transmission lines, grid capacity, and local energy demand, is essential for seamless integration. **System integration** plays a key role in efficiency, requiring the use of advanced power electronics such as inverters and converters to manage multiple energy sources. Implementing hybrid energy management and real-time monitoring ensures optimized performance while integrating battery or pumped hydro storage enhances grid stability and energy reliability. Moreover, **environmental, and regulatory compliance** is crucial, requiring an assessment of potential ecological impacts on aquatic ecosystems and biodiversity. Adhering to national and local regulations ensures responsible deployment, while sustainability measures should be adopted to minimize environmental disruption and maximize water conservation.

An aerial photograph of a vast floating photovoltaic (FPV) system installed on a large body of water. The solar panels are arranged in neat, parallel rows that stretch across the horizon. The sun is low in the sky, creating a warm, golden glow and long shadows. The water reflects the light from the sun and the panels. In the background, there are some structures and possibly a small boat on the water.

PERFORMANCE ASPECTS OF FPV SYSTEMS

3 Performance Aspects of FPV systems

3.1 Introduction

This document provides a comprehensive overview of the performance aspects of FPV systems. FPV systems have emerged as a promising solution for harnessing solar energy, especially in regions with abundant water bodies. FPV systems can mitigate land use constraints by deploying solar panels on water bodies, reduce water evaporation, and enhance overall solar energy efficiency.

A key performance aspect of FPV systems is their potential to increase energy output compared to traditional ground-mounted solar systems. The cooling effect of water bodies can lead to improved solar panel efficiency, particularly during peak solar radiation periods. To quantify the extent of this energy boost, a detailed analysis of data from various FPV installations is crucial. By collecting and analyzing data on FPV installations of different sizes, we can assess the reliability and consistency of claims related to increased energy output. This analysis will provide a clear understanding of potential efficiency improvements achievable through FPV technology. Additionally, it will help identify key factors influencing FPV performance, such as water temperature, solar irradiance, and system design.

To enhance understanding of FPV performance, we have undertaken primary analysis by visiting FPV installations for different sizes of plants. Further, we have done secondary research on energy production increases attributed to the cooling effect, which involves a comprehensive review of existing literature, case studies, and field data. By analyzing these data, we have developed a more accurate assessment of the potential benefits of FPV systems and identify areas for future research and development. A comprehensive understanding of FPV system performance, particularly the energy production increases attributed to the cooling effect, offers significant advantages to both EPC players and industry experts.

By leveraging the insights gained from the analysis of energy production increases in FPV systems, EPC players and industry experts can contribute to the sustainable growth of the solar energy sector and address the global energy challenges.

3.2 Factors Influencing FPV Performance

The performance of FPV systems is influenced by a combination of **climate-based factors**, **design-based factors**, and **efficiency & reliability metrics**. These factors collectively impact energy generation, system efficiency, and long-term operational reliability. A comprehensive understanding of these factors is essential for optimizing system performance under varying environmental conditions.

Climate-based factors significantly impact energy generation and system efficiency. These factors, such as solar irradiance, ambient temperature, water quality, and wind conditions, are beyond human control but can be managed through strategic planning and operational adjustments. Key climate-based factors include:

- **Solar Irradiance:** Directly determines the amount of solar energy available for electricity generation. Higher solar irradiance results in greater energy production.
- **Ambient Temperature:** High ambient temperatures can reduce the efficiency of photovoltaic modules, as their performance typically decreases with rising temperatures.
- **Water Temperature:** Floating systems benefit from the natural cooling effect of water, which enhances module efficiency. However, extremely high-water temperatures may reduce this cooling advantage.

Although these climate-based factors cannot be controlled, their effects are considered during site selection and throughout the operational phase to optimize system performance.

Design-based factors, in contrast, these factors can be controlled through engineering decisions. These factors include the overall system design, inverter efficiency, module efficiency, and float type, which all play a crucial role in maximizing energy capture and system efficiency. Key design considerations include:

- **System Layout and Tilt Optimization:** Proper orientation and tilt angle of modules maximize sunlight capture, significantly improving energy generation.
- **Inverter and Module Efficiency:** High-efficiency inverters ensure better energy conversion from DC to AC power, reducing energy losses. The selection of high-efficiency solar modules directly impacts the overall energy output of the plant.
- **Float Type and Spacing**, which ensure structural stability and minimize energy losses.

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Apart from the mentioned factors, cost-benefit analysis also influences the performance of the FPV system. For each design, conduct a cost-benefit analysis (P50, P19, P75) and choose the optimal design accordingly. Then, perform performance simulations using tools like SAM, PVsyst, etc. Based on the simulation results, finalize the optimal configuration.

Efficiency & Reliability Metrics are key indicators used to evaluate the overall operational performance, energy generation efficiency, and reliability of Floating Photovoltaic (FPV) systems. These metrics are essential for performance monitoring, benchmarking, and identifying areas for operational improvement. The primary Efficiency & Reliability Metrics include:

- **Capacity Utilization Factor (CUF)** represents the ratio of the actual energy generated by the FPV system to the maximum possible energy output over a specific period, based on its installed capacity. A higher CUF indicates better energy generation efficiency and consistent system performance.
- **Performance Ratio (PR)** measures the overall efficiency of the FPV system by comparing the actual energy output to the theoretical energy generation under ideal conditions. It accounts for energy losses due to inverter efficiency, temperature variations, and system inefficiencies — serving as a critical indicator of how effectively the system converts available solar energy into usable electricity.
- **Mean Time Between Failures (MTBF)** indicates the reliability of system components by calculating the average time between two consecutive failures. A higher MTBF signifies better equipment quality, longer operational uptime, and reduced maintenance frequency.
- **Plant Availability** represents the percentage of time the FPV system is operational and available to generate energy, excluding downtime caused by scheduled maintenance or unexpected equipment failures. Higher plant availability improves overall energy yield.
- **Grid Availability** denotes the percentage of time the grid infrastructure is available to receive and export energy from the FPV system. Limited grid availability can restrict energy export, directly impacting the plant's energy output and revenue generation.

Table 17: Classification of Factors Affecting FPV Performance

Classification	Factors	Impact on FPV Performance
Climate-Based Factors		
Factors to Control	None	Climate factors cannot be controlled but can be mitigated through design and operational strategies.
Factors Which Influence	Solar Irradiance, Ambient Temperature, Water Temperature Humidity	These factors directly affect energy generation, module efficiency, and system performance.
Factors to Be Considered	Seasonal Variability, Local Climatic Patterns, Water Body Characteristics, Impact of Airborne Pollutants on PV Surfaces	Considered during site selection and maintenance planning to ensure optimal performance.
Design-Based Factors		
Factors to Control	Inverter Efficiency, Module Efficiency, Float Type	These factors can be controlled through thoughtful engineering, material selection, and technology optimization.
Factors Which Influence	Module and BoS Losses (affected by layout and material choice)	Influence energy efficiency by improving sunlight capture and minimizing energy losses.
Factors to Be Considered	Compatibility with Environmental Conditions, Resilience to Climatic Variations, Structural Design for Stability	Key considerations for ensuring durability, stability, and efficiency in various environmental and operational conditions.
Efficiency & Reliability Metrics		

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Classification	Factors	Impact on FPV Performance
Factors to Control	Plant Availability, Grid Availability, Equipment availability Mean Time Between Failures (MTBF)	These factors can be optimized through regular maintenance, quality equipment selection, and operational strategies.
Factors Which Influence	Capacity Utilization Factor (CUF), Performance Ratio (PR)	Directly influence the system's energy yield, uptime, and operational performance.
Factors to Be Considered	Real-time Monitoring Systems, Preventive Maintenance Plans	Essential for ensuring high system availability, efficient energy production, and long-term operational reliability.

The following section offers insights into how various factors impact FPV plant performance, focusing on analysis, case studies, and optimization recommendations.

3.2.1 Climate-Based Factors

Factors Which Influence Climate-Based Factors on FPV Performance

a. Solar Irradiance

Solar irradiance is the key factor affecting PV system energy generation. In tropical regions like India, solar irradiance values are generally high due to consistent and intense sunlight throughout the year. The daily average solar energy incident on India lies between 4-7 kWh/m²/day⁴⁰In tropical regions like India, solar irradiance values are generally high due to consistent and intense sunlight throughout the year.

India's solar energy potential varies by region and can be broadly categorized into eight zones. The highest annual solar radiation (1,942–2,159 kWh/m²) is observed in Gujarat, Rajasthan (west and south), eastern Madhya Pradesh, Maharashtra, Karnataka, Telangana, Tamil Nadu, Andhra Pradesh, and Ladakh. Other regions, including Haryana, central India, Odisha, eastern West Bengal, Kerala, parts of the Himalayas, and northeastern states like Assam and Nagaland, also receive significant solar radiation (1,724–1,941 kWh/m²), making them viable for solar power generation⁴¹.

Higher solar irradiance directly increases PV module current and power output. I-V and P-V curves show power output rises with increased irradiance at constant temperature module performance is directly proportional to solar irradiance for ground-mounted and FPV systems.

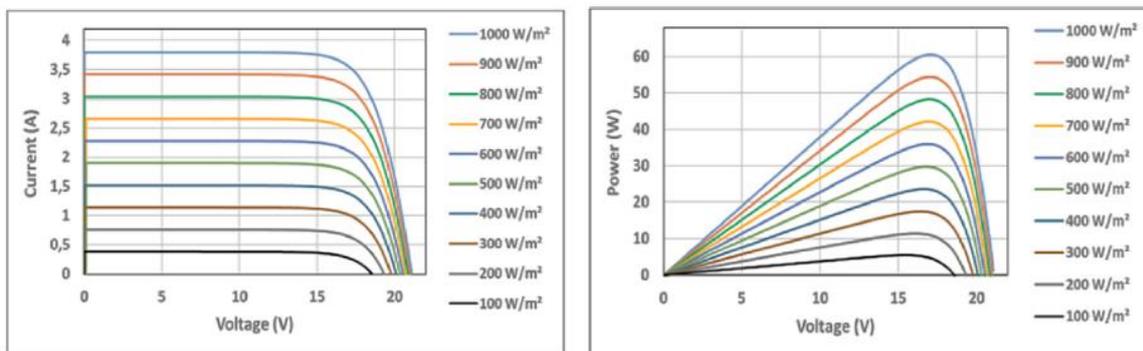


Figure 20: I-V and P-V characteristic with constant temperature (25° C) and variable irradiance

In India's climate, where ambient temperatures can be quite high, PV modules often operate above the standard test condition temperature of 25°C. This elevated operating temperature can lead to noticeable reductions in

⁴⁰ [Renewable Energy \(June 2014\): Solar power potential mapping in India using remote sensing inputs and environmental parameters](#)

⁴¹ [Renewable Energy \(Apr 2022\): An Assessment of Solar Power Potential and Prospects in India](#)

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power output. For instance, if a module's temperature rises to 45°C (a 20°C increase), the expected decrease in power output would be approximately 9% (0.45% x 20)⁴².

Global Examples Demonstrating Irradiance Impact:

Example 1 - Singapore's Tengeh Reservoir Plant⁴³

The Tengeh Reservoir Floating Photovoltaic (FPV) plant in Singapore achieves higher energy efficiency than land-based systems due to several carefully optimized factors:

- i. **Cooling Effect of Water:** Water naturally cools the solar panels, reducing thermal degradation and improving efficiency by maintaining lower panel temperatures. Compared to a rooftop solar PV system in Singapore, floating solar PV (FPV) systems performed noticeably better, generating 5-15% more energy. This boost in performance is largely due to the natural cooling effect of water and a combination of other contributing factors.
- ii. **Optimized System Design:**
 - **Tilt Angle:** The panels at Tengeh Reservoir are designed with an optimal tilt angle to maximize solar energy capture. **The tilt is typically set to match the latitude of Singapore (about 1°N), with the panels angled at approximately 10-15 degrees.** This tilt ensures that the panels are positioned to receive maximum solar irradiance throughout the day, capturing sunlight effectively even during the midday hours when the sun is at its highest point.
 - **Panel Layout:** The layout is carefully arranged to **minimize shading between modules**, which could otherwise reduce efficiency. The floating structure allows for flexibility in panel placement and adjustment to ensure the best possible sunlight exposure throughout the day.



Figure 21: 1MWp floating solar testbed on Tengeh Reservoir

Recommendations

Recommendation	Impact on Plant Performance
Panel Orientation	
<ul style="list-style-type: none"> ▪ Optimal Tilt Angle: Use PV systems having east-west orientation with a low tilt to maximize energy yield and minimize shading. Align panel tilt with the site's latitude. 	Maximizes sunlight absorption, increasing energy output.
<ul style="list-style-type: none"> ▪ Anti-Reflective Coating: Use panels with coatings to minimize light reflection. 	Increases light absorption, boosting energy yield.

Optimal tilt angle for FPV system should be carefully determined by considering wind speed, which affects structural stability, and shading effects that influence energy generation. Therefore, site-specific assessments are crucial for ensuring the best performance and durability of the FPV system. Increasing the tilt angle reduces the system's resistance to withstand high wind speeds. Additionally, it necessitates modifications to the floating structure, anchoring, and mooring design, leading to an increase in the Levelized Cost of Energy (LCOE). Therefore, rather than focusing solely on tilt angle for generation maximization, the preferred approach is to evaluate its impact on the overall LCOE, structural integrity and stability. Discussion with stakeholder consultation indicates a tilt angle of **5° to 7°** preferred.

b. Ambient Temperature

Ambient temperature plays a crucial role in the performance of FPV plants. High temperatures can reduce the efficiency of solar modules and accelerate component degradation, impacting energy output and system lifespan. However, FPV systems benefit from the cooling effect of water, which helps maintain stable module temperatures, reduces thermal stress, and ensures consistent energy generation. This makes FPV systems

⁴² [PV Education: Effect of Temperature \(Accessed on 24-04-2025\)](#)

⁴³ [Public Utilities Board \(PUB\)- Singapore National Water Agency: Tengeh Reservoir Case Study \(Accessed on 24-04-2025\)](#)

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more reliable and efficient, especially in regions with extreme temperature variations. During the installation of Floating PV (FPV) systems, weather monitoring stations are also set up to track ambient temperature and other environmental parameters. This helps in assessing the system's performance and analyzing its energy yield.

Global Examples Demonstrating Impact of Ambient Temperature

Example 1 - Singapore's FPV testbed⁴⁴

The Singapore FPV testbed provides valuable insights into how ambient temperature and cooling effects contribute to the efficiency of floating solar systems. Key Factors Influencing Ambient Temperature and Plant Efficiency:

1. Lower Ambient Temperature Above Water:

- The air temperature above the floating solar panels was **1–3°C lower** compared to adjacent rooftop installations. This reduction helped mitigate the thermal degradation typically seen in high ambient temperatures, improving module efficiency.

2. Water Cooling Effect:

- The **cooling effect from the water** beneath the floating panels maintained **lower module temperatures**, reducing temperature-induced efficiency losses. This is particularly important in tropical climates like Singapore's, where high ambient temperatures can impact solar performance.

3. Platform Design and Ventilation:

- **Free-standing floating platforms** provided the best cooling, as they allowed for better ventilation around the panels.
- **Smaller footprint platforms** with more open space at the back of the modules allowed increased airflow, further enhancing cooling.
- Platforms with larger water coverage and less ventilation showed the least cooling effect.

4. U-Value Optimization:

- By improving the **U-value** (thermal conductivity) of the platform from **30 to 35 W/m²-K**, a **2–3°C drop in module temperature** was achieved, leading to an estimated **1% increase in energy yield** (16 kWh/kWp).

Impact on Performance:

- The combination of water cooling, optimized platform design, and a favorable ambient temperature environment resulted in significant energy efficiency gains. The testbed demonstrated that effective cooling and strategic design adjustments could improve FPV performance in hot climates.

Recommendations

Recommendation	Impact on FPV Performance	Relevance to Indian Conditions
Leverage Water Cooling Effects	Water bodies naturally cool floating solar panels, reducing temperature-induced performance losses. This cooling effect can enhance energy efficiency by 5-10% over land-based systems, as the floating solar panels run at lower temperatures than land-mounted ones ⁴⁵ .	In India, with high ambient temperatures, utilizing floating solar systems on reservoirs and lakes can help mitigate heat stress, enhancing energy output.
Optimize Platform Design for Ventilation	Free-standing floating designs with adequate space between modules allow for better airflow, improving cooling efficiency.	In Indian regions with hot climates, free-standing platforms can provide better ventilation and lower module temperatures, improving overall system performance.
Select Platforms with Small Footprints and Better Ventilation	Platforms with smaller water coverage and more open space at the back of the	In areas with intense sunlight, such as Rajasthan or Gujarat, small footprint platforms can

⁴⁴World bank (Oct 2019): [Where sun meets water floating solar handbook for practitioners](#)

⁴⁵Cleaner Energy Systems (Dec 2024): [A comparative study of floating and ground-mounted photovoltaic power generation in Indian contexts](#)

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Recommendation	Impact on FPV Performance	Relevance to Indian Conditions
	modules offer better cooling and energy retention.	minimize heat buildup and optimize energy production.
Improve U-Value (Thermal Conductivity) of Floats	For a ground-mounted solar system, a conservative U-value of 29 W/m ² K is typically considered. However, for floating photovoltaic (FPV) systems, the U-value can be as high as 35 W/m ² K.	India's varied climate zones can benefit from selecting FPV platforms with better thermal insulation to maintain lower temperatures, improving energy yield during peak summer months.
Monitor and Adapt to Local Climatic Patterns	Continuous monitoring of temperature, humidity, and solar irradiance can help adapt system performance for optimal output.	In India, with diverse climates, adapting FPV system performance to local weather patterns (e.g., monsoon seasons or extreme heat waves) can ensure optimal energy generation throughout the year.

c. Water Temperature

Water temperature plays a crucial role in the performance of Floating Photovoltaic (FPV) systems. Cooler water temperatures help maintain lower module operating temperatures, improving efficiency, and preventing overheating, especially during peak sunlight hours. However, warmer water temperatures, particularly in shallow reservoirs or during hot seasons, can reduce the cooling effect, leading to slight efficiency losses. Additionally, prolonged exposure to warm water may accelerate the degradation of system components, impacting the long-term performance of the FPV plant.

Global Examples Demonstrating Water Temperature Impact

Example 1: Cirata Reservoir, Indonesia⁴⁶

The **Cirata Floating Photovoltaic (FPV) plant**, with a capacity of **145 MW**, is one of the largest FPV systems in Southeast Asia. It operates on a **deep-water reservoir**, which provides stable and cooler temperatures that are critical in enhancing system performance. Key factors contributing to the plant's high energy efficiency include:

- **Cooling Effect of Deep Water:**
 - The deep-water reservoir ensures stable and cooler temperatures, which regulate the temperature of the solar panels.
 - This cooling effect helps prevent overheating, which is common in land-based systems, especially during peak sunlight hours.
 - By mitigating temperature-induced losses, the system maintains optimal energy generation, even during hot periods.
- **Stable Temperature Environment:**
 - The **depth of the reservoir** contributes to a more **consistent and stable temperature** compared to shallow water bodies.
 - The cooler water at greater depths remains more constant, as deeper bodies of water experience slower temperature fluctuations. This reduces the temperature variability that could otherwise affect system performance.
 - This stability ensures that the FPV system performs reliably, even in areas with significant daily temperature variations, maintaining high efficiency and steady energy generation over time.
- **Thermal Stress Reduction:**
 - The cooling effect reduces thermal stress on the modules, preserving their performance and extending their lifespan.

This case study demonstrates the importance of **site selection** and **water body depth** in maximizing the cooling benefits of FPV systems. By leveraging the stable temperature environment provided by deep water,

⁴⁶Masdar (Nov,2023): Cirata Reservoir, Indonesia-Case study (Accessed on 24-04-2025)

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the Cirata FPV plant achieves stable, high-efficiency energy generation, making it a model for large-scale FPV projects in hot, tropical climates.

Recommendations

Category	Recommendation	Impact on Plant Performance
Site Selection	Prioritize reservoirs with depths greater than 5 meters. ⁴⁷	Ensures stable water temperatures, improving cooling effects and minimizing thermal-induced losses.
	Choose reservoirs with flowing water or natural circulation.	Enhances cooling through dynamic regulation, ensuring consistent energy output.
	Avoid shallow or stagnant water bodies, especially in tropical climates.	Reduces risks of elevated water temperatures, maintaining efficient module operation.
System Design	Optimize panel spacing to minimize shading while ensuring adequate airflow for improved cooling. While keeping low tilt of angle i.e. 5 to 7 degrees, the panel spacing can be reduced.	Improves air circulation and maximizes cooling effects, reducing module operating temperatures.
	Incorporate materials resistant to high temperatures (e.g., PID-resistant modules).	Protects against material degradation and ensures long-term system reliability.
Cooling Enhancements	Utilize designs that allow free water-air interaction under the platform. Use high-density polyethylene (HDPE) for floaters to ensure durability, UV resistance, and corrosion resistance.	Boosts convective cooling, minimizing overheating risks during peak sunlight hours.
	Consider phase change material (PCM) integrated coatings for the floating structure which absorb excess heat during peak hours and release it during cooler temperatures increasing efficiency of the PV systems ⁴⁸ .	Reduces heat absorption, preventing thermal build-up and supporting cooler operating conditions.

d. Humidity

Humidity significantly influences the performance of Floating Photovoltaic (FPV) systems. While higher humidity levels can enhance the cooling effect on solar panels, potentially improving efficiency, excessive humidity may also contribute to performance degradation through moisture ingress, corrosion, and variations in module temperatures. A study published in the journal *Energies* examined the impact of humidity on FPV systems, indicating that higher humidity levels could lead to a decrease in panel temperature, thereby enhancing efficiency.⁴⁹

A study conducted at IIT Dhanbad observed that the FPV module exhibited a 7°C lower temperature compared to a land-based module due to its direct contact with water, leading to a higher power output. However, over a 150-day period, the Performance Ratio (PR) of the FPV system declined by 6.6%, indicating long-term efficiency loss due to sustained high relative humidity (RH) levels.⁵⁰

Furthermore, a statistical analysis of an FPV system installed on a 24 m² water body in an urban setting highlighted the negative correlation between RH and both irradiance and ambient temperature. While RH does influence PV voltage, its impact is secondary to irradiance and temperature. Additionally, environmental factors

⁴⁷ [Applied Sciences \(Jan 2019\): Analysis and Prioritization of the Floating Photovoltaic System Potential for Reservoirs in Korea](#)

⁴⁸ [Journal of Cleaner Production \(Aug,2023\): Thermal regulation of photovoltaics using various nano-enhanced phase change materials: An experimental study](#)

⁴⁹ [Energies \(June,2023\): PV Temperature Prediction Incorporating the Effect of Humidity and Cooling Due to Seawater Flow and Evaporation on Modules Simulating Floating PV Conditions](#)

⁵⁰ [Jordan Journal of Electrical Engineering \(Mar,2023\): Effect of Humidity on the Generation Capacity of Floating](#)

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such as shading from nearby trees and evaporative cooling effects were found to alter the relationship between RH and FPV performance.⁵¹

In locations near sea level with high humidity, solar panels are particularly prone to Potential Induced Degradation (PID), especially during the rainy season. This factor must be carefully considered when designing and optimizing the FPV system to ensure long-term performance and reliability.

Recommendations

Factor	Recommendation	Impact on Performance
Ventilation and Airflow	Ensure proper spacing and ventilation between panels, guided by shadow analysis, to optimize performance and cooling efficiency.	Allows moisture to dissipate, preventing excessive buildup of humidity on the panels and reducing heat.
Humidity-Resistant Inverters	Use inverters specifically designed to withstand humid conditions.	Ensures reliable performance of inverters, preventing failures due to high humidity.
Surface Coatings	Apply anti-corrosion coatings to panels and electrical components.	Protects panels and electrical components from moisture-induced corrosion, ensuring consistent performance.
Localized Climate Monitoring	Use sensors to monitor humidity levels and adjust operations accordingly.	Provides real-time data to optimize plant performance and avoid humidity-induced losses.

These recommendations are aimed at optimizing FPV system performance in high-humidity environments by addressing the challenges that humidity presents.

Factors to Be Considered in Climate-Based Factors for FPV Systems

The **factors to be considered** in climate-based parameters play a critical role in the **operational performance** of Floating Photovoltaic (FPV) systems. While climate-based factors such as **solar irradiance**, **temperature**, and **humidity** cannot be controlled, understanding, and addressing these factors during the **site selection** and **maintenance planning** stages can significantly improve the system's **energy yield**, **durability**, and **operational efficiency**. Careful consideration of these factors helps minimize **performance degradation**, reduce **downtime**, and optimize long-term energy generation.

Factors to Be Considered	Impact on FPV Performance	Recommendations
Seasonal Variability	Seasonal changes in solar irradiance and temperature can cause fluctuations in energy generation. Low irradiance during monsoon or winter seasons reduces power output, while high temperatures can decrease module efficiency.	FPV system layout should be based on solar resource assessment with optimal tilt angles to maximize energy generation across all seasons.
Local Climatic Patterns	Frequent rainfall, fog, or high wind speeds can lead to reduced sunlight availability and temporary shutdowns , affecting plant availability.	Install weather-resistant components and use automated cleaning systems to prevent dirt buildup and improve module efficiency after rain or dust storms.
Water Body Characteristics	Water body properties such as water temperature , depth variations , and wave patterns can affect the cooling efficiency of modules and impact structural stability.	Conduct hydrological studies during site selection to ensure the anchoring and mooring systems are designed to withstand water level variations and turbulence.
Impact of Airborne Pollutants on PV Surfaces	Airborne dust, pollen, and algae growth can accumulate on module surfaces, reducing sunlight absorption and energy yield.	Implement regular module cleaning schedules and use anti-soiling coating materials to improve long-term module performance.

⁵¹ [IOP Conference Series \(Jul 2024\): Earth and Environmental Science - Influence of humidity on the performance of floating photovoltaic systems over ponds in a tropical urban environment](#)

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3.2.2 Design-based factors

Factors to Control in Design-Based Factors for FPV Systems

a. Module Efficiency

Module efficiency refers to the ability of photovoltaic (PV) modules to convert sunlight into usable electricity. Higher-efficiency modules are crucial for Floating Photovoltaic (FPV) systems, as they allow for more energy generation within a limited footprint, a critical factor when space is constrained by the size of the water body. Efficiency variations can directly affect energy yields, cost-effectiveness, and the environmental impact of FPV plants.

Global Examples Demonstrating Module Efficiency

Example 1: Omkareshwar Floating Solar Plant, India

The **Omkareshwar Floating Solar Plant** in Madhya Pradesh, India, utilizes **monocrystalline silicon modules** from **Tata Power Solar**. These high-efficiency modules play a crucial role in maximizing energy output within the limited space available on the Omkareshwar Reservoir. Key Factors for High Energy Efficiency:

- 1. Module Efficiency:** The use of **monocrystalline silicon panels** ensures high energy conversion, optimizing power generation despite limited space on the floating platform.
- 2. Cooling Effect of Water:** The floating panels benefit from the natural cooling effect of the water, which reduces thermal losses and enhances panel efficiency, especially in the hot climate of India.
- 3. Optimized Design:** The panels are carefully spaced and tilted at an optimal angle, ensuring maximum sunlight exposure, and reducing shading, further improving energy capture.
- 4. Inverter Efficiency:** High-performance inverters convert the DC power generated by the panels into AC power with minimal loss, maximizing the overall energy output.

In summary, the **Omkareshwar Floating Solar Plant** achieves high energy efficiency through **monocrystalline silicon modules**, effective cooling, optimized design, and efficient inverters, making it a successful model for floating solar technology in India.

Recommendations

Category	Recommendation	Impact on Plant Performance
Module Selection⁵²	Use monocrystalline, PERC, and n-type modules to ensure high efficiency based on LCOE and energy generation.	Higher efficiency modules convert more sunlight into electricity, increasing overall output.
Panel Quality	Select panels that are resistant to potential induced degradation (PID) to reduce power loss in environments with high humidity and temperature.	Reduces long-term degradation, maintaining higher energy yields over the lifespan of the system.
Anti-reflective Coating	Utilize anti-reflective coatings on modules to minimize light loss and increase absorption.	Improves light absorption and boosts energy output, improving overall module efficiency.
Panel Spacing	Optimize panel spacing to minimize shading while ensuring adequate airflow for improved cooling. Since panel spacing is a modeling parameter determined through shadow analysis in the chosen software, no fixed recommendation can be provided, as it varies based on site-specific conditions and simulation results.	Prevents shading and improves airflow, keeping panels cooler and more efficient.

⁵² [American Solar Energy Society: Monocrystalline vs Polycrystalline Solar Panels \(Accessed on 24-04-2025\)](#)

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b. Inverter Efficiency

Inverter efficiency, measured as the percentage of direct current (DC) from photovoltaic (PV) modules successfully converted into alternating current (AC), is a critical factor in the performance of Floating Photovoltaic (FPV) systems. Efficient inverters minimize energy losses during the DC-to-AC conversion process, ensuring maximum energy output. Efficient inverters maximize energy conversion, reduce system losses, and ensure steady power supply to the grid. Their ability to adapt to varying conditions in FPV environments makes them essential for optimizing the performance and energy yield of FPV systems.

Global Examples Demonstrating Inverter Efficiency

Example 1: Tengeh Reservoir FPV Plant, Singapore⁵³

The Tengeh Reservoir Floating PV Plant in Singapore utilizes **central inverters** to convert the direct current (DC) generated by the solar panels into alternating current (AC) suitable for the grid.

How Central Inverters Contribute to High Performance:

- **High Conversion Efficiency:** Central inverters are designed to handle large power capacities with high efficiency, ensuring minimal energy loss during the DC-to-AC conversion process.
- **Simplified Maintenance:** With a centralized system, maintenance and monitoring are streamlined, allowing for efficient identification and resolution of issues, which enhances overall system reliability.
- **Cost-Effectiveness:** For large-scale installations like the Tengeh Reservoir FPV Plant, central inverters can be more cost-effective due to economies of scale in both installation and operation.

Example 2: Wu-Shan-Tou Floating PV Plant, Taiwan⁵⁴

The Wu-Shan-Tou Floating PV Plant in Taiwan utilizes **string inverters** equipped with module-level power optimization.

How the Inverter Configuration Enhances Performance:

- **High Conversion Efficiency:** The string inverters achieve energy conversion efficiencies exceeding 98%, minimizing losses during the DC-to-AC conversion process and thereby enhancing overall plant performance.
- **Adaptability to Humidity:** Designed to withstand high pane levels typical of aquatic environments, these inverters ensure consistent performance in the floating PV setting.
- **Module-Level Optimization:** The inclusion of power optimizers at the module level allows for efficient operation even during partial shading or fluctuating sunlight conditions, maintaining stable energy output throughout the day.
- **Enhanced Monitoring and Maintenance:** Advanced monitoring capabilities enable real-time performance tracking at the module level, facilitating quick identification and resolution of inefficiencies, which improves overall system reliability.

By implementing this inverter configuration, the Wu-Shan-Tou Floating PV Plant effectively reduces energy losses and adapts seamlessly to environmental stresses, significantly enhancing the plant's energy yield and operational reliability.

⁵³ [Public Utilities Board-Singapore National Water Agency: Tengeh Reservoir Case Study \(Accessed on 24-04-2025\)](#)

⁵⁴ [Solar Edge: Taiwan Reservoir \(May,2022\) - Case Study \(Accessed on 24-04-2025\)](#)

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Recommendations

Category	Recommendation	Impact on Plant Performance
Inverter Selection	Choose inverters by considering their Levelized Cost of Energy (LCOE) to ensure cost-effectiveness and the type of floaters used for Floating PV (FPV) installations.	Improves energy yield and overall system performance.
Durability	Choose inverters with corrosion-resistant and water-sealed components. For floating PV systems where the inverter is placed in the water body, an IP68-rated inverter is ideal. If the inverter is installed on land, ensure the enclosure has at least an IP65 rating ⁵⁵ .	Extends the lifespan of the inverters in humid and water-proximal environments, reducing maintenance needs.

Traditional string inverters connect multiple solar panels in series, meaning the entire string's performance is limited by the lowest-performing panel. SolarEdge's solution integrates power optimisers at the module level to maximize energy production while still using a centralised string inverter for power conversion.

By prioritizing high inverter efficiency and ensuring they are well-suited to FPV-specific challenges, developers can enhance energy yield, improve grid integration, and reduce long-term operational costs.

c. Float type/ Selection of Floater

The selection of the floater type significantly impacts the performance and longevity of Floating Photovoltaic (FPV) systems. Durable materials like high-density polyethylene (HDPE) ensure resistance to environmental stresses, while modular and hybrid designs offer flexibility and stability, especially in challenging water conditions. Proper float material and design can also help regulate temperature, reducing the risk of overheating and boosting efficiency. Additionally, high-quality floats contribute to long-term performance by minimizing maintenance needs and preventing structural damage.

Global Examples Demonstrating selection of floaters

Example 1: Omkareshwar Floating Solar Plant, India

Floater Type Selection: The Omkareshwar Floating Solar Plant utilizes **Exile Floats**, made from high-density polyethylene (HDPE), which are specifically designed to offer enhanced tensile strength, ensuring long-term stability and durability in challenging aquatic environments. These floats provide essential buoyancy and structural support to the PV modules, which is crucial for their reliable operation in the reservoir.

Impact on Plant Performance:

- **Enhanced Durability and Stability:** The HDPE Exile Floats offer excellent resistance to UV radiation, corrosion, and water ingress, crucial for maintaining the structural integrity of the plant over time, even in harsh weather and fluctuating water conditions. This results in minimal maintenance requirements and extends the operational lifespan of the plant.
- **Adaptation to Water Conditions:** These specialized floats are well-suited to withstand the dynamic conditions of the Omkareshwar Reservoir, which includes varying water levels and occasional rough waters. The stability provided by the Exile Floats helps to ensure that the modules remain securely positioned, avoiding module misalignment and potential energy production losses.
- **Efficient Energy Harvesting:** The selection of robust floats contributes to a stable foundation for the solar panels, ensuring they are positioned optimally for maximum sunlight exposure. By minimizing downtime caused by floating platform instability, the plant can operate at peak efficiency, capturing solar energy more consistently throughout the day.

Energy Efficiency Gains: By selecting the appropriate float type, the Omkareshwar Floating Solar Plant is able to maintain high stability and minimal maintenance requirements, leading to enhanced operational reliability and energy generation. The durability and strength of Exile Floats play a key role in maintaining high efficiency,

⁵⁵ [International Electrotechnical Commission: IP Ratings](#)

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reducing maintenance costs, and ensuring that the solar panels continue to perform optimally without significant degradation from environmental factors.

This case study highlights the importance of float material and design in ensuring the long-term performance and efficiency of FPV systems, showing how the right selection of floats can directly impact energy output and reduce system losses over time.

Recommendations

Category	Recommendation	Impact on Plant Performance
Material Selection	Use high-density polyethylene (HDPE) for floaters to ensure durability, UV resistance, and corrosion resistance .	HDPE floats are lightweight, corrosion-resistant, and durable in both freshwater and saline environments, leading to lower maintenance costs and longer plant lifespan.
Float Design	opt for modular interlocking floats for flexibility and scalability.	Modular designs allow easy expansion and adaptability to varying reservoir sizes, ensuring optimal support and stability for PV modules.
Thermal Regulation	Choose light-colored or reflective floats to minimize heat absorption.	Light-colored floats help maintain cooler module temperatures, enhancing energy efficiency by preventing overheating.
Eco-friendly Design	opt for recyclable materials to reduce environmental impact.	Recyclable materials like HDPE promote sustainability and reduce environmental harm while supporting large-scale projects.
Long-term Performance	Choose high-quality, robust float designs that minimize risks of water ingress and degradation.	High-quality floats with robust designs reduce maintenance needs, improve plant stability, and extend operational life, maintaining high energy efficiency.

Factors Which Influence in Design-Based Factors for FPV Systems

d. Module and BoS Losses

System losses in FPV plants arise from resistance in cables, suboptimal electrical connections, and mismatched modules. These losses reduce the amount of energy that reaches the inverter and, ultimately, the grid. In FPV systems, the floating nature of the plant can lead to additional challenges, such as longer cable lengths and potential water ingress into electrical components. High-quality components, proper installation, and regular inspections are essential to minimizing these losses and maintaining consistent performance.

Global Examples Demonstrating Module and Bos Losses

Example 1. Floating Photovoltaic System in Indonesia⁵⁶

System Losses: In Indonesia, FPV systems faced challenges due to high humidity and dust accumulation, leading to soiling of photovoltaic panels. This soiling reduced light transmission and, consequently, energy output.

Impact on Performance: The accumulation of dust and debris on panel surfaces resulted in significant energy losses, especially in regions with frequent dry seasons.

Mitigation Strategies and Achieving High Energy Efficiency:

- **Automated Cleaning Systems:** The installation of automated cleaning mechanisms reduced the impact of dust accumulation. These systems were designed to clean the panels regularly without human intervention, ensuring continuous high performance. There are numerous water-based and waterless methods for cleaning the surface of solar PV panels. A study was conducted on a water-free automated process for cleaning PV panel surfaces, and the results showed that this technology may increase the system's efficiency by 9.05%.⁵⁷
- **Protective Coatings:** Hydrophobic coatings were applied to the PV modules, making them less prone to dust accumulation. This approach allowed the system to remain efficient, even in regions with high dust exposure.

⁵⁶ [Sustainability \(Feb.2024\): Floating PV Systems as an Alternative Power Source: Case Study on Three Representative Islands of Indonesia](#)

⁵⁷ [Energies \(Apr.2021\): Cleaning of Floating Photovoltaic Systems: A Critical Review on Approaches from Technical and Economic Perspectives](#)

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- **Monitoring:** The installation was equipped with advanced monitoring systems to detect performance drops caused by soiling, allowing for swift interventions.

Outcome: By implementing automated cleaning and hydrophobic coatings, the plant managed to mitigate the effects of soiling and maintain high energy efficiency throughout its operation. The system's design ensured that dust accumulation did not lead to significant energy losses.

Recommendations to mitigate module and BoS losses

Category	Recommendation	Impact on Plant Performance
Panel Efficiency	Implement regular cleaning schedules to reduce dust and debris accumulation.	Reduces soiling loss, maintaining high energy output and module efficiency.
Inverter Efficiency	Select inverters with high efficiency ($\geq 98\%$) and ensure they are designed for partial load conditions.	Increases DC-to-AC conversion efficiency, minimizing energy losses.
Shading Minimization	Optimize panel placement and spacing to minimize shading.	Ensures consistent sunlight exposure, avoiding energy losses due to shading.
Monitoring & Maintenance	Implement real-time monitoring systems to detect inefficiencies and faults.	Enables quick response to issues, preventing prolonged performance degradation.
Module Type Selection	Both energy generation and cost of module to be considered while choosing.	Increases energy output per unit area, improving overall system efficiency.
System Design	Ensure proper system configuration and layout to minimize wiring and connection losses.	Reduces transmission losses, enhancing overall energy yield.

Factors to Be Considered in Design-Based Factors for FPV Systems

The **Factors to Be Considered** in design-based aspects of Floating Photovoltaic (FPV) systems are critical elements that ensure the **durability, stability, and operational efficiency** of the plant in different environmental and operational conditions. These factors address how well the FPV system can withstand **climatic variations**, maintain **structural integrity**, and continue operating effectively over its lifetime. Considering these factors during the design and engineering phases helps minimize risks, improve system performance, and ensure long-term reliability.

Factors to Be Considered	Impact on FPV Performance	Recommendations
Compatibility with Environmental Conditions	Incompatible materials or designs may degrade faster in harsh environmental conditions, leading to frequent breakdowns and higher maintenance costs .	Use UV-resistant materials, corrosion-resistant coatings , and marine-grade components to enhance durability in humid or saline environments.
Resilience to Climatic Variations	Extreme weather conditions such as high winds, temperature fluctuations , or water level variations can damage the system and reduce energy generation.	Design systems with wind-resistant anchoring systems and flexible mooring solutions to withstand water level changes and adverse weather.
Structural Design for Stability	Poor structural design may cause system displacement, float damage , or shading losses , especially in areas prone to high wind speeds or water currents.	Implement robust float structures with adequate ballast systems and anchoring designs that are tested for the local environmental conditions.
Self-Cleaning Systems for Air Quality Management	Airborne pollutants, dust, and algae growth on module surfaces can reduce energy yield by blocking sunlight absorption .	Use self-cleaning coatings on PV modules or install automated cleaning systems to maintain consistent energy output.

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3.2.3 Efficiency & Reliability Metrics

Factors to Control in Efficiency & Reliability Metrics for FPV Systems

a. Plant, Grid and Equipment Availability

Plant Availability, Grid Availability and Equipment Availability are crucial parameters that directly impact the overall performance and energy generation potential of Floating Photovoltaic (FPV) systems. Plant Availability represents the percentage of time the FPV system is fully operational and capable of generating electricity. Higher plant availability ensures that the system consistently harnesses solar energy, especially during peak sunlight hours, maximizing energy output. Any downtime due to equipment failure, preventive maintenance, or unplanned outages reduces the plant's ability to generate energy, directly lowering overall energy yield. Normal range of Plant availability is 0.25% to 0.5%.

Grid Availability denotes the percentage of time the electricity grid is accessible to receive and transmit the energy generated by the FPV system. Even if the plant is generating electricity efficiently, limited grid availability can restrict energy export, causing energy curtailment and revenue losses. In regions with unstable grid infrastructure or frequent outages, the impact on system performance can be significant. Reliable grid connectivity is essential to ensure consistent energy export and revenue generation. Therefore, both **Plant Availability** and **Grid Availability** are interdependent factors that play a vital role in achieving optimal FPV performance, directly influencing the system's energy output, operational efficiency, and financial viability. Normal range of Grid availability is 0.25% to 0.5%.

Equipment Availability refers to the operational readiness of key components such as inverters, PV modules, transformers, and monitoring systems. The continuous functionality of these components is essential to maintain high plant availability. Frequent equipment failures can reduce plant availability and lead to prolonged downtime, affecting energy yield. Regular inspections, preventive maintenance, and maintaining a critical spare parts inventory can improve equipment availability and overall system performance.

Recommendations for Enhancing Plant and Grid Availability

Category	Recommendation	Impact on Plant Performance
Plant Availability	Implement Preventive Maintenance Schedule	Ensures regular servicing of critical components, reducing unexpected breakdowns and maximizing system uptime.
	Install Remote Monitoring and Fault Detection Systems	Enables real-time fault detection and quick response, minimizing downtime.
	Conduct Periodic Inspection of Anchoring & Mooring Systems	Prevents system displacements or structural damage, enhancing plant stability and availability.
Grid Availability	Collaborate with Utilities for Dedicated Grid Connection Infrastructure	Improves grid reliability and minimizes outage frequency.
	Install Energy Storage Systems (ESS) (if feasible)	Stores surplus energy during grid outages, ensuring uninterrupted energy export once the grid is restored.
	Use Grid Availability Monitoring Systems	Enables proactive grid outage detection and operational adjustments to minimize downtime impact.
Equipment Availability	Implement Condition-Based Monitoring Systems	Continuously tracks the health of critical equipment, allowing predictive maintenance before failures occur.
	Maintain Critical Spare Parts Inventory for Key Equipment	Reduces repair downtime by ensuring essential spare parts (inverters, transformers, and switchgear) are readily available.
	Perform Periodic Performance Testing of Inverters and Transformers	Ensures key equipment is operating at optimal efficiency, minimizing the risk of unexpected failures.
	Upgrade to High-Reliability Components (e.g., inverters with high MTBF ratings)	Enhances system longevity, reducing the frequency of equipment failures and maintenance needs.

Factors Which Influence in Efficiency & Reliability Metrics for FPV Systems

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b. Mean Time Between Failures (MTBF)

Mean Time Between Failures (MTBF) is a key metric that directly impacts the operational performance and reliability of FPV systems. MTBF represents the **average time duration between two consecutive failures of system components** such as inverters, transformers, or monitoring systems during regular operation. A **higher MTBF indicates greater equipment reliability**, resulting in fewer breakdowns and longer operational uptime.

When critical components experience frequent failures (low MTBF), the FPV system's overall availability is reduced, leading to **prolonged downtime** and **lower energy generation**. This not only affects the plant's energy yield but also increases maintenance costs and operational disruptions. Conversely, components with **high MTBF ratings** improve plant stability, allowing the system to generate electricity consistently with minimal interruptions. Regular preventive maintenance, timely equipment inspections, and the use of **high-quality components with longer life spans** are essential to increase MTBF, ensuring **greater plant availability** and **optimal performance** of FPV systems throughout their operational lifecycle.

Recommendations for Improving Mean Time Between Failures (MTBF) in FPV Systems

Category	Recommendation	Impact on Plant Performance
Preventive Maintenance	Implement Scheduled Preventive Maintenance Program	Reduces unexpected equipment failures by ensuring regular inspection and timely servicing of critical components.
Monitoring & Fault Detection	Install Condition-Based Monitoring Systems	Enables early detection of equipment degradation, allowing proactive maintenance to prevent component failures.
Equipment Quality	Use High-Reliability Components with Proven MTBF Ratings	Improves component lifespan, minimizing the frequency of equipment breakdowns.
Spare Parts Management	Maintain Critical Spare Parts Inventory On-Site	Reduces downtime by enabling faster replacement of faulty components.
Testing & Inspection	Conduct Periodic Performance Testing of Inverters and Transformers	Identifies early signs of malfunction, preventing sudden breakdowns and extending equipment life.

c. Capacity Utilization Factor (CUF)

CUF is a key performance metric that measures the **actual energy generated by a FPV system compared to its maximum possible energy output over a specific period**. A **higher CUF indicates better system performance**, reflecting optimal utilization of available solar resources. Several factors impact CUF, including **solar irradiance levels, plant availability, grid availability, equipment efficiency, and system losses**. Low CUF can result from frequent system downtimes, inefficient system layout, or high energy losses due to shading, soiling, or equipment failures. Improving CUF through **optimized system design, proactive maintenance, and advanced monitoring systems** directly enhances the plant's energy yield, revenue generation, and overall operational efficiency.

Recommendations for Improving Capacity Utilization Factor (CUF) in FPV Systems

Category	Recommendation	Impact on Plant Performance
System Design	Optimize Tilt Angle and System Layout to maximize sunlight capture	Improves solar energy absorption, enhancing energy generation and CUF.
	Use High-Efficiency PV Modules with low degradation rates	Increases energy yield and maintains higher CUF over the plant's lifetime.
	Minimize Shading Effects through proper panel spacing and orientation	Reduces energy losses and improves overall plant efficiency.
Operation & Maintenance	Implement Automated Cleaning Systems for PV modules	Prevents dirt accumulation, ensuring consistent energy generation.
	Conduct Regular Performance Testing of Inverters and Modules	Identifies underperforming components and minimizes energy losses.
Monitoring & Control	Install Real-Time Performance Monitoring Systems	Enables quick fault detection and corrective actions, maximizing energy output.

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The minimum functional requirement for the FPV plant at 132 kV side of Plant Substation is a **CUF of 22.6%**.

d. Performance Ratio (PR)

Performance Ratio (PR) is a critical parameter that indicates the overall efficiency of a Floating Photovoltaic (FPV) system by measuring the ratio of the **actual energy output** to the **theoretical maximum energy generation under ideal conditions**. A **higher PR reflects better system efficiency**, while a lower PR indicates greater energy losses due to factors such as **inverter inefficiency, module degradation, shading, soiling, or system downtime**. PR is independent of external environmental conditions like solar irradiance, making it a reliable indicator of plant performance.

Regular monitoring and optimization of PR through **preventive maintenance, cleaning schedules, and advanced monitoring systems** can significantly improve the plant's energy yield, operational efficiency, and long-term financial returns.

Recommendations for Improving Performance Ratio (PR) in FPV Systems

Category	Recommendation	Impact on Plant Performance
System Design	Use High-Efficiency PV Modules with low degradation rates.	Improves energy conversion efficiency and enhances overall PR.
	Optimize Inverter Sizing and Selection	Reduces inverter-related energy losses, improving energy yield.
Operation & Maintenance	Implement Automated and Regular Cleaning Systems	Prevents dirt accumulation on modules, ensuring consistent energy generation.
	Conduct Preventive Maintenance on Inverters and Transformers	Identifies and rectifies faults early, minimizing downtime and efficiency losses.
Monitoring & Control	Install Real-Time Performance Monitoring Systems	Detects underperformance and enables quick corrective action.
	Use String-Level Monitoring Systems	Pinpoints faults in individual PV strings, reducing localized energy losses.
System Loss Management	Optimize Cable Layout and Connections	Reduces transmission losses, improving overall energy conversion efficiency.
	Implement reactive and active power controls	Optimizes power flow and voltage stability, improving PR (%) and reducing system losses.

The Performance Ratio (PR) Guarantee Test shall commence within 60 days of the commissioning of the Plant Facilities to demonstrate that the plant has achieved the Guaranteed Performance Ratio. The PR test period shall consist of continuous measurements over 30 consecutive days. **The minimum required Performance Ratio (PR) is 84%** at the termination point of the DVC 33 KV Switchyard. The test shall be conducted in accordance with the **IEC 61724: 2021**.

Factors to Be Considered in Efficiency & Reliability Metrics for FPV Systems

e. Real-time Monitoring Systems

Real-time Monitoring Systems play a crucial role in optimizing the performance and reliability of Floating Photovoltaic (FPV) systems by providing continuous tracking of the plant's operational parameters. These systems collect and analyze live data from various components, such as **inverters, PV modules, weather sensors, and grid connections**, helping operators detect performance deviations, equipment malfunctions, or system faults at an early stage. By enabling **immediate fault detection** and **quick corrective actions**, real-time monitoring minimizes system downtime, enhances plant availability, and maximizes energy yield.

Real-time monitoring systems also support data-driven decision-making by generating performance reports, which can be used to optimize preventive maintenance schedules and improve plant operational strategies.

IS/ IEC 61724-1:2021 provides guidelines for monitoring the performance of PV systems, which is crucial for ensuring the long-term performance and sustainability of floating solar projects.

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Recommendations for Real-Time Monitoring Systems in FPV Systems

Category	Recommendation	Impact on Plant Performance
System Installation	Install Advanced SCADA Systems to monitor inverter performance, power output, and grid connection status.	Enables comprehensive plant-wide performance tracking and fault detection.
Fault Detection	Use String-Level Monitoring Systems to track individual PV string performance.	Identifies underperforming PV strings, improving energy yield and reducing localized energy losses.
Remote Monitoring	Deploy Cloud-Based Remote Monitoring Systems for real-time access to plant performance from any location.	Enables faster fault detection, quick troubleshooting, and operational flexibility.
Performance Optimization	Use Data Analytics Tools to generate performance reports and optimize preventive maintenance schedules.	Helps improve PR and CUF by proactively addressing performance deviations.

f. Preventive Maintenance Plans

Preventive Maintenance Plans play a vital role in enhancing the overall performance, reliability, and longevity of Floating Photovoltaic (FPV) systems. These plans involve **scheduled inspections, servicing, and replacement of critical components** to prevent unexpected equipment failures and minimize system downtime. By conducting regular maintenance of key components such as **inverters, PV modules, transformers, and anchoring systems**, the likelihood of performance degradation is significantly reduced. Preventive maintenance helps identify potential faults at an early stage, enabling timely corrective actions before they escalate into major failures.

Recommendations for Preventive Maintenance Plans in FPV Systems

Category	Recommendation	Impact on Plant Performance
Routine Inspections	Develop and implement Annual Preventive Maintenance Schedules for key components (inverters, transformers, PV modules).	Reduces unexpected equipment failures and ensures consistent plant availability.
Electrical System Maintenance	Conduct Periodic Electrical Testing of inverters, cables, and transformers.	Identifies early signs of component degradation, minimizing downtime and extending MTBF.
Float and Anchoring Systems Inspection	Perform Routine Structural Integrity Checks of floats and anchoring systems.	Prevents system displacement, ensuring long-term stability and plant availability.
Spare Parts Management	Maintain On-Site Critical Spare Parts Inventory for inverters, connectors, and essential components.	Reduces downtime by enabling quick component replacements during faults.

In the below table, we have summarized the factors and its impact on FPV performance:

Table 18: Factors affecting performance of FPV system

Factors	Impact on FPV Performance
Solar Irradiance	Higher irradiance increases energy production, but excessive radiation can raise module temperatures, reducing efficiency.
Ambient Temperature	High ambient temperatures lower module efficiency, but the cooling effect of water helps mitigate this impact.
Water Temperature	Cooler water enhances module efficiency by improving cooling, while warmer water reduces this effect, lowering performance.

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Factors	Impact on FPV Performance
Humidity	High humidity can improve cooling, but excessive moisture may lead to increased panel temperatures, reducing efficiency. Prolonged exposure to humidity can also cause corrosion and degradation of materials.
Seasonal Variability	Seasonal changes in solar irradiance , temperature , and water levels affect energy generation, requiring system design to accommodate performance fluctuations.
Local Climatic Patterns	Site-specific weather patterns such as rainfall , wind speeds , and storm frequency can impact system stability and performance. Proper site selection and design considerations help mitigate these effects.
Water Body Characteristics	Water quality, temperature variations , water level fluctuations , and wave action influence system stability, cooling effectiveness, and module efficiency.
Impact of Airborne Pollutants on PV Surfaces	Dust, pollen, and pollutants can accumulate on PV modules, reducing solar absorption and lowering energy output. Regular cleaning and self-cleaning technologies can mitigate this impact.
Module Efficiency	High-efficiency modules generate more energy for the same sunlight exposure, maximizing overall output.
Inverter Efficiency	Efficient inverters minimize energy losses during DC-to-AC conversion, increasing the energy delivered to the grid.
Module and BoS Losses	Electrical losses from cables and connections reduce energy output, but high-quality materials minimize these issues.
Float type	Different float designs impact system stability, cooling effectiveness, and resistance to environmental stresses. For example, reinforced or hybrid floats improve performance in high-wind conditions, while certain floats are better for saline or turbid waters.
Structural Design for Stability	Ensures the system remains stable under varying environmental conditions such as wind, waves, and water currents, improving plant durability.
Compatibility with Environmental Conditions	Proper selection of materials and designs ensures that system components perform effectively in specific climatic conditions like saline or freshwater environments.
Resilience to Climatic Variations	Systems designed to withstand extreme weather events improve long-term stability and reliability.
Plant Availability	Higher plant availability ensures that the system remains operational for a greater percentage of time, maximizing energy generation .
Grid Availability	Limited grid availability restricts energy export, causing energy curtailment and lowering overall performance.
Equipment Availability	Higher equipment availability ensures continuous system operation , minimizing downtime and increasing energy yield
Mean Time Between Failures (MTBF)	Higher MTBF indicates greater equipment reliability , reducing the frequency of breakdowns and improving operational efficiency.
Capacity Utilization Factor (CUF)	Higher CUF reflects better utilization of the plant's installed capacity, maximizing energy yield over a given period.
Performance Ratio (PR)	A higher PR indicates the system is efficiently converting solar energy into electricity, while a lower PR signals greater energy losses from inefficiencies.

Factors	Impact on FPV Performance
Real-time Monitoring Systems	Provides continuous performance tracking and enables early fault detection , reducing downtime and optimizing energy generation.
Preventive Maintenance Plans	Regular maintenance improves system uptime, prevents unexpected breakdowns, and enhances long-term operational reliability .

3.3 Degradation of PV Modules and Cables

In addition to the above factors, the degradation of PV modules and cables is an important factor that impacts the long-term performance and reliability of Floating Photovoltaic (FPV) plants. Over time, exposure to environmental stressors, such as UV radiation, high temperatures, humidity, saltwater, and mechanical wear, can lead to a decline in the efficiency and lifespan of the system components. Understanding and mitigating these degradation processes is crucial for optimizing energy output and reducing operational costs.

3.3.1 Module Degradation

PV module degradation refers to the gradual loss of efficiency in converting sunlight into electricity over time. This process is influenced by several factors, such as environmental conditions, material quality, and operational stresses. For Floating Photovoltaic (FPV) systems, module degradation can result in a significant reduction in energy output and system longevity. Understanding the causes and impacts of module degradation is essential to ensure the effective operation of FPV systems.

Types of PV Module Degradation

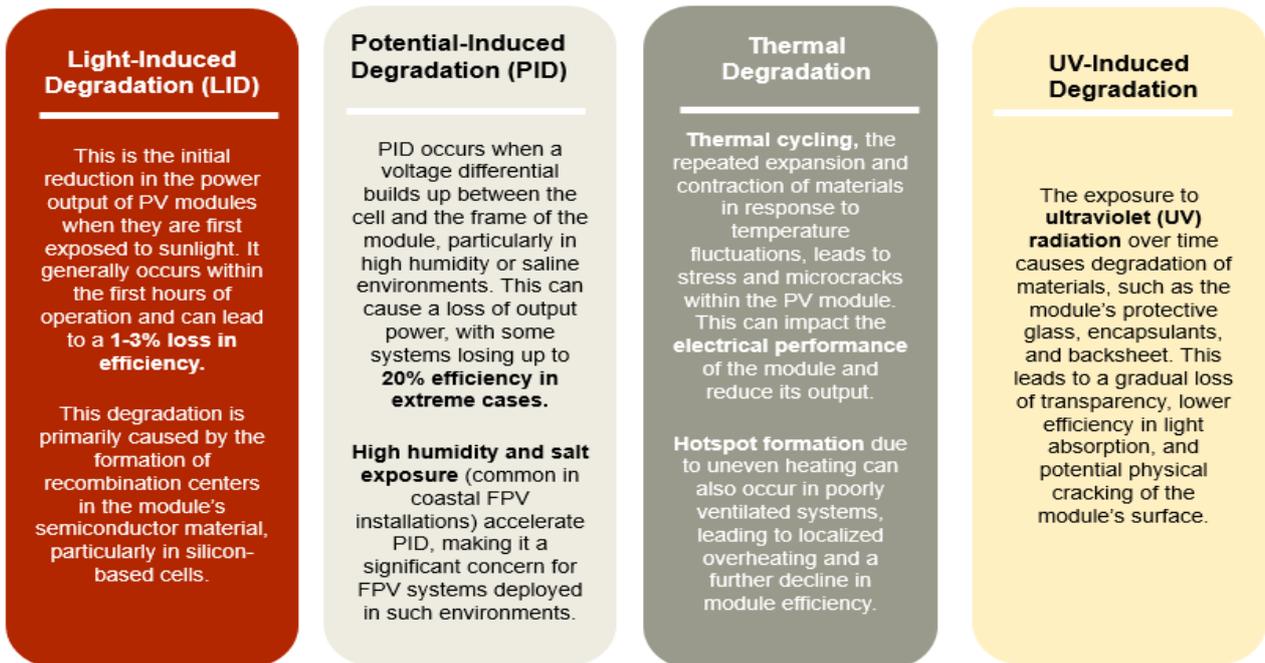


Figure 22: Types of Degradation in PV Modules

PV module degradation can result from various **internal and external factors** that gradually reduce the module's efficiency and lifespan. These degradation types are influenced by **environmental conditions**,

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electrical stress, and **mechanical loads**, especially in Floating Photovoltaic (FPV) systems where exposure to **water**, **humidity**, and **UV radiation** is higher.

Understanding the different types of degradation is essential for implementing effective **preventive measures** and **maintenance strategies** to sustain long-term system performance.

Case Study: Long-Term Performance of PV Modules in Seville, Spain⁵⁸

A study conducted in Seville, Spain, analyzed the degradation of 56 monocrystalline silicon PV modules after 22 years of outdoor exposure. The research identified significant signs of degradation, such as discoloration, delamination, and a decrease in power output. Despite these challenges, the study emphasized the importance of regular maintenance and the use of high-quality materials to mitigate degradation effects and sustain energy efficiency over the module's lifespan.

Mitigation Strategies for Module Degradation:

- **Material Selection:** Utilizing durable materials resistant to environmental stressors can reduce degradation rates.
- **Regular Maintenance:** Scheduled inspections and cleaning can identify and address degradation issues early, preserving module efficiency.
- **Protective Coatings:** Applying anti-reflective and anti-soiling coatings can minimize surface degradation and maintain energy output.

Tests to Predict Long-Term Degradation in FPV Modules

Regular diagnostic tests are essential for predicting and monitoring the **long-term degradation of PV modules** in Floating Photovoltaic (FPV) systems. These tests help assess the health of modules, detect early signs of deterioration, and identify performance losses caused by **environmental stressors** such as **humidity**, **UV exposure**, and **thermal cycling**. Implementing these tests as part of routine maintenance enables **proactive interventions**, improving the system's reliability, lifespan, and overall energy output.

Test Name	Description	Impact on Predictability
Light-Induced Degradation (LID) Test	Simulates the module's initial exposure to sunlight to measure performance loss.	Identifies modules prone to early efficiency losses , helping select higher-quality modules during procurement.
Electroluminescence (EL) Imaging	Detects microcracks , cell defects , and hidden hotspots by capturing infrared light emissions from the module.	Enables early fault detection before visible performance loss, allowing proactive maintenance .
Infrared (IR) Thermography	Identifies hotspots , thermal stress areas , and faulty interconnections using thermal imaging cameras.	Provides a visual representation of thermal-related degradation , supporting timely module replacements and preventing further damage.
IV Curve Tracing	Measures the current-voltage (IV) characteristics of PV modules to evaluate power output and system efficiency.	Detects performance drops and identifies degradation patterns over time, helping plan preventive maintenance and module replacements.

Implementing these diagnostic tests as part of routine maintenance provides several key benefits:

⁵⁸ [International Solar Energy Society \(May 2021\): Degradation analysis of photovoltaic modules after operating for 22 years. A case study with comparisons](#)

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- **Minimizes Unplanned Downtime:** Early fault detection prevents unexpected failures and system shutdowns.
- **Extends Module Lifespan:** Preventive actions reduce wear and tear, allowing modules to operate efficiently for a longer period.
- **Optimizes Energy Yield:** Ensures that all modules function at their maximum efficiency, increasing overall plant productivity.
- **Reduces Maintenance Costs:** Early intervention prevents costly emergency repairs and module replacements.
- **Improves Return on Investment (ROI):** A well-maintained FPV plant operates efficiently for a longer duration, ensuring greater financial returns.

By integrating these tests into routine inspections, FPV plants can proactively manage degradation, enhance performance, and ensure reliable energy generation. By adopting the following mitigation strategies, FPV plants can improve long-term performance and predict degradation more accurately:

Module Performance & Degradation Standards

The table lists module performance and degradation standards for photovoltaic (PV) systems,

Standard	Description
IS 17210 (Part 1): 2019/ IEC TS 62804-1: 2015	Photovoltaic (PV) Modules - Test Methods for the Detection of Potential-Induced Degradation Part 1 Crystalline Silicon

Module Performance & Degradation Standards ensure PV modules operate efficiently under various conditions. Adhering to these standards enhances durability, reliability, and long-term energy performance.

Here is the table of recommendations to mitigate module degradation:

Category	Recommendation	Impact on Degradation
Selection of High-Quality Materials	▪ Use PID-resistant modules with enhanced encapsulation and improved back sheet materials to prevent moisture and saltwater ingress.	▪ Reduces risks of potential-induced degradation (PID) and moisture-related damage.
	▪ Choose UV-resistant and thermally stable materials to minimize degradation due to UV exposure and thermal cycling.	▪ Enhances durability against environmental stressors like UV radiation and temperature variations.
Module Design and Coatings	▪ Implement high-efficiency, bifacial, or PERC (Passivated Emitter Rear Cell) modules for harsh environments to mitigate thermal and UV degradation. <i>Note: Bifacial modules may not deliver expected benefits due to water's low reflectivity (approximately 5% albedo).</i>	▪ Improves module performance and reduces the impact of environmental degradation factors.
	▪ Apply anti-reflective coatings and protective films to reduce surface degradation and heat buildup.	▪ Maintains surface quality, reduces soiling, and minimizes heat-related efficiency losses.
	▪ Use corrosion-resistant materials and anti-corrosive treatments for coastal or offshore systems to guard against saline water exposure.	▪ Prevents corrosion and ensures module longevity in saline environments.
	▪ Design modules with materials capable of withstanding thermal cycling and preventing hotspot formation in areas with extreme temperatures.	▪ Reduces material stress and hotspot-induced damage, maintaining module efficiency.

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Category	Recommendation	Impact on Degradation
Regular Monitoring and Maintenance	<ul style="list-style-type: none"> Install monitoring systems to track performance and detect early signs of degradation, such as efficiency drops or thermal stress. 	<ul style="list-style-type: none"> Enables timely identification and remediation of performance issues, extending module lifespan.
	<ul style="list-style-type: none"> Schedule routine inspections to identify and replace degraded modules or components. 	<ul style="list-style-type: none"> Ensures continuous optimal system performance and prevents degradation from escalating.
	<ul style="list-style-type: none"> Conduct periodic Electroluminescence (EL) and IR Thermography tests to detect microcracks and thermal defects. 	<ul style="list-style-type: none"> Improves predictability of degradation and prevents module failures.
	<ul style="list-style-type: none"> Perform IV Curve Tracing tests at regular intervals to assess module health. 	<ul style="list-style-type: none"> Identifies early degradation patterns, allowing proactive module replacements.
	<ul style="list-style-type: none"> Schedule routine inspections and cleaning to prevent soiling and corrosion. 	<ul style="list-style-type: none"> Ensures continuous optimal module performance and extends lifespan.

Module degradation is an inevitable challenge in FPV systems, but its impact can be significantly minimized through **high-quality material selection**, **proactive maintenance**, and **advanced diagnostic testing**. Regular implementation of **LID tests**, **Electroluminescence imaging**, **IR thermography**, and **IV curve tracing** provides valuable insights into the long-term health of PV modules, making systems more **predictable and resilient**. By adopting these mitigation strategies, FPV plants can maintain **high energy efficiency**, **reduce maintenance costs**, and **ensure reliable energy production** throughout their operational lifespan.

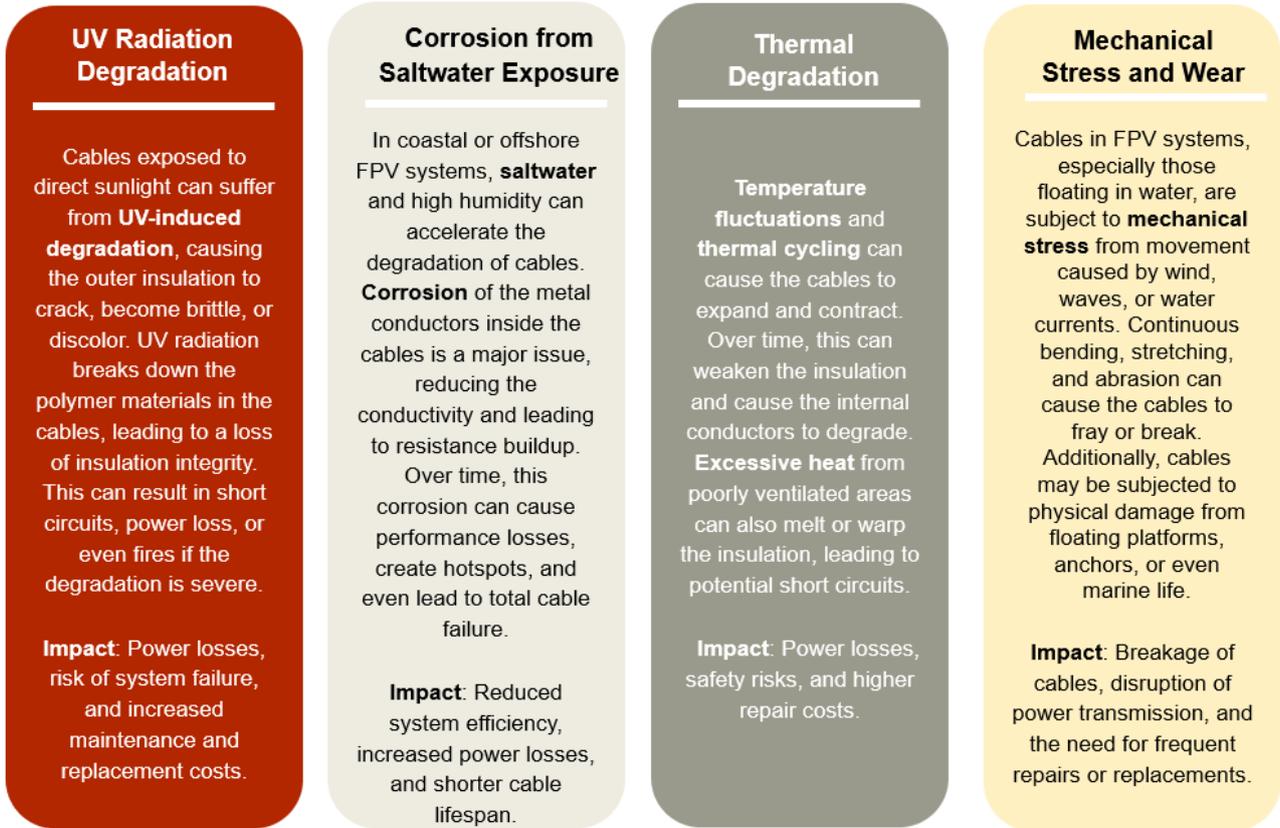
3.3.2 Cable Degradation

Cable degradation is a significant challenge in Floating Photovoltaic (FPV) systems, where cables play a critical role in **power transmission between PV modules, inverters, and the grid**. Unlike ground-mounted solar systems, FPV cables are constantly exposed to **aquatic environments**, making them more vulnerable to **environmental stressors** such as **water immersion**, **UV radiation**, **temperature variations**, and **saltwater corrosion**. These harsh conditions accelerate cable deterioration, potentially leading to **energy losses**, **system malfunctions**, and **safety hazards**. Proactive management of cable degradation through **material selection**, **protective coatings**, and **regular maintenance** is essential to maintain the **long-term reliability** and **efficiency** of FPV systems.

Types of Cable Degradation

Cables in Floating Photovoltaic (FPV) systems are exposed to harsh environmental conditions that accelerate their degradation over time. The combination of **UV radiation**, **temperature fluctuations**, **moisture**, and **mechanical stresses** can compromise cable insulation, conductivity, and structural integrity. Identifying the different types of cable degradation is essential to prevent **energy losses**, **system downtime**, and **safety hazards**. Understanding these degradation mechanisms helps in selecting **durable materials**, applying **protective measures**, and ensuring **long-term operational performance** of FPV systems.

Figure 23:Types of Cable Degradation



Cable degradation significantly **affects the efficiency, reliability, and safety of Floating Photovoltaic (FPV) systems**. As cables degrade, their resistance increases, reducing the efficiency of power transmission to the inverter or grid. This leads to lower energy yields, directly impacting the economic viability of the system.

Degraded cables can cause frequent interruptions in power transmission, resulting in increased downtime and reduced overall system availability. This not only lowers energy output but also necessitates more frequent maintenance or repairs, driving up operational costs.

In severe cases, **cable degradation can lead to complete failure, requiring costly replacements**. For large-scale FPV systems with extensive cable networks, such replacements can be both time-intensive and expensive, further affecting plant performance.

Additionally, **degraded cables pose significant safety risks, including electrical shocks, fires, and equipment malfunctions**. Corrosion and poor insulation increase the likelihood of accidents, highlighting the critical importance of robust maintenance and monitoring practices for cable integrity.

Tests to Predict Cable Degradation in FPV Systems

Regular diagnostic tests are essential to **predict, monitor, and mitigate cable degradation** in Floating Photovoltaic (FPV) systems. These tests help identify early signs of **insulation damage, mechanical wear, and electrical faults** before they lead to system failures. Proactive testing enables timely interventions, extending cable lifespan, improving system reliability, and minimizing downtime.

Test Name	Purpose	Impact on Predictability
Insulation Resistance Test	Measures the resistance of cable insulation to detect moisture ingress, aging effects, or contamination .	Helps identify insulation deterioration at an early stage, preventing potential short circuits and electrical faults .
High Voltage (Hipot) Test	Applies high voltage stress to cables to verify the breakdown strength of insulation under extreme operating conditions.	Detects weak insulation points before they cause system failures , improving overall system safety.

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Infrared (IR) Thermography	Uses thermal imaging to detect hotspots caused by increased resistance, loose connections, or overheating cables.	Enables early detection of hotspots, allowing for proactive cable replacements and reducing energy transmission losses.
Continuity Testing	Checks for discontinuities in the cable circuit to ensure uninterrupted current flow.	Confirms the integrity of cable conductors and joints, helping prevent power transmission failures.

By incorporating these tests into regular maintenance and system monitoring, FPV plants can achieve:

- **Higher Energy Efficiency** – Early detection of faults ensures modules and electrical components operate at peak efficiency.
- **Improved System Safety** – Prevents electrical hazards such as short circuits, insulation breakdowns, and overheating.
- **Extended Equipment Lifespan** – Reduces premature degradation of modules, cables, and inverters.
- **Lower Maintenance Costs** – Proactive fault detection minimizes the need for emergency repairs and replacements.
- **Enhanced Reliability and ROI** – Ensures stable power generation, reducing financial losses due to downtime.

By implementing these diagnostic tests, FPV plants can significantly **improve long-term performance, reduce energy losses, and ensure safe and efficient operation** under floating conditions.

Insulation-Related Damage and Cable Category Selection in FPV Systems

Insulation-related damage is one of the primary causes of cable degradation in Floating Photovoltaic (FPV) systems. The insulation layer acts as a protective barrier, preventing **electrical faults, moisture ingress, and mechanical damage.** However, continuous exposure to **UV radiation, humidity, saltwater, and temperature fluctuations** in aquatic environments can cause the insulation to deteriorate over time. This degradation increases the risk of **short circuits, power losses, and safety hazards,** significantly affecting the system's performance and lifespan.

Choosing the right **cable category** is essential to mitigate insulation damage and ensure the long-term reliability of FPV systems. **Marine-grade cables** are highly recommended for FPV installations due to their superior **durability, water resistance, and corrosion-resistant properties.** These cables are specifically designed to withstand **prolonged exposure to saline water, UV rays, and mechanical stresses** in aquatic environments.

Recommended Cable Categories for FPV Systems

Cable Category	Application	Features	Impact on Cable Degradation
ISO 12944 C5/C5M Standard Cables	Power Transmission in Marine Environments	High corrosion resistance, UV protection, moisture-resistant insulation	Prevents saltwater corrosion and enhances cable lifespan in saline water environments.
Marine-Grade Rubber-Sheathed Cables	DC Power Transmission in Aquatic Systems	Water-resistant rubber sheathing, flexible design	Protects against water ingress and abrasion, extending cable durability.
XLPE (Cross-Linked Polyethylene) Insulated Cables	AC Power Transmission in UV-Exposed Areas	UV-resistant, high-temperature tolerance	Reduces UV degradation and maintains insulation integrity in hot environments.
Halogen-Free Flame Retardant (HFFR) Cables	Electrical Installations in Floating Platforms	Non-toxic, flame-resistant, UV and moisture resistant	Minimizes fire risk while offering protection against UV and moisture-related degradation.

Selecting **marine-grade cables** with **UV-resistant, moisture-resistant, and corrosion-resistant** insulation is essential to prevent cable degradation in FPV systems. These cables are specifically designed to withstand the **harsh aquatic environment,** ensuring **reliable power transmission, longer service life, and enhanced safety.** Combining proper **cable category selection** with **regular insulation testing** and **preventive maintenance** helps protect FPV systems from premature cable failures and supports long-term operational performance.

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Case Study: Omkareshwar Floating Solar Plant, India:

The Omkareshwar Floating Solar Plant by Tata Power employs robust cabling practices to ensure water resistance and durability. **All AC and DC cables are strategically routed on the floating platforms, minimizing exposure to water immersion.** For AC power transmission, **3-core 33kV cables** are utilized, providing reliable and efficient power delivery. To handle DC power generation, **non-armored single cables with superior water resistance are employed**, ensuring long-term durability and performance in the aquatic environment. These cabling practices contribute to the overall reliability and efficiency of the Omkareshwar Floating Solar Plant. To summarize cabling practices at the Omkareshwar Floating Solar Plant:

- Cable Placement: All AC and DC cables are routed on the floating platforms to minimize water exposure.
- AC Cables: 3-core 33kV cables are used for AC power transmission.
- DC Cables: Non-armored single cables with superior water resistance are used for DC power generation.

These cabling practices ensure water resistance, durability, and reliable operation of the Omkareshwar Floating Solar Plant.

Here is the table of recommendations to mitigate cable degradation:

Recommendation	Details	Impact on Cable Degradation
Use of Corrosion-Resistant Materials	Opt for cables that comply with ISO 12944 C5 and C5M standards, which offer clearer guidelines on corrosion resistance and material specifications compared to traditional marine-grade cables. Use tinned copper or aluminum conductors with insulation materials specifically designed to resist moisture and salinity. ⁵⁹	Reduces the risk of saltwater corrosion, extending cable lifespan in marine or saline environments.
UV and Thermal Protection	Use cables with UV-resistant coatings and heat-resistant insulation materials like XLPE or silicone rubber.	Minimizes degradation from UV radiation and high temperatures, ensuring durability in harsh conditions.
Marine-Grade and Rubber-Sheathed Cables	Opt for marine-grade cables with rubber sheathing to withstand prolonged water exposure and prevent water ingress.	Improves cable durability, minimizes maintenance costs, and extends cable lifespan in aquatic systems.
Cable Maintenance and Monitoring	Conduct regular inspections and electrical testing to identify cracks, wear, or corrosion. Use thermal imaging for detecting hotspots. Install monitoring systems to track cable condition continuously.	Early detection of degradation prevents failures and reduces downtime, enhancing overall system reliability.
Proper Installation Practices	Install cables with proper spacing, and protect them using armored cables, conduits, or protective coverings.	Prevents physical damage, abrasion, and mechanical stress, particularly in high-stress environments.
Use of Cable Management Systems	Utilize floating platforms with integrated cable management systems to reduce cable movement and abrasion.	Maintains cable stability and reduces mechanical stress, prolonging cable integrity and performance.

Cables that comply with ISO 12944 C5 and C5-M standards, marine-grade cables and rubber-sheathed cables are highly recommended for FPV systems due to their superior durability and performance in aquatic environments. These cables are specifically designed to resist prolonged water exposure, saltwater corrosion, and physical wear, which are common challenges in floating solar installations. The use of rubber sheathing further enhances their resilience by preventing water ingress and providing additional protection against mechanical stress.

⁵⁹ [Institute of Corrosion: ISO 12944-5:2018 – Protective Paint Systems \(Accesses on 24-04-2025\)](#)

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By minimizing maintenance requirements and extending the lifespan of cables, marine-grade and rubber-sheathed cables contribute to the overall reliability, safety, and cost-effectiveness of FPV systems, making them a preferred choice for sustainable and efficient operations.

3.4 Operations and Maintenance Aspects of FPV systems

3.4.1 O&M approach and activities

The operations and maintenance of FPV systems are critical for ensuring their long-term reliability, safety, and optimal energy generation. FPV plants, being located on water, face unique challenges compared to ground-mounted systems, requiring specialized O&M approaches and activities tailored to their aquatic environments.

Key operations and maintenance activities for FPV systems are vital for maintaining performance and ensuring long-term reliability. These include cleaning PV modules to prevent soiling and biofouling, inspecting electrical and structural components to identify potential faults, and managing environmental factors such as water quality and debris. Regular monitoring and data analysis help detect inefficiencies, while maintaining detailed records supports compliance and warranty claims. Together, these actions minimize energy losses, reduce downtime, and enhance the overall lifespan of the system.

Description	Frequency	Purpose and Benefits
Cleaning and Soiling Removal		
Routine cleaning and maintenance of PV modules to remove accumulated dirt, algae, bird droppings, and biofouling. Particular attention to bird droppings, which can lead to hotspot formation, adversely affecting module performance and longevity.	Monthly or site-specific; more frequent in dusty, humidity or high-biofouling regions.	Maintains optimal solar irradiance absorption, prevents long-term performance degradation, mitigates thermal stress from hotspots, and enhances overall system reliability and lifespan.
Visual Inspections		
On-site inspections should cover PV modules, electrical connections, floats, and anchoring systems, checking for any visible signs of wear, damage, or misalignment. Additionally, using thermal imaging can help detect dead cells, faulty panels, and other hidden issues that could impact overall system performance.	Quarterly or after extreme weather events.	Allows for early identification of issues such as cracks, corrosion, or structural weaknesses before they escalate.
Electrical Inspections		
Testing system parameters like voltage, current, and inverter performance to detect faults in cables, connectors, and components.	Quarterly, more frequently in high-humidity regions.	Identifies electrical faults, minimizes downtime, and ensures reliable energy output.
Component Replacement		
Proactive or reactive replacement of degraded or damaged modules, cables, floats, or connectors.	As needed, based on inspections.	Sustains system reliability and prevents cascading failures due to malfunctioning components.
Structural and Mooring Maintenance		
Examination of anchoring systems and mooring lines for wear and displacement caused	Semi-annually, after high winds or waves.	Maintains platform stability, ensuring system alignment

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Description	Frequency	Purpose and Benefits
by water currents, wind, or waves.		and preventing drifting or structural failures.
Water Quality Management		
Monitoring water quality (turbidity, salinity, pH), sediment accumulation, and floating debris.	Annually or site-specific.	Protects components from corrosion, biofouling, and sediment-related mechanical or thermal stresses.
Performance Data Analysis		
Continuous monitoring of energy production, module temperatures, and inverter efficiency through data acquisition systems.	Continuous with periodic reviews.	Identifies underperforming areas and optimizes energy output through informed decision-making.
Reporting and Documentation		
Preparing comprehensive records of inspections, maintenance tasks, and repairs to track system health and compliance.	After each maintenance activity.	Facilitates future planning, performance benchmarking, and compliance with regulatory requirements.

Note:

- **Frequency:** Activities such as cleaning and inspections depend on environmental conditions like dust, algae growth, and weather events.
- **Special Considerations:** Activities in aquatic environments must include safety measures for personnel and equipment, particularly during high winds or waves.

3.4.2 Safety Protocols for O&M Activities

Operations and Maintenance (O&M) activities on floating photovoltaic (FPV) systems, especially in aquatic environments, present unique safety challenges. Ensuring the safety of personnel involved in these activities is crucial to prevent accidents, protect lives, and maintain system integrity. Below is a detailed explanation of the key safety protocols for O&M activities in FPV systems.

1. Pre-Work Preparations

Before any O&M activities commence, thorough preparations must be made to ensure worker safety. Working with solar energy equipment involves electrical risks, especially since solar panels generate power and connect to live circuits. To keep workers safe during installation and maintenance, employers should ensure that panels are covered, and proper precautions are taken around electrical circuits.

One critical safety measure is Lockout/Tagout (LOTO), a set of procedures designed to prevent machinery and equipment from unexpectedly starting up or releasing hazardous energy during servicing. By following these safety protocols, employers can create a safer work environment and protect their teams from potential hazards.

Some of the requirements of a Lockout / Tagout procedure required under a Lockout/Tagout program are⁶⁰:

⁶⁰ [World Bank \(Aug 2024\): Solar Energy Corporation of India Limited, India - Innovations in Solar Power and Hybrid Technologies Project: Environmental and Social Impact Assessment on Preparatory Studies for Floating Solar Photovoltaic Power Project at Getalsud Dam in Jharkhand, India](#)

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5. To undertake servicing or maintenance, only authorized personnel are permitted to lockout or tagout machinery or equipment.
6. Tagout devices (tags) and lockout devices (locks) must only be used to control energy and cannot be utilized for any other reason.
7. Devices that use lockout and tagout (locks and tags) need to notify the worker's name and it is necessary to identify and isolate all equipment's energy sources.
8. Only authorized personnel may lock out or tag out the isolating device or devices in a safe or off position after the energy has been isolated from the machine or equipment.
9. Once lockout or tagout devices are applied to energy-isolating devices, any stored or residual energy must be safely discharged or relieved.
10. Before beginning work, the authorized employee must verify that the equipment is fully isolated from the energy source, such as by testing the on/off switch.
11. Locks and tags should remain in place until the work is fully completed and only the authorized employee who applied the lock or tag is allowed to remove it.

- **Risk Assessment and Hazard Identification**

Conduct a detailed risk assessment to identify potential hazards such as electrical risks, slips, trips, drowning, wildlife encounters, and weather conditions.

- **Personnel Training**

Ensure that all personnel are trained in:

- Working in aquatic environments.
- Electrical safety, particularly when handling FPV systems.
- Emergency response, including water rescue and first aid.

- **Safety Briefings**

Conduct pre-work briefings to inform the team of the day's tasks, potential hazards, and mitigation measures.

- **Use of Permits**

Implement permit-to-work systems for high-risk tasks, including electrical isolation and confined space entry.

2. Personal Protective Equipment (PPE)

Appropriate PPE is essential to safeguard workers from environmental, electrical, and physical hazards.

- **Aquatic PPE**

- Life jackets or personal flotation devices (PFDs) are mandatory when working on or near water.
- Non-slip footwear for stable footing on wet or slippery surfaces.

- **Electrical PPE**

- Insulated gloves and tools to prevent electric shock.
- Arc-rated clothing for tasks involving high-voltage systems.

- **Environmental Protection**

- Sun protection (hats, UV-protective clothing, sunscreen).
- Wet weather gear during adverse conditions.

3. Safe Access and Work Practices

Working on FPV systems requires careful planning for access and on-site safety.

- **Access to FPV Arrays**

- Use stable, certified floating platforms, boats, or walkways to reach the FPV system.
- Ensure access paths are clearly marked and free of obstructions.

- **Fall Protection**

- Use fall restraint systems when working on elevated or unstable platforms.
- Install guardrails where feasible to prevent accidental falls.

- **Work Area Management**

- Limit the number of personnel in the work area to reduce congestion and the risk of accidents.
- Keep tools and equipment secured to prevent them from falling into the water.

4. Electrical Safety Protocols

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Electrical hazards are a significant concern during FPV O&M activities.

- **System De-Energization**
 - Isolate and de-energize electrical circuits before performing maintenance.
 - Use lockout-tagout (LOTO) procedures to prevent accidental re-energization.
- **Inspection of Electrical Components**
 - Regularly inspect cables, connectors, and junction boxes for damage, wear, or water ingress.
 - Use waterproof connectors and ensure proper grounding.
- **Avoiding Electrocutation Risks**
 - Never work on electrical components during wet conditions or when submerged in water.
 - Maintain a safe distance from live components and use insulated tools.

5. Environmental Considerations

Aquatic environments present unique challenges that require additional precautions.

- **Weather Monitoring**
 - Monitor weather forecasts and avoid work during adverse conditions such as storms, high winds, or heavy rain.
 - Be prepared to evacuate the site quickly in case of sudden weather changes.
- **Wildlife Awareness**
 - Be cautious of aquatic wildlife, such as snakes, alligators, or other potentially dangerous species.
 - Take measures to prevent contamination of the waterbody during maintenance activities.

6. Emergency Preparedness and Response

In the event of an emergency, having a well-defined response plan is vital.

- **Rescue Equipment**
 - Keep rescue equipment, such as life rings, throw ropes, and rescue poles, readily available.
- **Emergency Drills**
 - Conduct regular drills for scenarios such as drowning, electrical shocks, and fire.
- **Communication Systems**
 - Use reliable communication devices (e.g., waterproof radios) for constant contact between team members and supervisors.
- **First Aid Readiness**
 - Have first aid kits and an automated external defibrillator (AED) on-site.
 - Ensure at least one team member is certified in first aid and CPR.

7. Post-Work Activities

Proper closure of work activities ensures long-term safety and system reliability.

- **Site Inspection**
 - Inspect the work area for loose tools, unsecured equipment, or hazards.
 - Ensure all systems are safely re-energized after maintenance.
- **Reporting and Documentation**
 - Document all maintenance activities, including any incidents or near misses.
 - Review and update safety protocols based on lessons learned.

O&M activities in FPV systems require strict adherence to safety protocols to address the unique challenges of aquatic environments and electrical systems. The below table outlines safety standards for photovoltaic (PV) systems, focusing on electrical and fire hazard prevention, grounding, and lightning protection.

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3.4.3 Operations and Maintenance Checklist

Below is a detailed tabular representation of an O&M checklist for floating photovoltaic (FPV) systems:

Category Checklist Item	Frequency	Remarks
Safety	Ensure all personnel are equipped with appropriate PPE (life jackets, insulated gloves, etc.)	Daily Verify PPE compliance before accessing FPV arrays.
	Conduct pre-work safety briefing.	Daily Discuss tasks, hazards, and mitigation measures.
	Inspect rescue and emergency equipment (e.g., life rings, first aid kits, radios).	Weekly Replace damaged or missing items immediately.
	Confirm weather forecast for safe working conditions.	Daily Avoid work during storms, heavy winds, or lightning.
Electrical Systems	Inspect cables for wear, water ingress, or insulation damage.	Monthly Replace or repair damaged cables promptly.
	Check and tighten electrical connections at junction boxes.	Quarterly Use proper tools to ensure connections are secure.
	Verify grounding system integrity.	Quarterly Use testing equipment to confirm proper grounding.
	Perform thermal imaging of key electrical components to identify hotspots.	Annually Address overheating issues immediately.
Mechanical Systems	Inspect floatation devices for leaks, cracks, or degradation.	Monthly Replace damaged floats to maintain stability.
	Check mooring lines and anchors for tension, wear, or displacement.	Monthly Adjust or replace as needed to prevent drifting.
	Ensure platform stability and alignment.	Quarterly Address any structural misalignments promptly.
PV systems	Inspect solar panel surfaces for dirt, debris, bird droppings, or algae growth.	Monthly Clean panels using approved methods for aquatic environments.
	Check for cracks, discoloration, or delamination on panels.	Quarterly Replace damaged panels to prevent performance issues.

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Category Checklist Item	Frequency	Remarks
	Measure output performance and identify underperforming panels.	Quarterly Replace or troubleshoot low-performing panels.
Monitoring Systems	Verify data logger functionality and communication links to remote monitoring systems.	Monthly Address connectivity issues immediately.
	Check the calibration of sensors (e.g., irradiance, temperature, humidity).	Annually Recalibrate sensors as necessary.
Environmental	Monitor for algae or vegetation growth around FPV arrays.	Monthly Take corrective action to minimize ecological impacts.
	Inspect for signs of wildlife interference (e.g., nests, damage from animals).	Monthly Implement deterrent measures if needed.
	Ensure that maintenance activities do not introduce contaminants into the water.	Daily Follow guidelines to prevent spills or waste discharge.
Emergency Response	Conduct emergency response drills (e.g., drowning, fire, electrocution).	Biannually Include all team members to ensure preparedness.
	Verify clear access to evacuation routes and emergency equipment.	Weekly Remove any obstructions immediately.
Documentation	Record all maintenance activities, including inspections and repairs.	Per Task Keep records updated for compliance and reference.
	Report incidents, near misses, or identified risks.	Per Incident Analyze reports to improve safety protocols.

This checklist helps ensure systematic and thorough maintenance while prioritizing safety, performance, and environmental compliance in FPV systems.

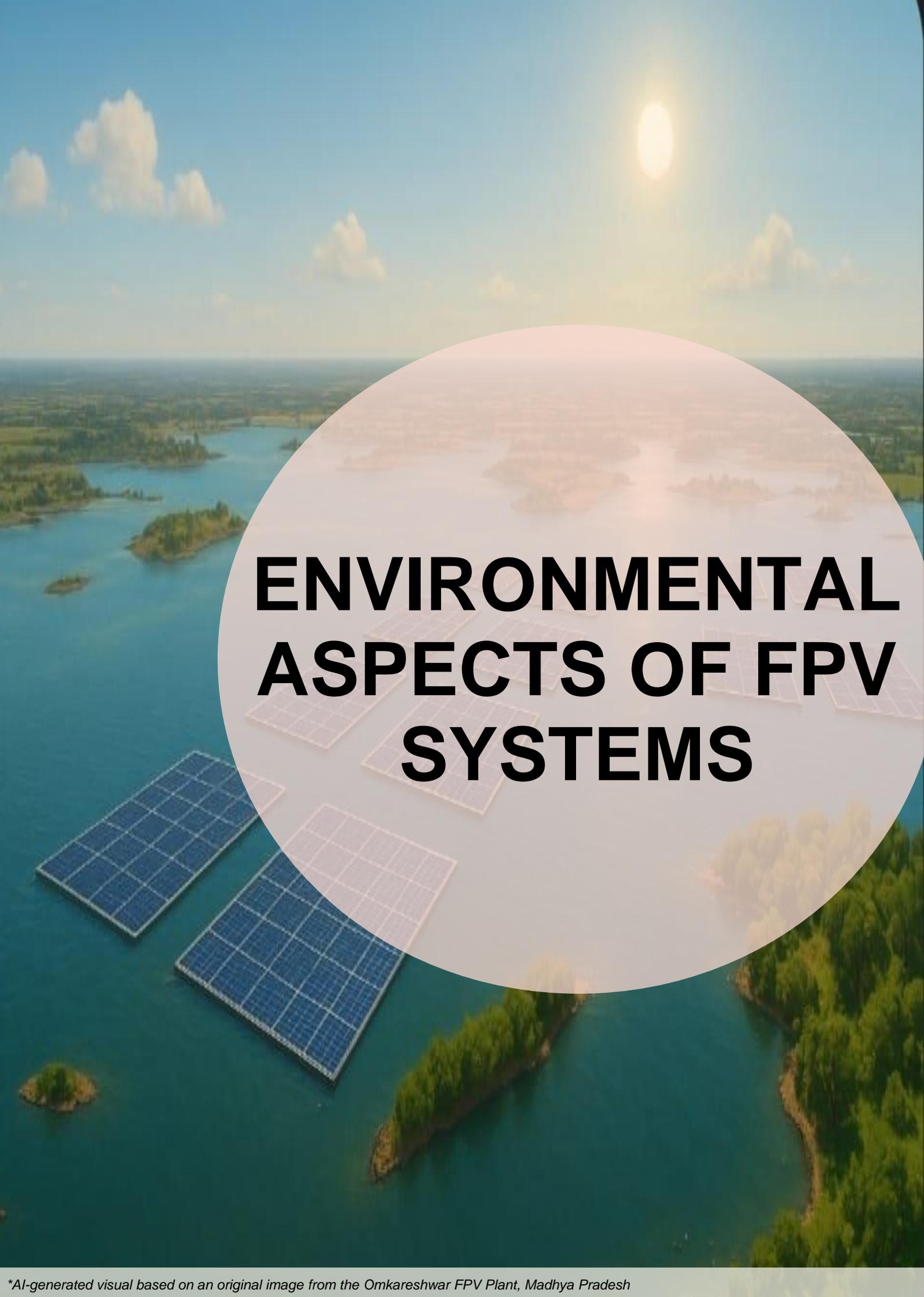
3.5 Decommissioning Procedures

The decommissioning phase represents the final stage of a Floating Photovoltaic (FPV) system's operational life, undertaken for either repurposing or complete dismantling. A well-defined decommissioning and deconstruction plan must be in place before construction begins, ensuring adherence to relevant permits and regulations. This phase may occur at the end of the system's intended lifespan or earlier if significant malfunctions or damage compromise system performance. The decommissioning process involves systematic deactivation of the system and either removing or appropriately handling its components in compliance with applicable laws. The plan should include a comprehensive timeline that accounts for weather conditions and seasonal variations. Furthermore, it must align with manufacturer guidelines, industry standards for power cables, and regulatory mandates, with provisions for revisions during installation and O&M phases as circumstances evolve. A risk assessment should be conducted to identify and mitigate potential safety and environmental hazards, with proper documentation. Coordination with local authorities may be necessary, and the process should aim to restore the project site to its original state unless specified otherwise in the permits.

During decommissioning, both environmental and commercial impacts must be carefully evaluated. Potential environmental risks include disturbances to aquatic and terrestrial ecosystems, alterations in water quality, pollutant discharge, and emissions resulting from removal and transportation activities. Efforts should be made to preserve the water body's physical characteristics, such as bathymetry, as much as possible. Additionally, potential disruptions to navigation, commercial activities, and nearby infrastructure must be assessed to minimize interference.

To address the long-term sustainability of FPV, the decommissioning and deconstruction plan should incorporate sustainable disposal and PV recycling strategies for both hazardous and non-hazardous materials that promote circularity. Degraded panels could be repurposed for secondary applications—such as powering water pumping systems—rather than being discarded. Developing clear guidelines for end-of-life solar panel recycling will support the emergence of a circular economy in the solar energy sector and reinforce the long-term environmental sustainability of floating solar technologies. Components left in the water or withdrawn but not fully removed must be documented and managed according to regulatory provisions, and proper records should be maintained for any unintended material losses during the decommissioning process⁶¹.

⁶¹[DNV Guidelines: DNV-RP-0584 Design, development, and operation of floating solar photovoltaic systems](#)

An aerial photograph of a large reservoir with several floating solar panel arrays. The sun is bright in the sky, and there are some clouds. The water is a deep blue-green color, and there are some small islands or peninsulas with green vegetation. The solar panels are arranged in rectangular grids on the water's surface.

ENVIRONMENTAL ASPECTS OF FPV SYSTEMS

4 Environmental Aspects of FPV Systems

4.1 Introduction

This chapter summarizes the potential environmental impacts commonly associated with the development, construction, and operational phases of FPV activities and provides recommendations for their management.

The environmental impact associated with FPV systems depend on various key factors, which vary across different locations. The scale of the impact is influenced by factors such as design, installation size, site characteristics, the proportion of the water body covered, waterbody topography, materials used for FPV including shading, impacts on hydrodynamics and water-atmosphere exchange, energy emissions, impacts on benthic communities, and impacts on mobile species.

FPV plants are commonly installed on in-land water bodies, which serve multiple purposes such as drinking water supply, irrigation, recreation, and electricity generation. A few of the potential impacts of deploying large-scale FPV plants are due to the following:

- Shading of the water surface can lower water temperature, influence thermal stratification, and alter dissolved oxygen levels.
- Impact on water quality due to leaching of chemicals.
- Impact due to exposure to electromagnetic fields associated with underwater electrical cables.
- Impact on migratory bird’s habitats
- Impact on fishing pattern
- Impact on local marine aquaculture because of reduction in sunlight reaching the water surface.

Currently, limited data are available on the long-term effects of large-scale FSPV deployment on water bodies. Given the diverse characteristics of water bodies, the impact varies from site to site. Therefore, it is essential to consider all relevant factors before large-scale implementation.



Figure 24: Key Environmental Impact Factors

Environmental Impacts of Floating Solar PV Systems

Possible Soiling by Birds	Decreased Dissolved Oxygen	Change in Water Temperature and Stratification	Limited Water Mixing
Reduction in Harmful Algal blooms	Impact on Benthic Habitat / Littoral Zone	Impact on Aquatic Species and Associated Habitat	Chemical Leaching and Pollution

Figure 25: Environmental Impacts of FPV Systems

Note: This list is not exhaustive, and each site will have its own unique characteristics and impacts.

4.2 Environment Screening

The environmental impacts of FPV projects depends on **project size, site characteristics, technology, and local conditions**. FPV plants consist of components such as floating platforms, anchoring and mooring systems, cables, and inverters, all of which are continuously exposed to water. Additionally, these water bodies are often used for various social purposes, including fishing, farming, navigation, and drinking, with characteristics that vary significantly by site.

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FPV projects can impact water quality and aquatic biodiversity, with the extent of impact varying based on reservoir type (natural, manmade, onstream, off-stream) and its intended use (hydropower, recreation, conservation, water supply, etc.). Key influencing factors include location, seasonality, water body size, FPV coverage percentage, incoming water sources, and the materials used in the installation.

Therefore, conducting a detailed Environmental Impact Assessment (EIA) for each location is essential to evaluate the long-term effects of FPV deployment and determine its suitability for the specific water body.

- Assessments should be based on up-to-date project descriptions, site characteristics, and Environment baseline data to identify risks, impacts, and mitigation strategies. *The Final Environmental and Social Management Framework document of SECI* provides guidance on conducting Environmental and Social Impact Assessments (ESIA), formulating an Environmental and Social Management Plan, and implementing project monitoring and evaluation.
- Assessments should be based on up-to-date project descriptions, site characteristics, and environment baseline data to identify risks, impacts, and mitigation strategies. Conducting assessments early in the project cycle helps maximize options for risk avoidance and impact mitigation.
- Baseline assessments should include seasonally representative data on hydrology, aquatic and terrestrial ecology, and other relevant factors.
- Project developers must evaluate direct, indirect, and cumulative E&S risks across the entire project life cycle.
- Research funding can be allocated to study the long-term effects of floating PV installations on aquatic biodiversity.
- Additionally, periodic impact assessments throughout the project's lifespan can be mandated to validate assumptions with empirical data.

The sustainability, performance, and efficiency of a FPV project are largely influenced by the hydro-climatic and ecological characteristics of the water body.

A. Climatic Characteristics:

Climatic characteristics play a crucial role in influencing construction, foundation stability, system design, layout, and overall reliability. Seasonal variations, including temperature fluctuations, thermal stratification, precipitation levels, humidity, pollution index, lightning frequency, and storm patterns, must be thoroughly analysed to ensure optimal system performance and durability.

- Temperature⁶²

FPV systems are expected to cause localized cooling of the water beneath the panels by limiting solar irradiation exposure. The extent of this cooling effect depends on factors such as coverage area, vertical mixing, and horizontal water transport. In areas with limited water exchange, such as lakes, reservoirs, and coastal lagoons, FPV-induced surface temperature reductions may be noticeable at local scales. Additionally, lower irradiation levels could alter seasonal temperature patterns by reducing heat storage in the water body. In general, the impact of FPV-induced temperature reductions on biological communities is expected to be minor.

- Thermal Stratification

Temperature stratification, the formation of distinct water layers based on temperature, is most common in deep reservoirs where limited water flow restricts mixing. This effect is often more pronounced in reservoirs with minimal wind exposure. The installation of FPV systems can enhance stratification and reduce water mixing beneath and around the floating structures, potentially leading to lower dissolved oxygen levels.

The extent of increased stratification is site-specific and depends on the proportion of the water body covered by FPV installations. For instance, a coverage ratio of 3 - 4% would result in only a slight increase in stratification, with minimal to negligible effects on water quality⁶³. However, at higher coverage ratios, FPV arrays could

⁶² [iScience \(Nov 2022\): Environmental and technical impacts of floating photovoltaic plants as an emerging clean energy technology](#)

⁶³ [World bank \(Oct,2019\): Where sun meets water floating solar handbook for practitioners](#)

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significantly reduce solar radiation penetration at the water's surface, limiting top-layer heating and potentially leading to broader ecological impacts.

- Evaporation

Installing FPV on water bodies minimizes evaporation, enhancing water efficiency. This reduction in water loss is particularly beneficial for drought-prone regions, where conserving significant amounts of water can support sustainability and resource management.⁶⁴ Partial coverage of water surfaces with FPV systems also help in reduction in water evaporation rates. This is particularly important in water-scarce regions, where conserving water resources is critical for sustainability.⁶⁵

- Humidity

High humidity and voltage levels can accelerate Potential Induced Degradation (PID), requiring careful consideration on prevailing humidity and air temperature conditions. Increasing panel clearance using pontoons or stilts can help mitigate humidity-related impacts on FPV systems.

B. Ecological Characteristics

When selecting a water body for a FPV plant, ecological characteristics play a crucial role in ensuring minimal environmental disruption and sustainable operation. The following factors need to be carefully assessed to minimize risks of a water environment:

- Dissolved Oxygen

FPV installations can influence DO levels by limiting surface-atmosphere oxygen exchange and reducing photosynthetic oxygen production due to shading. FPV installation should prioritize water bodies with stable DO levels. Coverage ratios should be carefully managed in stratified systems, and pre-installation DO assessments should be conducted to evaluate potential risks.

- Animal Activities

Other than impact by bird droppings, wildlife species present in the natural habitat, such as otters, crocodiles, water rats, snakes, and fish, may impact system performance, operations, and maintenance (O&M), and personnel safety.

Sites with natural habitats of protected species, high bird activity, or aquatic species dependent on stable water temperature, dissolved oxygen levels, and sunlight should be given low preference for FPV deployment due to potential ecological disturbances.

4.3 Impact on Water Quality

FPV projects affect water quality to varying degrees, depending on their type and design characteristics. Water quality is important for the health of flora and fauna inhabiting various water bodies and for the people and species that depend on these ecosystems for food and nutrient transfer. The physical, chemical, and biological characteristics determine the suitability of water and its quality. For example, Contaminated water negatively impacts the environment and flora and fauna that rely on it.

FPV systems can influence water quality variables such as dissolved oxygen (DO), nutrients - including phosphate and nitrogen, algae, alkalinity, and compounds - pH. The water quality standards approved by the Food and Agriculture Organization (FAO) have been summarized in Table 13.

Table 19: Food and Agriculture Organization (FAO) approved water quality standards⁶⁶

Parameter	Value
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⁶⁴ [Solar Power Europe: Floating PV Best Practice Guidelines Version 1 \(Accessed on 24-04-2025\)](#)

⁶⁵ [Heliyon \(Dec,2022\): Floating photovoltaics performance simulation approach](#)

⁶⁶ [Food and Agriculture Organization \(Oct,1985\): Water Quality for Agriculture](#)

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DO irrigation	4 mg/L
DO freshwater	5mg/L
Total Nitrogen	5mg/L
Total Phosphorus	0-2mg/L
pH	6.5-8.4

4.3.1 Water Temperature

FPV systems reduce surface heating by blocking solar radiation and altering diurnal temperature variability, potentially leading to cooler and more stable water temperatures. FPV systems are expected to cause localized cooling of the water beneath the panels. Decreased radiation can lead to alterations in seasonal lake water temperature patterns. Cooler temperatures impact oxygen solubility, stratification patterns, and metabolic rates, influencing species survival, reproduction, and community dynamics. These changes may also affect food webs, nutrient cycling, and carbon processing, potentially mitigating or amplifying ecological effects depending on the extent of FPV coverage.

In general, it is found that low FPV coverage (2%) shows minimal impact, but larger coverage (>50%) significantly reduces temperatures, affecting ecological processes.⁶⁷

Further studies are needed to better understand the extent of FPV-induced temperature changes and their long-term effects on aquatic ecosystems, water quality, and hydrological processes, ensuring that FPV deployment aligns with environmental sustainability.

4.3.2 Lake Stratification and Overturn

Temperature stratification occurs when water layers form based on temperature or climate change, when water remains still for extended periods due to limited mixing. Thermal stratification happens in deeper lakes during the warm season, caused by significant density differences between warm and cold water. Changes in stratification timing impact lake ecology, influencing oxygen, nutrient exchange, species interactions, and phytoplankton blooms.

In a study by Exley et al.⁶⁸, using a model, predicted substantial FPV coverage (**greater than 50%**) could lead to significant temperature changes and considerable changes in stratification timing. Commonly observed effects included reduced water temperature, a shorter stratification period, and a shallower mixed depth. Conversely, in scenarios with **low FPV coverage, stratification tended to last longer.**

In summer, the surface water of a lake warms, increasing temperature differences between the surface and deeper layers. Warm surface water, heated by the sun, becomes less dense and remains above the cooler layer below. This creates distinct layers:

- **Epilimnion:** The upper layer of the well-mixed water zone
- **Metalimnion:** The second layer functions as a barrier that hinders mixing and the transfer of heat between epilimnion and the deeper state
- **Hypolimnion:** The deeper layer, composed of cold water that is not mixed with the above layers.

When FPV systems cover a water body, they decrease the amount of solar radiation reaching the surface, providing a shield that mitigates wind mixing effects, thereby altering water temperature and stratification.

⁶⁷[HAL open science \(Oct 2023\): Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning](#)

⁶⁸[Solar Energy \(Mar 2021\): Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification](#)

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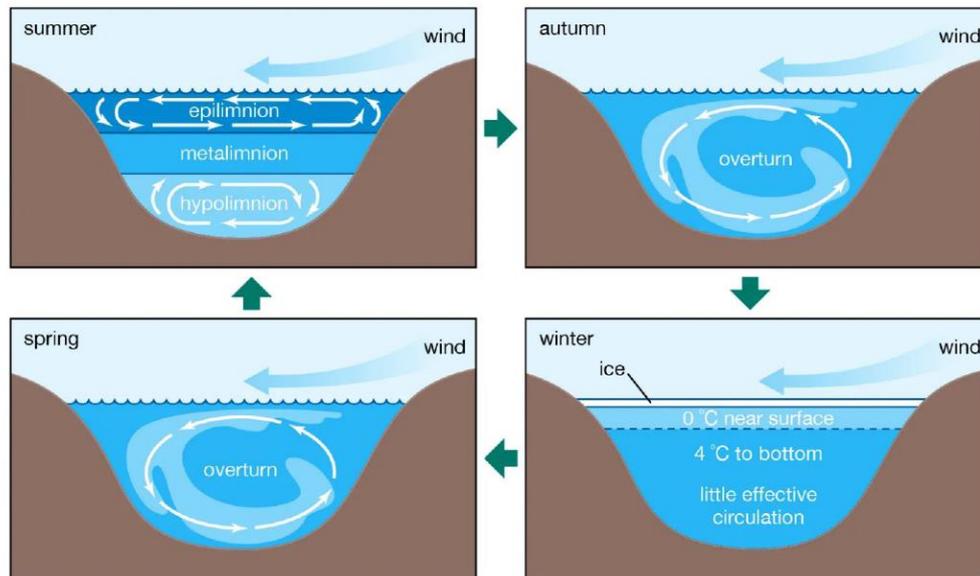


Figure 26: Layers of Water in a Lake Across Seasonal Changes⁶⁹

4.3.3 Dissolved Oxygen

Dissolved Oxygen (DO) is the total mass of oxygen dissolved in the water. Low dissolved oxygen levels in water can indicate pollution. It is an important factor in evaluating water quality, pollution control, and treatment processes. Most aquatic plants and animals depend on oxygen. **For instance, most fish cannot survive for long in water with less than 4 mg/L of DO.**

Covering lakes or reservoirs with FPV installations can increase temperature stratification, limiting water mixing. This results in lower dissolved oxygen levels, especially in the water layers below and near the FPV installation. Additionally, FPV reduces light penetration, impacting benthic vegetation that contributes to DO, and minimizes wind and wave effects, further decreasing mixing and oxygen distribution. **This effect would also vary depending on the nature of the water body.**

Case Study: De Lim Andini, S., & Setiawan, E. A. (2021): Effect of FPV on Dissolved Oxygen Levels in Mahoni Lake⁷⁰

This 3-week study collected data using mesocosm experiments at various depths in two setups: mesocosms with 100% FPV cover and control mesocosms without FPV cover.

The study revealed significant differences in DO levels between the mesocosms with 100% FPV cover and the control mesocosms. The lowest dissolved oxygen measured in mesocosms with 100% FPV cover was 3.4 mg/L, while the highest was 4.3 mg/L.⁸ The mesocosms without FPV cover showed a significant increase in dissolved oxygen concentration.

DO levels in the mesocosms with 100% FPV cover were significantly lower, with concentrations dropping below 4 mg/L, which is below the minimum threshold required to support aquatic life.

Case Study: De Lima et al, 2021: Underwater exploration at Bomhofsplas⁷¹

This 10-month study collected data using underwater drones and sensors at various depths in two areas: beneath the FPV plant and in open water.

- Project Location: Bomhofsplas Lake, Netherlands
- Installed Capacity: 27.4 MWp
- Size: 70 ha
- FPV Coverage: 26%

The study revealed minimal differences in temperature balance and stratification behaviour between the water beneath the solar park and the open water.

⁶⁹ [Inland water ecosystem \(Oct 2022\) - Permanent bodies of standing fresh water](#)

⁷⁰ [7th International Conference on Modern Approaches in Science, Technology & Engineering \(June 2021\): Evaluating the Effect of Floating Photovoltaic on Trophic State using Mesocosm Experiments](#)

⁷¹ [Sustainability \(June 2021\): In-Situ Water Quality Observations under a Large-Scale Floating Solar Farm Using Sensors and Underwater Drones](#)

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Dissolved Oxygen (DO) levels remained healthy, with concentrations staying above 6.48 mg/L. This is well above the minimum threshold of 3-4 mg/L required to support aquatic life.

4.3.4 Chemical Leaching and Micropollutants

FPV systems typically utilize high-density polyethylene (HDPE) pontoons or floats to support the racking system for solar panels, electrical component enclosures, and walkways. Although the American Water Works Association has approved its use in potable water⁷²,

The leaching of toxicants from various FPV components could contaminate water bodies, contribute to dissolved oxygen depletion, and increase environmental toxicity. Prolonged contact and anthropogenic activities may lead to the release of microplastics, organic carbon, heavy metals, and metalloids from FPV components at higher levels over time.

Drinking Water Compatibility

When installing FPV systems on reservoirs for drinking water, the risk of contamination is a critical concern. Structural materials may leak harmful substances that could threaten human health.

To prevent chemical spills, BayWA r.e FPV projects use a biodegradable FR3 fluid for transformers instead of traditional synthetic oil. To further mitigate risks, transformers are enclosed within a sealed collecting tank, effectively preventing oil discharge into the water, even in the unlikely event of a spill.

Plastics used in FPV systems, such as those in floaters providing buoyancy, must be UV-stable. In the event of a fire, materials should not ignite or melt, which could lead to harmful substances leaking into the water.

Case Study: Mathijssen et al - Potential impact of floating solar panels on water quality in reservoirs⁷³

- The study examined the impact of partial solar panel coverage on a drinking water reservoir in Kratingen, Netherlands, focusing on microbial load and pollutant release from solar modules, particularly the mortality rates of *Cryptosporidium*, *Giardia*, and *Campylobacter*.
- The results showed low germ elimination rates and minimal heavy metal leaching from floats, components, sealing materials, and solar modules. Organic compounds were also studied, with no adverse effects found.
- **A 30% coverage of the lake area for the project is unlikely to affect the use of the water for drinking purposes.**
- However, determining the appropriate coverage percentage requires a site-specific assessment rather than a one-size-fits-all approach. Factors such as local climate conditions, including temperature variations and evaporation rates, play a crucial role in assessing the impact of floating solar installations on water quality.
- Hydrological characteristics, such as water flow, depth, and replenishment rates, influence oxygen levels and nutrient cycling, which are critical for maintaining water quality.
- The percentage of water surface covered by floating solar installations should be determined on a case-by-case basis, ensuring that the project does not compromise the water body's ecological balance or its suitability for drinking water use.

Water Quality Modelling Tools⁷⁴

- Several 3D hydrodynamic and water quality modeling tools, such as ELCOM-CAEDYM, MIKE, and Delft3D, can analyze the effects of FPV systems on water quality.
- ELCOM-CAEDYM and Delft3D-FLOW combined with Delft3D-WAQ are suitable for evaluating water quality impacts in lakes and reservoirs.
- MIKE3 WITH MIKE ECO Lab and Delft3D-FLOW with Delft3D-WAQ apply to estuarine and coastal areas.
- Hydrological catchment modeling tools like MIKE FLOOD/SHE or SOBEK can provide more accurate surface runoff estimates and comprehensive water quality assessments.

Figure 27: Water Quality Modelling Tools

4.4 Evaporation Reduction

FPV systems can significantly reduce water evaporation by shading water bodies, lowering surface temperatures, and minimizing direct exposure of the lake water to the atmosphere. This is especially beneficial

⁷²World bank (Oct,2019): [Where sun meets water floating solar handbook for practitioners](#)

⁷³Water Practice and Technology (July,2020): [Potential impact of floating solar panels on water quality in reservoirs: pathogens and leaching](#)

⁷⁴World bank (Oct,2019): [Where sun meets water floating solar handbook for practitioners](#)

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in arid regions where water scarcity is a critical concern. The extent to which floating solar installations reduce evaporation depends on multiple interrelated factors:

Climatic Conditions: Key parameters such as solar radiation, relative humidity, vapor pressure, wind speed, ambient air temperature, and water body temperature directly influence evaporation rates. Higher solar radiation and wind speeds can accelerate water loss, whereas increased humidity levels may help mitigate it.

Coverage and Layout: The percentage of the water surface covered, and the arrangement of floating solar panels determine the extent of shading and wind flow disruption.

Lake Area and Turbidity: Larger water bodies with high surface area-to-depth ratios tend to experience greater evaporation losses. Additionally, turbidity - affected by sediment load, organic matter, and algal presence - can influence water temperature and light penetration, indirectly impacting evaporation dynamics.

Panel Configuration and Its Influence on Evaporation Reduction

The configuration of floating solar panels plays a significant role in influencing evaporation rates. For instance, east-west-oriented panel setups, often preferred for better wind resistance, can alter local airflow patterns above the water surface. These changes may either enhance or reduce the evaporation-reducing effect, depending on the site-specific climatic and hydrological conditions.

However, detailed studies on these impacts remain limited. Large reservoirs also pose additional challenges such as stronger waves and fluctuating water levels.

Recommendation:

- Conduct site-specific assessments to understand how panel configuration affects evaporation and local conditions.
- Install monitoring systems to track actual evaporation reduction.
- In large reservoirs, include wave breakers and flexible anchoring solutions to improve stability and ensure long-term performance.
- FPV projects may include a hydrological impact assessment to evaluate changes in water flow, evaporation, and temperature dynamics.

Case studies on evaporation reduction

Several studies have examined evaporation in the context of FPV, with the majority based on experimental designs or modeling approaches. In modeling, the limited availability of empirical measurement data often results in outcomes that are subject to uncertainties. The different models require different input parameters, including water surface temperature, air temperature, relative humidity, wind speed, and vapor pressure.

- A study by Bontempo Scavo et al⁷⁵ Observed that **FPV covering 30% of the basin area resulted in a 49% reduction of evaporation.** This conclusion was drawn using numerical evaporative models (EVMfree and EVMFPV), validated through comparisons with existing literature and experimental measurements.
- In Brazil, Lopes et al.⁷⁶ Studied regions with semi-arid climates and concluded that FPV coverage scenarios of 21.2%, 50%, and 70% could reduce reservoir evaporation by 15.3%, 37%, and 55.2%, respectively.
- In Jordan, Abdelal et al⁷⁷ Installed an experimental FPV system with 100% coverage in a semi-arid region. The study revealed that FPV reduced evapotranspiration by approximately 60% compared to an uncovered set up in the same area.

Above case studies demonstrates that **FPV coverage ranging from 21% to 70% can reduce evaporation by 15.3% to 55% depending on site-specific conditions such as climate, water body characteristics, and system design.** FPV systems enhance water resilience in semi-arid regions, making them particularly valuable during droughts. While methodologies vary across studies, the findings consistently highlight FPV's significant water-saving potential.

However, nearly all studies demonstrate that FPV has the potential to significantly reduce evaporation and improve water balance, a particularly important effect in arid regions.

⁷⁵ [International Journal of Energy Research \(Feb 2020\): An assessment study of evaporation rate models on a water basin with floating photovoltaic plants](#)

⁷⁶ [7th International Conference on Modern Approaches in Science, Technology & Engineering \(June 2021\): Evaluating the Effect of Floating Photovoltaic on Trophic State using Mesocosm Experiments](#)

⁷⁷ [International Journal of Low-Carbon Technologies \(Jan 2021\): Floating PV: an assessment of water quality and evaporation reduction in semi-arid regions](#)

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Case Study: Abd-Elhamid et al, examines strategies to mitigate evaporation from a lake in Egypt.⁷⁸

A study by Abd-Elhamid et al. explored strategies to reduce evaporation from Lake Nasser, a vital water resource in Egypt supplied by the Nile.

Using annual evaporation rates calculated through the bulk aerodynamic approach with meteorological data from 2009 to 2020, the study revealed significant water losses averaging 12.00 billion m³ per year, equating to 22% of Egypt's Nile water share.

Conclusion:

- The study proposed deploying FPV systems to cover shallow sections of the lake, enabling substantial water conservation while generating renewable electricity.
 - Covering shallow depths of up to 1.0 m could save approximately 1.9 billion m³ of water annually. This approach aligns with Egypt's environmental goals, offering a sustainable solution that combines water conservation and renewable energy production.
-
- Floating solar panels **can reduce evaporation by 10-20%***, increasing available water in high-demand areas. However, excess water must be properly managed.
 - FPV installations can incorporate reflective designs to regulate temperature and maintain ecological balance. Additionally, a reduction in evaporative cooling may cause localized heating effects similar to the urban heat island phenomenon.

4.5 Reduction in Algae Growth

Algae are a natural part of aquatic ecosystems and can have both good and bad effects on water. Excessive growth of algae can cause algal blooms. Certain alga types, like blue-green algae and cyanobacteria, can be harmful to humans, aquatic ecosystems, animals, and plants. They produce dangerous toxins, create low oxygen "dead zones," and affect water quality, increasing the cost and complexity of drinking water treatment.

Floating PV systems, particularly on water reservoirs, can address the issue of algal blooms. These systems reduce algae growth by limiting sunlight penetration through the water surface and lowering overall water temperature. Warm climates and direct sunlight encourage algal blooms by stimulating photosynthesis in water bodies. By providing shade, floating PV structures help mitigate algae growth and improve water quality.

The impact of floating PV on algae reduction depends on factors like water body type and nutrient availability. Evidence indicates that floating PV systems reduce algae photosynthesis, thereby limiting algal blooms and their negative effects.

Case Study: Haas et al., 2020: Predicting impacts by FPV in Chile⁷⁹

The research examined the effects of FPV deployment on Chile's Rapel hydropower reservoir, focusing on algal bloom formation as a key indicator of water quality and oxygen dynamics.

Using the ELCOM-CAEDYM numerical hydrodynamic model, it compared the reservoir's current state without FPV to scenarios with different FPV coverage levels. The findings on algae growth revealed that:

- Minimal FPV coverage (0-20%) has little to no effect on algae growth, showing limited ecological benefits.
- FPV coverage of 40-60% effectively mitigates algae blooms, improving water quality without harming the ecosystem.
- Coverage exceeding 60% eliminates algae blooms but may negatively impact the natural food web balance.

The study suggests that maintaining FPV coverage between 40-60% on the Rapel hydropower reservoir is ideal for controlling algae concentrations effectively.

Conclusion:

FPV **coverage up to 40% - 60%** of a water body can substantially decrease algal bloom while preserving ecological balance. However, the effectiveness of FPV in controlling algal growth depends on specific water body characteristics, including nutrient availability, location, and ambient conditions.

⁷⁸ [Water \(Mar 2021\): Reservoir Management by Reducing Evaporation Using Floating Photovoltaic System: A Case Study of Lake Nasser, Egypt](#)

⁷⁹ [Energy Conversion and Management \(Feb 2020\): Floating photovoltaic plants: Ecological impacts versus hydropower operation flexibility](#)

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While extensive FPV deployment shows potential for reducing or even eradicating algal blooms, it is essential to conduct comprehensive field studies to fully understand the ecological impacts and optimize FPV design and coverage for sustainable outcomes.

4.6 Impact on Light Permeability

Light plays a key role in various biological and chemical processes within a water body, such as primary production, photosynthetic oxygen balance, and temperature regulation. The light permeability of FPV systems is determined by factors like the design of the floating structure, its arrangement, spacing, and the orientation of the modules.

FPV systems partially or fully cover the surface of water bodies, reducing the amount of sunlight that penetrates below the surface. This reduced light availability can have a significant **effect on benthic vegetation** - plants that grow at the bottom of lakes, reservoirs, and other aquatic environments.

Case Study: BayWa r.e. Internal Study

BayWa r.e conducted a study on light permeability under a floating structure designed as their technical standard. Annual light permeability is defined as the percentage of incoming solar irradiance that penetrates the FPV structure and reaches the water below.



Figure 28: Light going through the PV Modules (source: BayWa r.e)

For an **FPV system with a non-transparent walkway**, the yearly average light permeability was **5.5%**, while a system with a **semi-transparent walkway** showed a slightly higher value of **5.93%**. Simulations indicated that the FPV structure achieved a light permeability of approximately 5.9% in southern Germany. The actual transmittance was found to be lower than the transparency visible in a top view due to lower sun angles and their resulting incidence angles.



Figure 29: Underwater picture of an FPV installation (source: BayWa r.e)

BayWa r.e.'s internal study on light permeability indicates that FPV structures allow approximately 5.9% of light to pass through. The impact on aquatic ecosystems is minimal, particularly in open water zones where light already has limited penetration to the waterbody's bottom.

Recommendation:

Conduct more in-depth studies on the environmental impacts of floating solar panels. This should focus on understanding the effects of light reduction on benthic vegetation and aquatic life, enabling the development of mitigation strategies to protect ecosystems while deploying floating solar systems.

Understanding the extent of this impact is essential for selecting appropriate FPV coverage ratios and designing mitigation strategies.

4.7 Impact on Biodiversity and Aquatic Ecosystem

Biodiversity plays a vital role in maintaining ecosystem health, resilience, and functionality. Incorporating biodiversity considerations in the planning and management of FPV installations is vital to preserving habitats, enhancing environmental benefits, and promoting a sustainable energy transition.

Lakes and reservoirs consist of three biologically distinct zones, each corresponding to specific physical features of the water body.

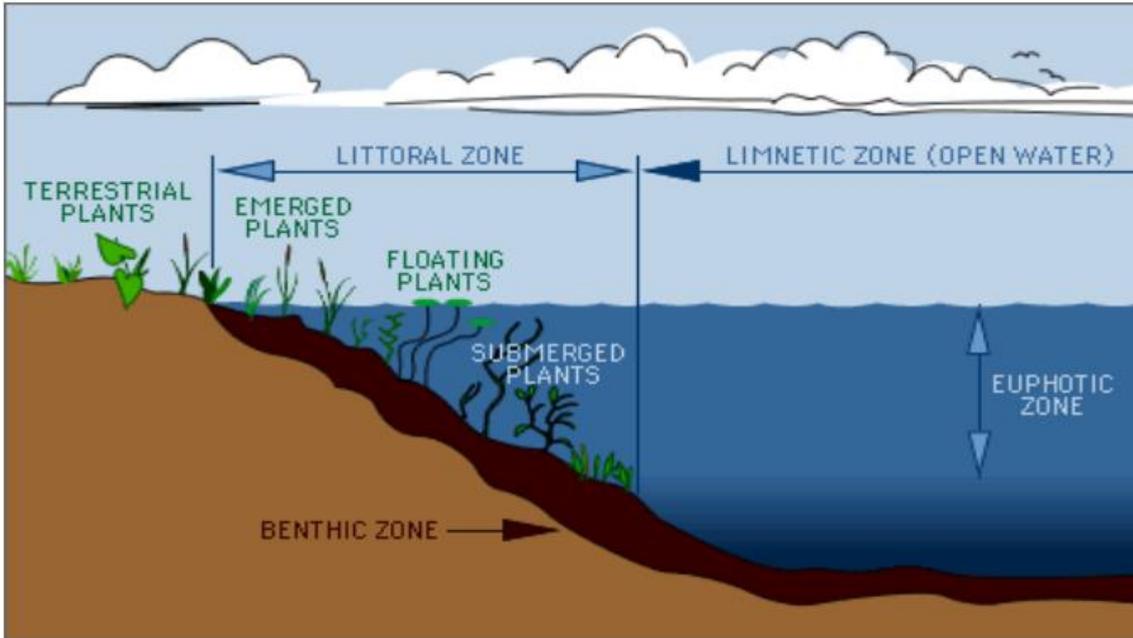


Figure 30: Different types of lake zones⁸⁰

List of suggested parameters to be monitored when evaluating the ecological impacts of FPV on freshwater biodiversity and ecosystem functioning.

Biodiversity				Ecosystem Functioning		
Phytoplankton, epiphyton and macrophytes	Zooplankton and Macroinvertebrates	Fish and Amphibians	Birds	Pelagic and benthic primary production	Greenhouse gases emission (GHGs)	Lake Metabolism

Figure 31: Parameters for ecological impacts by FPV Systems

Parameter	Rationale
1. Phytoplankton, periphyton and macrophytes	<ul style="list-style-type: none"> Alterations in light arrival induced by FPV can lead to a reduction in algal growth, mainly in the area covered by FPV, and a shift in community structure adapted to low light conditions.
2. Zooplankton and macroinvertebrates	<ul style="list-style-type: none"> Changes in light distribution and wind can influence patterns of zooplankton diel vertical migration and horizontal distribution.

⁸⁰ [Water on the Web: Lake Ecology - Biological - Lake Zones \(Accessed on 24-04-2025\)](#)

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Parameter	Rationale
	<ul style="list-style-type: none"> Biomass and community structure of zooplankton and macroinvertebrates may change following changes in the structure of primary producers and aquatic vertebrates consuming them.
3.Fish and Amphibians	<ul style="list-style-type: none"> FPV will reduce predation pressure by providing refuge from piscivorous birds, will increase habitat complexity, provide shaded areas, and reduce water temperature, which can influence the spatial distribution of fish, fish behavior, food availability as well and fish metabolism. Amphibians inhabiting littoral habitats are likely to be less affected by FPV than fish.
4.Birds	<ul style="list-style-type: none"> FPV can alter birds' behavior and habitat use as they can be attracted by FPV platforms for nesting, but they may also avoid the area due to the use of repellent technologies or reduced availability of predation areas.
5.Pelagic and benthic primary production	<ul style="list-style-type: none"> Light is the main source of energy for primary producers and changes in primary production. Floater can represent a novel growing area (i.e., biofouling), leading to a new source of organic matter for consumers and providing habitat for sessile organisms.
6.Greenhouse gas emissions (GHGs)	<ul style="list-style-type: none"> FPV may change the role of the water bodies as a source or sink of GHGs. Water bodies can become a sink of CO₂ if FPV leads to lower organic matter production.
7.Lake metabolism	<ul style="list-style-type: none"> FPV can alter lake metabolism, as FPV may affect the oxygenation of the water column through <ul style="list-style-type: none"> Changes in gas exchanges at the air-water interface Changes in oxygen solubility due to modification in water temperature Changes in metabolic rates of primary producers and consumers.

4.7.1 Shading Effects

FPV systems significantly reduce underwater light levels due to shading effects, potentially impacting photosynthetic organisms such as phytoplankton, benthic species like seagrasses and macroalgae, and even coral reefs.

The extent of shading depends on factors **like latitude, time of day, and water column properties**. Near the equator, the sun's high angle (close to 90° relative to the horizon) results in a sharp, localized shadow near the FPV system. In contrast, at higher latitudes, lower solar angles create a broader, slanted shading area. In enclosed freshwater systems, such as reservoirs, shading from FPV systems can be advantageous by reducing harmful algal blooms.

Studies indicate that shading can alter and reduce ambient light patterns, which may hinder plant growth and recruitment, decrease surface phytoplankton production, change flora and fauna compositions, and influence animal behaviour. (*Beauchamp, Byron, and Wurtsbaugh 1994; Bolding, Bonar, and Divens 2004; Colle, Cailteux, and Shire-man 1989; Garrison and others 2005; Helfman 1981; Rondorf, Rutz, and Charrier 2010; Kahler, Grassley, and Beauchamp 2000, citing White 1975*).

Shading also reduces aquatic vegetation and phytoplankton populations, leading to a decline in habitat availability and primary production.⁸¹

⁸¹ [World Bank \(Oct,2018\): Where Sun Meets Water: Floating Solar Market Report](#)

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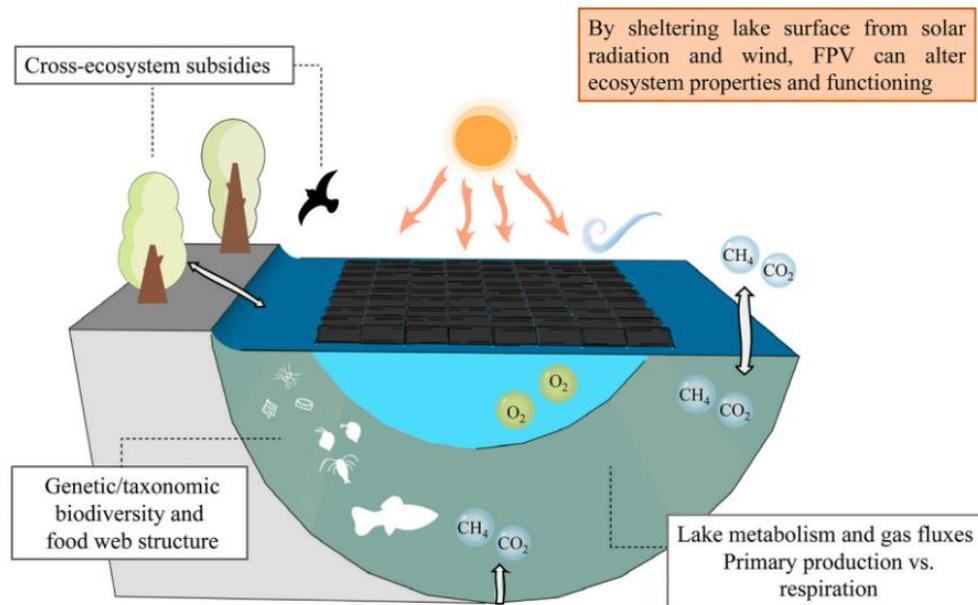


Figure 32: Potential impacts of FPV on lake ecology. FPV will partially block sunlight and wind, impacting lake temperature and ecological changes across biological levels.⁸²

Case Study: Bomhofsplas explored by Ecocean⁸³

The BayWa r.e. Bomhofsplas project serves as a key site for studying the impact of FPV installations on the lake's ecosystem and water quality. In 2020, French biodiversity specialists Ecocean conducted a comprehensive analysis of the lake's aquatic environment.



Figure 33: Bomhofsplas FPV (source BayWa r.e.)

- Twenty biohuts were installed at the edge of the FPV plant, serving as nurseries for small fish and providing habitats and spawning sites for fish, microorganisms, and invertebrates.
- Fishes were monitored from 2020 to 2023, showing growth in species colonization and development over time with FPV.
- In 2022, mobile fauna species grew rapidly compared to the first year, stabilizing in 2023, showing the ecosystem's ability to adapt to new species.
- A total of 2,382 organisms were recorded, including three fish species (common perch, cyprinids, and tubenosed goby) and two invertebrate species (Limnae sp and gammarid shrimp), with 1,951 invertebrates and 431 fish.

⁸² [Renewable and Sustainable Energy Reviews \(Dec 2023\): Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning](#)

⁸³ [7th International Conference on Modern Approaches in Science, Technology & Engineering \(June 2021\): Evaluating the Effect of Floating Photovoltaic on Trophic State using Mesocosm Experiments](#)

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- The abundance of species like daphnia and gammarids at the bottom of the food chain shows that the biohut environment supports aquatic life. Their role as prey for fish and larger animals highlights a favourable habitat crucial for the ecosystem's health and stability.

Conclusion:

- Incorporating biohuts into FPV installations promoted the growth and maturation of aquatic life, enhancing species diversity and ecosystem health.
- Biohuts integration contributed to maintaining a balanced ecological environment within the artificial water body, supporting both the lower and higher trophic levels of the aquatic food chain.



Figure 34: Installed Biohuts in Bomhofsplass

4.7.2 Impact on Birds

Birds have different behaviours based on their interactions with the environment. Studies show that birds find FPV systems to be safe and convenient places to land and rest.

To assess the impact of FPV on birds (and vice versa), it is important to monitor their population and behaviour. Strategically placing vegetation or artificial structures around FPV arrays can offer additional nesting or shelter, supporting habitat diversity and conservation efforts.

Case Study: Royal Haskoning DHV monitors geese at BayWa r. e's Weperpolder FPV plant, Netherlands

From 2018 to 2019, Royal Haskoning DHV conducted two years of bird monitoring at the Weperpolder FPV plant, located at a sand mining lake known for being a resting site for waterbirds.

The study compared the tundra goose population before and after the plant's construction, with counts taken over three months.

In 2018, before construction, 200 geese were observed, while in 2019, after the plant was completed, the number increased to 370. **The findings showed no negative impact on the bird's choice of resting areas.**



Figure 35: Bird Monitoring at Weperpolder in 2019 (source: BaWa r.e)

Case Study: Migratory bird behavior at BayWa r. e's Bomhofsplas and Nijbeets FPV plants, Netherlands

Bird monitoring was assessed at BayWa r. e's Bomhofsplas and Nijbeets FPV plants by Buro Bakker and AKTB. The projects covering 26% and 29% of their respective lake areas were surveyed for breeding birds using the BMP-A protocol across sand-mining lakes.

Between 2020 and 2021, eight visits were made to Bomhofsplas and five to Nijbeets. Observations were recorded using handheld field computers and processed with the Avimap entry program and Sovon auto-cluster program.

The findings indicated that migratory birds utilize FPV systems as a sanctuary for resting.

4.7.3 Impact on Fish

FPV systems influence fish behaviour and distribution by creating artificial habitats in aquatic environments. Mobile fish species often aggregate around such infrastructure, a phenomenon like fish aggregation observed near wind farms, oil and gas platforms, and floating fish aggregation devices (FADs)⁸⁴.

The rapid colonization of FPV systems by fish has been observed, although individual fish may not reside near these structures for extended periods. In some cases, FPV installations could function similarly to Marine Protected Areas (MPAs), as fishing around these systems is often impractical, allowing fish populations to thrive with reduced human interference.⁸⁵ If fish become preferentially associated with FPV infrastructure, localized increases in abundance and reproductive outputs could occur. However, the long-term ecological impact of such artificial aggregations needs further investigation to understand whether these systems enhance fish populations or merely alter their spatial distribution. The presence of large stationary floating infrastructure may also impact trophic interactions by attracting certain predatory species, potentially altering local food webs.

While FPV systems may provide favourable conditions for certain fish species, **shading effects must be carefully considered**. Studies on floating piers indicate that deep-shaded areas may be suboptimal habitats for various fish species, particularly those reliant on vision for foraging. In enclosed freshwater systems, FPV can reduce phytoplankton blooms, leading to increased water clarity over time. This could further amplify the impact of shading by altering fish distribution, favouring species that thrive in clearer waters while potentially disadvantaging others. Additionally, as offshore infrastructure such as FPV arrays, floating wind farms, and wave energy converters expand, their cumulative impact on fish movement patterns and ecosystem dynamics will require continuous monitoring and assessment.

⁸⁴ [Renewable and Sustainable Energy Reviews \(Dec 2023\): Potential ecological impacts of floating photovoltaics on lake biodiversity and ecosystem functioning](#)

⁸⁵ [Renewable and Sustainable Energy Reviews \(July 2024\): Potential environmental impacts of floating solar photovoltaic systems](#)

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Careful consideration of the potential environmental impacts on fish distribution and movement patterns is essential when planning FPV system deployments.

4.8 Environmental Monitoring and Management

Environmental monitoring should be carried out before installation, during operation and after decommissioning of an FPV to investigate its environmental impact that are identified as having potentially significant impacts on the environment. Monitoring data should be analyzed and reviewed at regular intervals and compared with operating standards to ensure that necessary corrective actions can be taken.

Environmental and site conditions encompass all natural and local factors that may impact the design of an FPV system. These include, but are not limited to, meteorological conditions, limnological and oceanographic factors, water depth, soil conditions, seismic activity, biological aspects, ground conditions, water quality, contamination, water basin topography, bathymetry, waterproofing, and human activities in the area.

FPV project developer should use environmental monitoring outcomes to inform adaptive design and mitigation strategies for environmental sustainability.

Environmental Impact of Submerged Biomass and Mitigating GHG Emissions in FPV Projects

- In Floating Solar PV (FPV) projects, areas submerged under water often retain existing trees, biomass, and abandoned structures.
- As these materials decompose underwater - especially in shallow reservoirs (10 to 20 meters deep) - they can release significant amounts of greenhouse gases (GHGs), such as methane and carbon dioxide, contributing to long-term environmental impact.



Figure 36: Submerged Trees at Omkareshwar FPV plant (source: plant visit by IIT-Roorkee)

Recommendation:

- Bathymetric studies and technical feasibility assessments should include the environmental impact of submerged biomass and organic matter decomposition.
- FPV projects should consider the removal of trees and vegetation before submergence to help reduce greenhouse gas emissions and minimize long-term environmental risks.

A. Water Quality

Water quality information is essential for selecting materials for anchoring and mooring systems, floating platforms, and cables, as well as understanding the long-term impacts it may have on the lifespan of FPV plant components. Hence, it is important to conduct a thorough investigation of water quality across multiple sampling points in the water body.

Recommendation: A water quality report should include details on the physical and chemical properties of water, such as pH, turbidity, salinity, dissolved oxygen (DO), total dissolved solids (TDS) levels, water temperature, etc., and should comply with IS:10500:2012 standards.

Sensors for Water Quality Monitoring

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Water bodies can be monitored using three methods: static sensors placed at fixed locations and depths, underwater robots equipped with onboard sensors for mobility, or water sample collection for laboratory analysis.

B. Fouling

The potential types of fouling that the FPV system may encounter should be investigated. The impact of fouling on the soiling level of the PV modules, as well as on the material quality and drag coefficients of the system, should be assessed.

C. Marine Growth

The potential for marine growth on structures and power cables must be evaluated, considering its impact on hydrodynamic loads, dynamic response, accessibility, and the corrosion rate of components.

D. HSE Risk Assessment

The project specific HSE risk assessment shall address various risks associated with plant installation, commissioning, operations, and maintenance, with tasks broken down at a detailed level to identify appropriate mitigation measures. All identified risks shall be documented and integrated into the HSE management plan. Additionally, the fire safety plan and lifting plan shall be developed and incorporated into the HSE management plan. Implementation of the HSE management plan shall be the responsibility of the engineering, procurement, and construction (EPC) team, operations, and maintenance (O&M) personnel, as well as all contractors and subcontractors working at the FPV site.

General Health and Safety Recommendations:

- All personnel working on site must always wear life vests, and workers shall never work alone.
- Professionally trained and certified divers should be considered for underwater installation and maintenance tasks.
- All personnel working on the floating platform should possess basic swimming certification to enhance water safety.
- Lifeboats should be strategically positioned throughout the FPV array for emergency use.
- The risk of drowning and injury should be mitigated by having trained personnel available to supervise operations and provide first aid.
- A robust communication system should be always maintained between workers on the floating platform and personnel on shore.
- Walkways should be designed with sufficient width to allow workers to move safely while carrying equipment and parts.
- Physical markers (e.g., stickers or signs) should be placed to prevent workers from stepping on fragile or unsafe elements of the installation.
- Mitigating Flood Risk & Enhancing Knowledge Sharing for Safe Floating Solar Installations: To mitigate this risk, FPV systems should be designed with secure mooring and positioning strategies that ensure panels remain clear of spillway gates.
- Implementing automated monitoring and emergency detachment mechanisms can further prevent any obstruction, safeguarding the reservoir's flood management capabilities.

Social Impacts of FPV in Aquatic Ecosystems in India

The development of FPV projects in India can have significant social implications, particularly in regions where water bodies support multiple livelihoods. Fishing communities may face restricted access to traditional fishing zones, leading to concerns over income loss and displacement. Similarly, local communities relying on water bodies for domestic or recreational purposes might experience reduced access, raising issues of equity and social acceptance.

Limited research on people-technology complexities around FPV comes from land-based lake and reservoir arrays for societal challenges around access to livelihood activities, such as fishing, and concern over the health and safety of workers on-site and in FPV factories. Perceptions were based on interactions with livelihood activities, leisure accessibility and visual impact, and lack of trust in the legal, planning, technological and environmental management processes, and procedures.

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Public perception of FPV projects in India will depend on awareness, trust in environmental safeguards, and perceived benefits. Concerns over the visual impact of large-scale FPV installations on scenic lakes or reservoirs may influence acceptance, particularly in areas dependent on tourism. Additionally, uncertainties about ecological impacts, such as water quality changes and effects on aquatic biodiversity, could lead to resistance from local stakeholders, including environmental groups and policymakers.

Access to water bodies specially fishermen rights – a detailed communication plan to be developed and disseminated upfront regarding accessibility and coverage of water bodies. Specific social considerations and appropriate mitigation measures for any impacts are dependent on the location and scale of an FPV operation, as well as its environmental and economic interactions, and the cultural, political and policy contexts of the area. For a 50 MW FSPV fishermen were signed with developer for certain percentage of revenue.

Social challenges also extend to **governance, planning, and policy integration**. FPV projects must align with existing **water management policies** and **involve structured stakeholder consultations** to address concerns early in the development process. Effective community engagement, compensation mechanisms for affected groups, and co-benefit strategies - such as integrating FPV with fisheries or water conservation efforts can help enhance social acceptance. **As FPV is still in its infancy from a global perspective, there is the opportunity for transdisciplinary research to contribute to the development of decision-making tools.**

E. Environmental Standards to be Considered for FPV Projects

Standard	Description
IS 10500: 2012 ⁸⁶ (Reviewed in 2023)	Drinking Water - Specification
IS 15410:2003 or equivalent BS 6920:2014 ⁸⁷	Test for Drinking Water Compatibility; Material Safe for Drinking Water
IS 3025 Series ⁸⁸	Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater
IS 4701:1982 (Reviewed in 2024) ⁸⁹	Code of Practice for Earthwork on Canals
IS 6494:1988 (Reviewed in 2020) ⁸⁹	Code of Practice for Waterproofing of Underground Water Reservoirs
ISO 14001 ⁸⁹	Environmental Management Systems (EMS)

For Floating Photovoltaic (FPV) projects located on water bodies designated for drinking water supply, adherence to **IS 10500:2012** (Drinking Water – Specification) should be ensured to protect and maintain potable water quality throughout the project lifecycle. To further safeguard public health, **IS 15410:2003** or its international equivalent, **BS 6920:2014**, shall be followed to verify that all materials used in FPV systems are suitable for contact with drinking water and do not release harmful substances.

Where FPV systems are deployed on water bodies used for purposes such as irrigation, ecological conservation, or industrial applications, the **IS 3025 series** shall be applicable. These standards provide standardized methodologies for sampling and testing the physical and chemical characteristics of water and wastewater, forming the basis for effective water quality monitoring and environmental reporting.

All FPV installations shall also implement **ISO 14001:2015**, the international standard for Environmental Management Systems (EMS). This ensures a structured approach to managing environmental responsibilities,

⁸⁶ [The Energy Research Institute TERI \(2019\): Floating Solar Photovoltaic \(FSPV\) A Third Pillar to Solar PV Sector](#)

⁸⁷ [Solar Energy Corporation of India Limited, SECI \(2025\): Request for Selection \(RfS\) Document](#)

⁸⁸ [National Thermal Power Corporation, NTPC \(2024\): TECHNICAL SPECIFICATIONS for FPV plant at Maroda Reservoir](#)

⁸⁹ [National Thermal Power Corporation, NTPC \(2018\): Endeavours Towards Environmental Stewardship report](#)

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achieving regulatory compliance, and minimizing ecological impacts during planning, construction, and operation phases.

For FPV projects situated on or adjacent to canal infrastructure, **IS 4701:1982** (Reviewed in 2024) shall be followed to uphold best practices in earthwork and civil engineering design. In cases involving underground or partially submerged water storage reservoirs, **IS 6494:1988** (Reviewed in 2020) shall apply to ensure robust waterproofing and to prevent seepage, thereby safeguarding surrounding water resources.

Apart from the list of standards applicable to FPV projects, the following international agreements, conventions, and national/state-level policies are also relevant to the implementation of FPV projects.⁹⁰

International Agreements and Conventions	Description
Ramsar Convention on Wetlands	<ul style="list-style-type: none"> ▪ The Convention on Wetlands is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. ▪ The convention entered into force in India on February 1, 1982.
International Union for Conservation of Nature (IUCN)	<ul style="list-style-type: none"> ▪ IUCN is a democratic union that brings together the world's most influential organizations and top experts in a combined effort to conserve nature and accelerate the transition to sustainable development. ▪ India became a State Member of IUCN in 1969, through the MoEFCC. ▪ IUCN in India operates under four projects: marine & coastal, inland waters, business and biodiversity and species conservation.
Convention on Biological Diversity	<ul style="list-style-type: none"> ▪ The Convention recognizes that biological diversity is about more than plants, animals and microorganisms and their ecosystems – it is about people and their need for food security, medicines, fresh air and water, shelter, and a clean and healthy environment in which to live.
National level policies	Description
Environmental Clearance under EIA notification 2006	<ul style="list-style-type: none"> ▪ MoEFCC is the nodal agency responsible for the environmental management of the country at the national level. ▪ The responsibilities include environmental policy planning, environmental legislation, regulation for environmental protection, environmental clearance of projects, monitoring of environmental conditions imposed in the EC process, conservation and management of biological diversity, protection of waterbodies and coastal areas.
World Heritage sites Ancient Monuments and Archaeological Sites and Remains Act	<ul style="list-style-type: none"> ▪ Conservation of cultural and historical remains found in India. ▪ For a project located within 300m of such features (first 100 meters as prohibited area followed by 200 meters to be regulated area), approval from Archaeological Dept. the central government, Indian Heritage Society and Indian National Trust for Art and Culture Heritage is required.
Important Coastal and Marine Biodiversity Areas (ICMBAs)	<ul style="list-style-type: none"> ▪ ICMBAs are ecologically significant sites along India's coastlines and marine zones identified for their rich biodiversity and conservation value.
Right to Fair Compensation and Transparency in Land Acquisition and Resettlement Act 2013	<ul style="list-style-type: none"> ▪ Revenue Department through office of District Collector is responsible for implementation of this Act to ensure that land acquired is for public purpose and to provide fair compensation to the affected owners when private land is acquired for the project.

⁹⁰ [Worldbank \(2023\): Unlocking the potential of floating solar photovoltaics in India](#)

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The Forest (Conservation) Act 1980	<ul style="list-style-type: none"> State Forest Department MoEFCC's permission is required to divert forests for non-forestry use. Need to undertake compensatory afforestation if forestland is acquired.
Environmental Protection Act 1986	<ul style="list-style-type: none"> To protect and improve the overall environment. The Department of Environment at the State level is the apex body for all environmental related issues and has administrative responsibility for managing the State Pollution Control Board.
State level policies	
	Description
The Water (Prevention & Control) Act 1974	<ul style="list-style-type: none"> To prevent and control water pollution by regulating the discharge of pollutants into water bodies and ensuring the maintenance or restoration of water quality through the establishment of Pollution Control Boards.
The Air (Prevention & Control) Act 1981	<ul style="list-style-type: none"> To prevent, control, and mitigate air pollution in order to manage and maintain air quality.
The Noise (Regulation & Control) Rules 2000	<ul style="list-style-type: none"> Regulate and control noise pollution to protect public health and the environment, particularly in residential, industrial, and sensitive zones.
The Batteries (Management & Handling) Rules 2001 as amended	<ul style="list-style-type: none"> Regulate the manufacture, handling, disposal, and recycling of batteries to minimize environmental and health impacts.
Solid Waste Management Rules 2016	<ul style="list-style-type: none"> Comprehensive framework for the segregation, collection, processing, and disposal of solid waste in an environmentally sound manner.
E-Waste Rules 2016	<ul style="list-style-type: none"> Regulate the management, handling, and disposal of electronic waste to ensure environmentally sound recycling and reduce the adverse impact of e-waste on health and the environment.
Hazardous and Other wastes (Management & Transboundary movement) Rules 2016	<ul style="list-style-type: none"> To govern the safe handling, storage, treatment, and disposal of hazardous waste, including guidelines for its import, export, and transport across borders to prevent environmental and health risks.
Reservoir Fishery Policy	<ul style="list-style-type: none"> To promote responsible fishing practices, enhance fish biodiversity, and ensure the sustainable development of fishery-based livelihoods, while protecting water bodies.
Wildlife (Protection) Act 1971	<ul style="list-style-type: none"> Projects located inside the boundary of Wildlife Sanctuary or National Park, Wildlife reserves or bio-reserves or National biodiversity reserves, have to comply with the Act.

The above international agreements, conventions, and national/state-level policies are applicable to Floating Photovoltaic (FPV) projects in India. These frameworks and regulations ensure that FPV installations are aligned with environmental conservation efforts, biodiversity protection, and sustainable land and water management. Compliance with these regulations will also support the minimization of environmental impacts, the protection of aquatic and terrestrial ecosystems, and the proper handling of waste and pollutants during the construction and operational phases of FPV projects. Furthermore, adherence to these policies is essential for obtaining necessary approvals and clearances, maintaining the integrity of natural resources, and promoting responsible development practices in the country.

An aerial photograph of a large-scale floating solar photovoltaic (FPV) plant. The solar panels are arranged in neat, rectangular rows on a body of water. In the background, there are green, forested mountains under a clear blue sky with a bright sun in the upper left corner. A small white boat is visible on the water to the left. A large, semi-transparent white circle is overlaid on the center of the image, containing the text.

REGULATORY/ APPROVAL COMPLIANCE

5 Regulatory/Approval Compliance

Unlike ground-mounted solar PV, FPV projects face unique regulatory hurdles due to their dependence on water bodies. Some of the common challenges include obtaining licenses, permits, and authorizations, which can vary widely across jurisdictions. Some countries, like the United States, have complex permitting processes, which can delay project timelines from a few months to several years. A clear and streamlined regulatory framework is crucial to reduce development costs, attract investment, and facilitate smoother project implementation. The development of FPV systems involves adhering to various national, state, and local regulations covering technical, environmental, legal, and commercial aspects. These regulations ensure that FPV projects comply with various norms and guidelines. The report outlines the key regulatory bodies, approvals, and permits required for FPV projects and identifies critical challenges that could impact the project timeline.

The FPV project lifecycle involves several stages: conducting a feasibility study, obtaining necessary permits and clearances, securing financing, project design, and development, construction, and commissioning, and ensuring smooth operations.

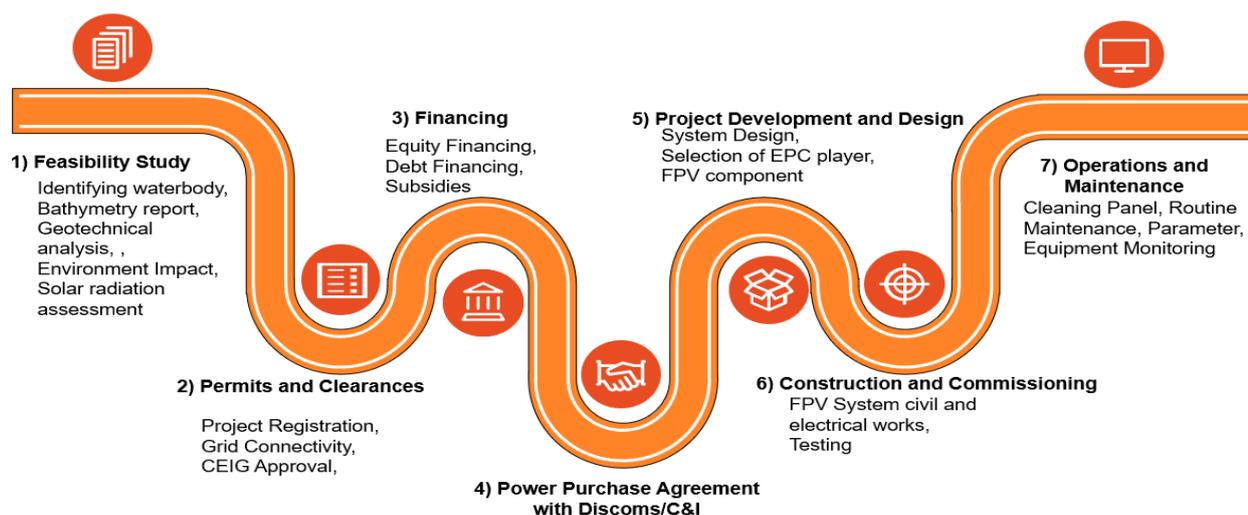


Figure 37: FPV project roadmap

FPV projects often require a range of approvals⁹¹, including:

- **Water Access and Usage Permits:** For site control, restricted areas, dam protection zones, and adherence to environmental regulations.
- **Site Lease Agreements:** For water bodies and adjacent land required for infrastructure such as substations.
- **Environmental and Land-Use Clearances,** Including compliance with water, fishing, agricultural, and planning laws.
- **Community and Stakeholder Engagement:** Addressing cultural, heritage, and local community concerns, including potential compensation.
- **Grid and Power Generation Approvals:** Applications for grid connections, electricity generation licenses, and cable-laying permissions.

As the FPV sector grows, regulations are expected to evolve, adapting to the unique needs of this emerging technology. Harmonizing international standards with localized policies will provide greater regulatory clarity, streamline permitting processes, and reduce uncertainties for developers and investors. These advancements are likely to foster broader adoption of floating PV, encourage increased investment, and promote innovation, ultimately contributing to sustainable development and a more robust renewable energy transition worldwide.

5.1 Overview of Global FPV Regulations

The rapid global expansion of FPV technology underscores the need for robust regulatory frameworks. Currently, there are no universal international standards specifically tailored for FPV projects. To address this, stakeholders in the industry emphasize the importance of adopting joint guidelines, commonly referred to as Recommended Practices (RPs). These RPs integrate existing standards, such as **IEC standards** for solar PV equipment and

⁹¹[World Bank \(Oct,2019\): Where Sun Meets Water: Floating Solar Handbook for Practitioners](#)

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ISO norms, with additional quality, safety, and environmental requirements specific to FPV systems. One notable example is the "**DNV GL RP – Design, Development, and Operation of Floating Solar PV Systems**," developed by DNV, an internationally accredited registrar and classification society based in Norway. This RP outlines key requirements and recommendations for the various stages of FPV project development, ensuring reliability and safety.

Only a few countries offer exclusive support or incentives for FPV projects. Unlike ground-mounted solar PV, FPV lacks specific standards or policies, although some Asian nations, such as **Japan, Malaysia, and Vietnam**, have implemented preferential feed-in tariffs for FPV. Most FPV projects in these countries are small-scale (less than 5 MW) and primarily financed by local or national banks in domestic currencies. However, a shift is occurring, with large international commercial banks and multilateral development banks now extending support beyond small-scale studies to finance large-scale FPV projects. In countries like China, Japan, Korea, and India, renewable energy targets set under national policies are driving demand for larger FPV projects (greater than 2–5 MW). **Tenders and auctions** are the predominant mechanisms for implementing projects larger than 2 MW.⁹² Rules and regulations for FPV projects often differ within countries due to state or regional variations. Case studies of leading countries in FPV installation, such as **China, Japan, Germany, the United States, and the Netherlands**, are presented below, showcasing their advancements and strategies in deploying floating PV systems.

5.1.1 Regulatory Framework in the Netherlands

The regulatory framework for FPV projects in the Netherlands is shaped by the country's commitment to sustainable energy and its unique geographic and environmental conditions. The Netherlands, with its extensive shallow inland water bodies, has prioritized FPV development as a key contributor to its renewable energy goals, addressing land scarcity and aiming to reduce CO₂ emissions by **49% by 2030** compared to 1990 levels. FPV systems are treated as building structures under Dutch law, given their long-term installation and connection to the ground through cables. Developers must obtain environmental permits, ensuring compliance with relevant regulations. Developers must first determine the controlling authority of the water body:⁹³

- **National Waterbodies:** Managed by the Ministry of Infrastructure and Water Management (Rijkswaterstaat).
- **Regional Waterbodies:** Governed by regional water utilities or provincial authorities.
- **Private water bodies:** Regulated under private law.

Applicable laws and permits^{69,94}:

- **Environmental Permit:** Required for compliance with environmental regulations.
- **Public Works and Water Management Act Permit:** Necessary for activities involving public works or water management structures, such as roads, motorways, viaducts, tunnels, bridges, or dykes.
- **Water Permit:** Mandatory if the solar PV facility falls under the Water Decree provisions as per Dutch legislation.
- **Large-Scale Energy Connection:** Applicable exclusively to solar PV systems connected to a large-scale grid network.

The Stimulation of Sustainable Energy Transition and Climate Transition (SDE++) scheme in the Netherlands supports FPV projects by offering financial incentives. It classifies FPV systems into two categories: those with a capacity of ≥ 1 MWp floating and ≥ 1 MWp floating with sun-tracking capabilities. To qualify, projects must be completed within four years, include feasibility studies and technical drawings, and secure essential permits such as environmental, water, and public works permits. Additionally, the systems must be connected to a large-scale energy grid, ensuring alignment with the country's renewable energy and climate goals. **Under SDE++**, for floating solar, a subsidy intensity of €175 per tCO₂ (\$210 per tCO₂) and an incentive of €0.08 per kWh (\$0.10 per kWh) has been announced. These incentives aim to reduce the upfront costs of floating solar projects, making them more economically attractive and driving their growth in the Netherlands.

⁹² [The Energy Research Institute, TERI \(2019\): Floating Solar Photovoltaic \(FSPV\): A Third Pillar to Solar PV Sector?](#)

⁹³ [World Bank \(Oct,2019\): Where Sun Meets Water: Floating Solar Handbook for Practitioners](#)

⁹⁴ [India-EU Clean Energy & Climate Partnership \(May,2022\): Detailed Project Report of 160 MW Floating PV plant in Indravati reservoir in Odisha State, India](#)

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Netherlands replaces SDE++ subsidies with CfDs for onshore wind, solar: In the Netherlands, the highly successful SDE++ subsidy scheme for onshore wind and solar energy projects has been replaced with a two-way Contract for Difference (CfD).⁵

A CFD is an agreement entered into between the government and the developer of an onshore solar or wind project that **sets a fixed price for the electricity generated**. If the market price for electricity is lower than the agreed price, the government will pay the difference up to the agreed amount. Vice versa, if the market price exceeds the agreed price, the project developer will pay the surplus to the government. In principle, subsidy payments under the SDE++ subsidy are like a CfD. The main difference, however, is that under the SDE++ subsidy, revenue above the agreed price (i.e., surplus) does not have to be paid to the government but instead may be kept by the generator.⁵

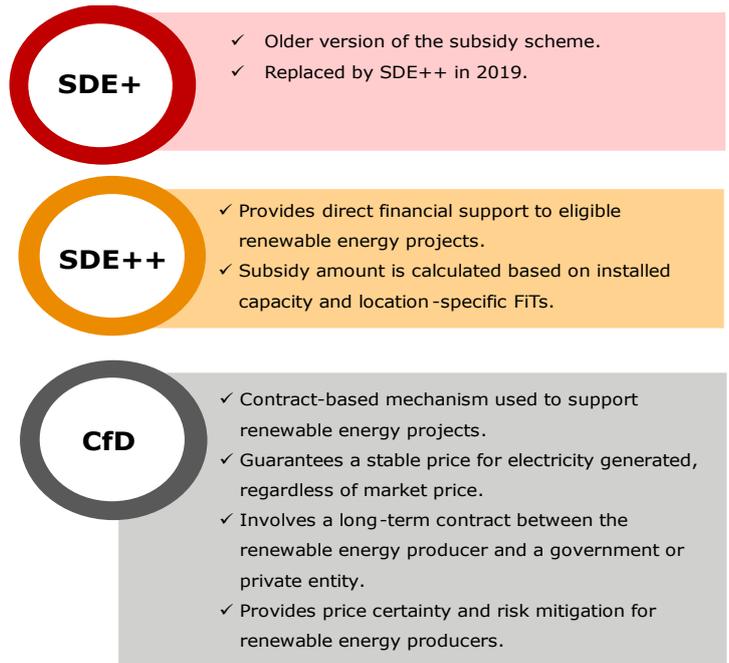


Figure 38: Key difference between SDE+, SDE++, CfD

5.1.2 Regulatory Framework in Germany

Germany has been a pioneer in the adoption of renewable energy technologies, and floating solar is no exception. The country's favourable policy environment and financial incentives have played a significant role in promoting the growth of floating PV systems. The Renewable Energy Sources Act (EEG) is the central instrument for the expansion of renewable energy in the electricity sector.

German EEG (Renewable Energy Act 2023) recognizes the dual land use for solar projects, including floating PV. The law proposes a new tender category for special PV plants with higher bidding limits and includes floating PV as well as other innovative technology categories.⁹⁵

EU ETS's Innovation Fund is one of the world's largest funding programs for the demonstration of innovative low-carbon technologies. The Innovation Fund, funded 100% by the EU ETS, will provide around EUR 38 billion of support from 2020 to 2030 (calculated at EUR 75 / tCO₂), depending on the carbon price, for the commercial demonstration of innovative low-carbon technologies, aiming to bring to the market industrial solutions to decarbonize Europe and support its transition to climate neutrality. EU ETS Innovation Fund is indeed applicable to Germany and can potentially support floating solar plants. However, the specific eligibility requirements and the level of funding available may vary depending on the project's details and the overall competition for funding.⁹⁶

In Germany, the **Water Balance Act** (WHG) sets out a limited scope for water surface coverage where **15% maximum coverage of the water surface** is allowed for FPV systems, and a minimum distance of 40m is required between the plant and the shore.⁷¹

5.1.3 Regulatory Framework in Japan

In Japan, FPV systems are typically not allowed on water bodies located in national parks (protected by the Natural Parks Act) or in areas with fishing rights where specific fishing laws apply. Developers must consider environmental impacts, such as the effects on local wildlife and ecosystems, especially in areas with specific land use and environmental protection guidelines. Applicable national laws are mentioned below.⁹⁷

- **Electricity Business Act:** To initiate an FPV project, developers must first obtain approval from the **Ministry of Economy, Trade, and Industry** (METI), which involves receiving an identification number under the Electricity Business Act.
- **Grid Connection:** After METI approval, developers must secure a grid connection from the local utility. This requires obtaining approval from the utility's engineering department ensuring that the grid can manage the additional capacity.

⁹⁵ [Solar Power Europe \(Apr 2024\): Recommendations for onshore Floating PV \(Accessed on 24-04-2025\)](#)

⁹⁶ [European Commission: EU Funding for climate action - Innovation Fund \(Accessed on 24-04-2025\)](#)

⁹⁷ [World Bank \(Oct 2019\): Where Sun Meets Water: Floating Solar Handbook for Practitioners](#)

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- **Agricultural Land Use:** FPV projects built on agricultural land must comply with Japan's Basic Law on Food, Agriculture, and Rural Areas. The law does not traditionally allow electricity generation on agricultural land, requiring modifications for FPV projects in such areas.
- **Environmental Impact Assessments:** Projects of size **≥40 MW** are required to undergo an EIA, which assesses their impact on various environmental factors, including air, water, soil, ecosystems, noise, and visual effects. EIAs are not typically required for smaller-size projects unless specified by local government ordinances or specific environmental concerns.
- **Approval and Compliance:** Local governments (prefectures or municipalities) require FPV projects to adhere to local regulations, including construction permits, environmental protection rules, and confirmation that the project will not harm the surrounding environment.
- **Water Body Ownership:** FPV projects in Japan are primarily developed on water bodies owned by municipalities, farmers' associations, or homeowners' associations. Developers need to secure approval from the relevant owner before leasing the water surface for project installation.

FPV projects were previously eligible for FiTs, which guaranteed fixed payment rates for electricity sold to the grid. However, since 2017, larger projects (**≥2 MWp**) are no longer eligible for FiTs and must instead participate in a competitive bidding process for electricity tariffs. Organizations like the **Japan International Cooperation Agency (JICA) and the Asian Development Bank (ADB)** have played a significant role in supporting both domestic and international FPV projects through financing and technical assistance.⁹⁸

5.1.4 Regulatory Framework in China

Under the 2019 Renewable Portfolio Standard, China aims to source **20% of its primary energy from non-fossil fuels by 2030**. This target has fuelled demand for new renewable energy projects, including FPV systems, to meet the country's renewable energy needs. China encourages the deployment of FPV systems on otherwise unused land and artificial water bodies (such as flooded mines or reservoirs), as opposed to natural water bodies. This policy reduces the complexity of environmental reviews, which are more stringent for projects impacting natural ecosystems.⁶⁹

FPV projects in China must align with national and provincial energy grid integration policies. Utility companies in each province are required to develop capacity expansion plans that comply with renewable portfolio standards. This ensures that FSPV projects are efficiently connected to the grid, facilitating their integration into the national renewable energy framework.

While large-scale FPV projects are not typically incentivized through direct feed-in tariffs, they benefit from **government-backed policies and subsidies** that promote the expansion of renewable energy capacity, including FPV. These incentives are part of China's broader strategy to reduce carbon emissions and transition to clean energy sources.

5.1.5 Regulatory Framework in the United States

The regulatory framework for FPV projects in the United States is decentralized, with regulations varying across states and counties. Developers must adhere to state-specific solar ordinances, land-use laws, and water rights regulations, often requiring them to navigate complex local interpretations of these rules. A critical first step in the permitting process is securing site control, typically through lease agreements, followed by obtaining a GIA with local utilities. In addition, developers must assess potential infringements of land-use laws and water rights, with specific requirements varying based on the project location.

Environmental impact assessments play a crucial role in the permitting process, especially in states like **California and Massachusetts**. In California, projects with minimal environmental impact may be eligible for a notice of exemption, while other projects may require more detailed environmental site assessments. Similarly, Massachusetts requires an EIA for each FPV project, overseen by the Department of Environmental Protection. Developers are also tasked with addressing concerns related to water bodies and ecosystems, including potential environmental contamination and impact on local habitats.⁷⁰

In addition to environmental assessments, FPV projects must comply with water rights and jurisdictional regulations. Projects located on water bodies may require permits from state and local water authorities, with special scrutiny applied to projects on hydropower dams or protected wetlands. In states like **New Jersey**, where most reservoir beds are classified as **protected wetlands**, developers must use specific installation methods, such as bank anchoring, to comply with environmental regulations. The permitting process can be lengthy, requiring careful coordination with local utilities and environmental agencies. For example, the permitting process

⁹⁸ [India-EU Clean Energy & Climate Partnership \(May,2022\): Detailed Project Report of 160 MW Floating PV plant in Indravati reservoir in Odisha State, India](#)

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for the **Sayreville project in New Jersey** took **18 months** due to jurisdictional disagreements between energy and water departments.⁹⁹

Overall, while FPV projects in the U.S. face a patchwork of regulations, developers can ease the permitting process by conducting initiative-taking studies, engaging with relevant stakeholders, and addressing local environmental concerns. The regulatory landscape, though complex, is evolving as utilities and governments increasingly recognize the benefits of FPV systems for water management and renewable energy production.

5.2 Overview of Indian FPV Regulatory Bodies

FPV projects require compliance with various Ministry guidelines and coordination with multiple regulatory authorities at the national, state, and local levels. Each regulatory body plays a crucial role in ensuring compliance with relevant laws, guidelines, and standards, contributing to the smooth execution of the project.

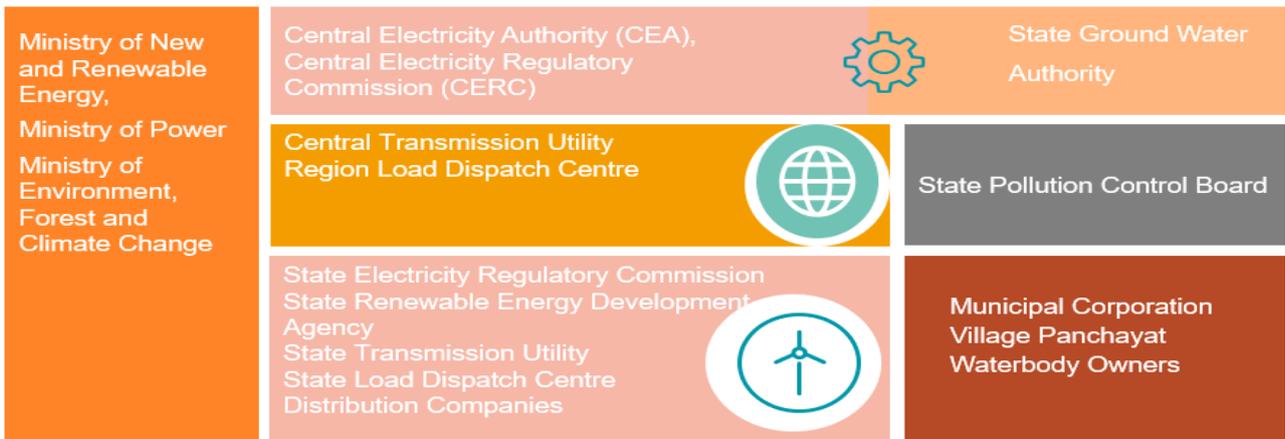


Figure 39: Indian FPV regulatory bodies

5.3 Permit and Licensing Requirements

FPV installations require multiple permits and licenses to comply with various national, state, and local regulatory frameworks. These approvals span across several sectors, including power, environment, water usage, labor, and administrative requirements. Obtaining these permits timely is crucial to ensure smooth project execution and avoid potential delays.

5.3.1 Power Sector Approval

Power sector approvals relate to grid connectivity, electrical safety, tariff adoption, synchronization of FPV projects, etc. These approvals are essential to ensure compliance with regulatory frameworks governing power generation and transmission. Various types of approval required are as follows:

Table 20: Key stakeholders involved in power regulatory approval

Permit/Approval	Issuing Entity
Letter of award/allotment of the project	Tendering entity (SECI or state nodal agency).
Project Registration	State Nodal Agency
Power Sale Agreement (PSA)	DISCOMS
Adoption of Tariff	SERC
Application for grid Connectivity (ISTS/InSTS)	Central transmission utility (CTU)/State transmission utility (STU)

⁹⁹ World Bank (Oct,2019): Where Sun Meets Water: Floating Solar Handbook for Practitioners

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Permit/Approval	Issuing Entity
Connectivity Agreement	CTU/STU
Approval for transmission scheme (Section 68 and Section 164)	MoP
Right of Way (RoW)	NHAI/State highway authority
Chief Electrical Inspector to Government (CEIG)/ CEA approval	CEIG/CEA
Load dispatch center approval for drawal of startup power, injection of infirm power	RLDC/SLDC
Synchronization approval	DISCOM/SLDC/RLDC
Commissioning certificate	Nodal agency/Discom

5.3.2 Environment Approval

FPV projects require compliance with various environmental regulations and need to obtain fire safety permits and clearance from the forest and mining department as applicable. As FPV Projects have been included under the **“White category”** (Non-polluting) by the Ministry of Environment, Forest, and Climate Change (MoEFCC), “Consent to Establish/ Operate” clearance for the FPV Project is not required. However, developers must inform the relevant State Pollution Control Board. Various types of environmental approvals required are as follows:

Table 21: Key stakeholders involved in environmental approval

Permit/Approval	Issuing Entity	Relevant Regulation
Intimation regarding the establishment and operation.	State Pollution Control Board	Water (Prevention and Control of Pollution) Act, 1974, and Air (Prevention and Control of Pollution) Act, 1981
Fire & safety permit	Fire Department	National Building Code of India 2016
Forest NOC	Forest Department	Forests (Conservation) Act, 1980, and Rules and amendment
Mining NOC	Mining Department	Mines & Minerals (Regulation & Development) Act
Environmental clearance (if required)	Ministry of Environment, Forest, and Climate Change (MoEFCC)	Environment Protection Act, 1986, Environmental Impact Assessment (EIA) Notification, 2006 and amendment

5.3.3 Water Use Approval

FPV installations require approvals from the state or central water authorities, depending on the ownership and usage of the water body. However, FPV projects installed on private reservoirs, such as NTPC’s Ramagundam and Simhadri FPV plants, do not require water use permissions. In cases where FPV installations are near ports or coastal areas, approvals from port trusts, coastal regulation zones, or naval authorities are needed. Various types of water use approvals required are as follows:

Table 22: Key stakeholders involved in Water use approval

Permit/Approval	Issuing Entity	Relevant Regulation
No Objection Certificate for water body	Water Resource Department	

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Permit/Approval	Issuing Entity	Relevant Regulation
Approval from Irrigation Department	Water Resource Department	
Water use permission for surface and groundwater	Central/State Ground Water Authority	Guidelines for Groundwater Abstraction (16.11.2015) & amendments
Waterbody Permission Agreement	Owner of the waterbody	
NOC/approval from the port trust, coastal regulation zone, and naval authorities	Relevant Authorities	Coastal Regulation Zone (CRZ) 2019

5.3.4 Labor and Administrative Approval

Labor and administrative approvals involve permits related to workforce management, including factory licenses, contract labor regulations, and NOCs from local governing bodies such as gram panchayats. Labor and administrative approvals include:

Table 23: Key stakeholders involved in Labor and administrative approvals

Permit/Approval	Issuing Entity	Relevant Regulation
Factory License	Labour Department	Indian Factories Act and others
Factory plan approval	Labour Department	
Contract labour regulation, Provident Fund (PF)	Labour Department	Building and Other Construction Workers, Contract Labor (Regulation and Abolition) and others
Gram panchayat NOC	Gram panchayat	The Provision of the Panchayats (Extension to the Scheduled Areas) Act, 1996
Land Lease Agreement/ Land Sales Deed	Revenue department	The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement Act
Power & Telecommunication approval	Power & Telecom Department	

5.4 Annual Compliance Requirement

Once operational, FPV projects must adhere to various compliance requirements related to scheduling, environmental, labor, and safety standards. Key compliances are:

- **Environmental Compliance:** Submission of an Annual Environmental Statement to the State Pollution Control Board by the Environment Protection Act.
- **Labor Compliance:** Compliance with various labor laws such as the Contract Labor (Regulation & Abolition) Act, Occupational Safety, Health and Working Conditions Code, and others.
- **Hazardous and E-Waste Management:** Compliance with E-waste Rules and Hazardous and Other Wastes Rules to ensure the proper disposal of electronic waste, batteries, PV cells, transformer oil, and other chemicals generated at the FPV project site.
- **Qualified Control Agency:** Appointment of QCA as per CERC - Procedure for implementation of framework on forecasting, scheduling, and imbalance handling, 2017 and relevant state regulation for scheduling of power.

5.5 Challenges and Recommendations

FPV projects face various challenges that can affect timelines, costs, and overall project feasibility. These challenges arise from regulatory and coordination of approvals across multiple bodies. The key regulatory challenges faced by FPV projects are as follows:

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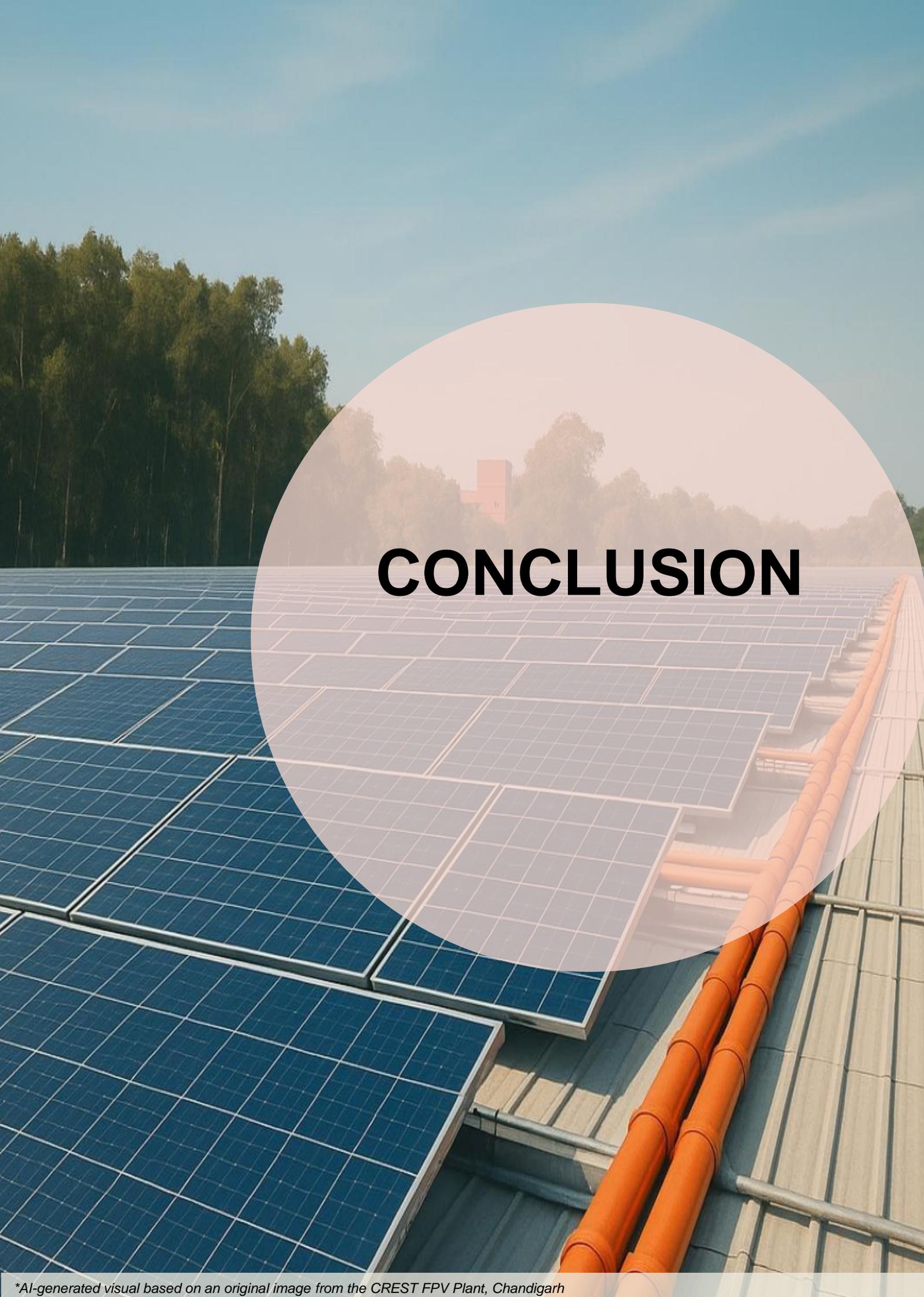
Table 24: Key regulatory challenges faced by FPV projects

Category	Challenges
Grid Connectivity	Grid connectivity requires compliance with various CEA, CERC, and State Regulations and agreement with the Central or State Transmission Utility (CTU/STU). The Right of Way (RoW) approvals for transmission lines may involve clearance from multiple government agencies and may face delays. The approval of transmission schemes as per the Act often has long lead times, requiring early initiation.
Environmental Impact	FPV installations may affect water quality, aquatic ecosystems, and local biodiversity. For example, the 600 MW Omkareshwar FPV project in Madhya Pradesh conducted a detailed Environmental and Social Impact Assessment (ESIA) to assess risks to physical, biological, and social environments. Such assessments are crucial for gathering baseline data, identifying potential risks, and formulating mitigation measures.
Forest NOC	If FPV projects require forest area for installation or associated facilities such as substations or transmission lines or cutting trees, developers must obtain a No Objection Certificate (NOC) from the Forest Department and pay necessary compensation for cutting trees.
Waterbody Permissions	Water bodies often serve multiple purposes (irrigation, fishing, drinking water), which can involve coordination with several agencies (irrigation, fisheries, and public works departments) and might have conflicting requirements.
Land Acquisition	Although FPV projects require less land than traditional ground-mounted solar PV systems, land acquisition is required for onshore facilities such as control rooms, substations, and transmission lines. For projects involving private land acquisition, obtaining the consent of affected landowners is mandatory under the Land Acquisition Act. Delays in securing land can impact project timelines significantly. Developers must engage with local communities and conduct public consultations to address concerns related to land use and project impact.
Approval Coordination	FPV projects require approvals from multiple authorities across various sectors, such as power, environment, water, labor, and local bodies. The individualistic approach to securing approvals increases the risk of delays and raises project costs.

Despite these challenges, the **Government of India and the state government** have taken steps to streamline the approval process, making it more time-bound and structured. However, further efforts are needed to simplify and expedite approvals for faster FPV deployment. Suggested recommendations for the development of FPV projects are as follows:

- **Proactive Permit Management:** Early identification of required permits and engaging with relevant authorities early on can prevent bottlenecks during critical project phases.
- **Feasibility Studies** Conducting feasibility studies, including environmental and social impact assessments, can identify potential risks and develop mitigation strategies before seeking approvals.
- **Data Availability:** A list of potential water bodies, along with data on water bodies, such as wind speed, wave current, and water levels, may be made available to help developers design reliable FPV systems.
- **Streamlining Approvals:** While some states have streamlined processes for renewable energy projects, the need for multi-sector approvals can be a challenge and have significant lead time. Centralized or single-window clearances can greatly enhance project approval.

The successful development of FPV systems requires navigating multiple approvals across national, state, and local levels. By proactive planning and greater coordination with regulatory bodies, FPV developers can reduce delays and ensure smooth project execution. Streamlining the regulatory framework through centralized clearance systems and fostering collaborative efforts among developers, regulatory bodies, and local communities can play a crucial role in accelerating the growth of FPV projects and meeting renewable energy targets.

A large-scale solar panel installation on a roof. The panels are blue with white grid lines, arranged in rows. Orange conduits run along the edge of the roof. A circular graphic overlay is centered on the image, containing the word "CONCLUSION" in bold black text. The background shows a clear blue sky and a line of trees.

CONCLUSION

6 Conclusion

The **Floating Solar Photovoltaic (FPV) Guidelines** represent a strategic framework designed to address India's unique challenges and suggest potential recommendations for deploying FPV technology while capitalizing on its immense potential. By offering a structured approach to site selection, system design, performance aspects, and environmental considerations, these guidelines ensure a streamlined and sustainable pathway for FPV adoption. They underscore the importance of tailoring global best practices to India's diverse hydrological and regulatory landscapes, enabling the effective utilization of water bodies for renewable energy generation.

By combining technical insights with global examples and case studies, the guidelines aim to foster collaboration among developers, policymakers, and investors, ensuring a holistic and coordinated approach to FPV deployment. This pragmatic framework underscores India's commitment to driving innovative renewable energy solutions, contributing significantly to the nation's ambitious energy goals and environmental conservation efforts. With these guidelines in place, FPV systems are well-positioned to play a transformative role in meeting India's energy aspirations redefining the nation's path toward a sustainable energy future.



ANNEXURE

7 Annexure – Policy Recommendations including Technical Specifications

7.1 Key Floating PV Considerations

- FPV projects must undergo an Environmental Screening to assess their impact on aquatic ecosystems, water quality, and biodiversity.
- FPV projects shall assess and mitigate greenhouse gas (GHG) emissions from submerged biomass decomposition, particularly in shallow reservoirs. Pre-submergence removal of trees and organic matter shall be considered to reduce carbon release and long-term environmental risks.
- All Floating Photovoltaic (FPV) projects shall adhere to relevant national and international standards to ensure environmental protection, water quality preservation, and structural integrity across all phases of development and operation. For Floating Photovoltaic (FPV) projects located on water bodies designated for drinking water supply, adherence to IS 10500:2012 (Drinking Water – Specification) should be ensured to protect and maintain potable water quality throughout the project lifecycle. To further safeguard public health, IS 15410:2003 or its international equivalent, BS 6920:2014, shall be followed to verify that all materials used in FPV systems are suitable for contact with drinking water and do not release harmful substances.
- Where FPV systems are deployed on water bodies used for purposes such as irrigation, ecological conservation, or industrial applications, the IS 3025 series shall be applicable. These standards provide standardized methodologies for sampling and testing the physical and chemical characteristics of water and wastewater, forming the basis for effective water quality monitoring and environmental reporting.
- FPV systems shall minimize adverse impacts on water quality, with requirements tailored to the type and designated use of the water body (e.g., irrigation, freshwater ecosystem, or industrial use). Key indicative thresholds include dissolved oxygen (DO) ≥ 4 mg/L for irrigation and ≥ 5 mg/L for freshwater, total nitrogen ≤ 5 mg/L, phosphorus between 0–2 mg/L, and pH within 6.5–8.4.
- All FPV installations shall also implement ISO 14001:2015, the international standard for Environmental Management Systems (EMS). This ensures a structured approach to managing environmental responsibilities, achieving regulatory compliance, and minimizing ecological impacts during planning, construction, and operation phases.
- For FPV projects situated on or adjacent to canal infrastructure, IS 4701:1982 shall be followed to uphold best practices in earthwork and civil engineering design. In cases involving underground or partially submerged water storage reservoirs, IS 6494:1988 shall apply to ensure robust waterproofing and to prevent seepage, thereby safeguarding surrounding water resources.
- FPV deployment shall be managed to mitigate algal blooms by optimizing coverage levels, ensuring a balance between water quality improvement and the preservation of ecological stability. Site-specific assessments shall be conducted to prevent unintended disruptions to aquatic ecosystems.
- FPV deployment shall be designed to optimize light permeability, ensuring sufficient solar penetration to sustain aquatic ecosystems while balancing energy efficiency. Structural considerations shall be tailored to minimize ecological disruptions.
- The FPV layout shall maintain an appropriate percentage of open water surface, ensuring a balance between energy generation, ecological preservation, and operational efficiency.
 - a. Freshwater Bodies: For water bodies intended for ecological preservation, aquatic life, or public use, FPV system surface coverage shall typically range between 10% to 40%, ensuring sufficient sunlight penetration, natural water flow, and overall ecosystem balance.
 - b. Non-Potable Water Bodies: In cases where water bodies, such as mining ponds, are unsuitable for drinking purposes, up to 70–80% of the surface may be utilized for FPV installations. Although such

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water bodies typically support minimal aquatic life, a portion of the surface shall be left uncovered to facilitate maintenance, sediment control, and preservation of any remaining aquatic ecosystems. This approach ensures a balance between maximizing energy generation and maintaining baseline ecological integrity.

- FPV deployment shall incorporate biodiversity considerations to minimize disruptions to aquatic ecosystems by regulating impacts on light availability, nutrient cycling, and habitat structure. Site-specific assessments shall ensure a balanced approach to renewable energy deployment and ecological integrity.
- FPV systems impact aquatic ecosystems by altering light, habitat conditions, and biodiversity. Mitigation measures shall address shading effects, conservation strategies, and ecosystem stability. Integrating biohuts can enhance habitat complexity and support species diversity.
- Floating solar systems shall be designed to minimize risks to wildlife, including waterfowl and aquatic species. Measures shall be taken to prevent entanglement, habitat disruption, and interference with migratory or breeding behaviours.
 - a. FPV systems shall include continuous bird population monitoring to assess habitat interactions and minimize disturbances. Strategic vegetation, biohuts, or artificial structures shall be integrated to enhance habitat diversity and support avian conservation.
 - b. FPV systems may influence fish behaviour and distribution by creating artificial habitats, necessitating careful evaluation of shading effects, trophic interactions, and long-term ecological impacts to maintain ecosystem balance and prevent disruptions to local food webs.
- Environmental monitoring shall be conducted pre-installation, during operation, and post-decommissioning of FPV systems to assess and mitigate ecological impacts. Key factors such as meteorology, water quality, and biodiversity shall be analysed, with corrective actions implemented to ensure compliance and sustainability.
- FPV projects shall incorporate long-term in-situ environmental monitoring with modern sensors to track key parameters such as dissolved oxygen, chlorophyll levels, and temperature variations, ensuring sustainability and transparency.
- FPV systems shall leverage natural water cooling and optimized platform design to minimize thermal losses and enhance efficiency. Adequate ventilation, proper module spacing, and thermally efficient materials shall be incorporated. U-values shall be adapted to environmental conditions, and continuous climate monitoring is required for optimal performance.
- Floating solar installations shall be prioritized on artificial water bodies, including reservoirs at steel plants, thermal power plants, and hydroelectric dams, to drive capacity expansion. Common infrastructure shall be developed to reduce costs, streamline implementation, and facilitate large-scale FPV deployment.
- Proper waste management practices shall be implemented to prevent pollution of water bodies. This includes safe disposal and handling of installation materials, solar panel components, packaging waste, and other associated debris in accordance with environmental regulations.
- End-of-life handling of FPV systems shall be planned in advance. Provisions for decommissioning, recycling, and safe disposal of solar panels and electronic components shall be integrated into the project lifecycle to minimize long-term environmental risks.
- FPV projects shall obtain all necessary environmental, navigational, and land-use permits from relevant local and national authorities. Approvals must consider the impact on water rights, recreational use, and aquatic ecosystems, in line with applicable environmental standards.
- Installation of FPV systems shall avoid ecologically sensitive areas, such as wetlands, mangroves, and designated breeding zones. Site selection and layout planning must prioritize the preservation of existing natural habitats.
- In the event of any reported health hazards from operational FPV projects, timely public notifications and investigations shall be mandated. Lessons learned shall inform future project design and operational guidelines.
- FPV projects shall comply with relevant international agreements, including the Ramsar Convention on Wetlands, the Convention on Biological Diversity, and guidelines from the International Union for

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Conservation of Nature (IUCN). These projects must also adhere to national laws, including the Environmental Protection Act, the Forest (Conservation) Act, the Wildlife (Protection) Act, and the Environmental Impact Assessment (EIA) Notification 2006. Compliance with the Water (Prevention & Control) Act, the Air (Prevention & Control) Act, and other regulations governing pollution, hazardous materials, waste management, and land acquisition.

- FPV projects must meet state-level regulations, including those governing Important Coastal and Marine Biodiversity Areas (ICMBAs) and reservoir fishery policies. Special consideration is required for projects near or within protected areas such as World Heritage Sites, wildlife sanctuaries, national parks, and biodiversity reserves. Any site-specific legal obligations related to cultural heritage, water body protection, and biodiversity conservation must be incorporated into the project planning, development, and operational process.

7.2 Key O&M Considerations

- To ensure the long-term reliability, safety, and efficiency of Floating Photovoltaic (FPV) systems, the following maintenance and monitoring protocols shall be implemented:
 - a. **Regular cleaning of PV modules** shall be conducted monthly or more frequently in dusty or high-biofouling regions to remove dirt, algae, bird droppings, and biofouling that could obstruct sunlight and reduce efficiency. Guidelines for water sourcing and usage of water from existing water bodies must be ensured with a proper site-specific Operation & Maintenance plan to ensure that the required quality of water is used for PV panel cleaning.
 - b. **Comprehensive visual inspections** of PV modules, electrical connections, floats, and anchoring systems shall be performed at suitable interval or after extreme weather events to detect wear, damage, misalignment, or structural weaknesses as per the detailed O&M plan. Thermal imaging at an appropriate interval shall be employed to identify faults such as dead cells, cracked panels, and other hidden defects affecting performance.
 - c. **Electrical inspections** considering system parameters, including voltage, current, and inverter performance (active and reactive power), shall be measured on a real time, daily, weekly basis as per the SCADA system architecture installed at site, to detect faults in various components of the PV project including but not limited to PV Modules, Inverters, cables, connectors, and electrical components, minimizing downtime and ensuring stable energy output.
 - d. **Component replacement** for degraded or damaged PV modules, electrical components, floats, or connectors shall be replaced as needed, based on inspection findings to sustain system reliability, and prevent cascading failures. For the human safety point of view, it is recommended to check the physical damage of modules before every cycle of wet module cleaning.
 - e. **Anchoring systems and mooring lines** shall be inspected semi-annually and after high winds or waves to identify wear, displacement, or structural stress caused by water currents, wind, and waves, ensuring platform stability and alignment.
 - f. **Water quality monitoring** considering regular assessment of water parameters, including turbidity, salinity, pH, and sediment accumulation, shall be conducted annually or as per site-specific conditions to prevent corrosion, biofouling, and structural degradation of FPV components.
 - g. **Performance Data Monitoring and Analysis** considering automated monitoring systems shall track energy generation, module temperatures, and inverter efficiency continuously, with periodic reviews, to optimize performance and identify underperforming areas.
 - h. Detailed / Weekly / Monthly / yearly records of inspections, maintenance activities, repairs, and replacements shall be maintained after each maintenance activity for compliance tracking, performance benchmarking, and regulatory reporting as per the site-specific management process and O&M plan. Specific requirements for employing skilled manpower for O&M activity for floating PV project needs to be prepared in alignment with the safety requirements and local safety guidelines.
- O&M activities must follow strict safety protocols, including risk assessments for electrical hazards, slips, drowning, and weather conditions. Lockout/Tagout (LOTO) procedures shall be enforced, with only authorized personnel permitted to isolate energy sources. Workers must be trained in aquatic safety, electrical hazard mitigation, and emergency response.
- Workers must use appropriate Personal Protective Equipment (PPE) to mitigate environmental, electrical, and physical hazards. Mandatory gear includes life jackets or PFDs near water, non-slip footwear, insulated gloves, arc-rated clothing for electrical safety, and sun protection or wet weather gear based on site conditions.

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- Access to FPV systems must be planned to ensure worker safety. Certified floating platforms, boats, or walkways should be used, with clearly marked, obstruction-free paths. Fall restraint systems and guardrails must be installed where feasible. Work areas should be managed to minimize congestion, and tools must be secured to prevent accidental drops into the water.
- To mitigate electrical hazards in FPV O&M activities, all circuits must be isolated and de-energized before maintenance, with strict adherence to lockout-tagout (LOTO) procedures. Regular inspections of cables, connectors, and junction boxes should be conducted to detect damage, wear, or water ingress. Waterproof connectors and proper grounding must be ensured. Work on electrical components must be avoided in wet conditions, and insulated tools should be used to prevent electrocution risks.
- FPV O&M activities must include weather monitoring to avoid operations during adverse conditions and ensure quick evacuation if needed. Workers should remain vigilant of aquatic wildlife and implement measures to prevent water contamination during maintenance.
- FPV O&M activities must include readily available rescue equipment, regular emergency drills, reliable communication systems, and on-site first aid kits with AEDs. At least one team member should be certified in first aid and CPR to ensure swift response to emergencies.
- After FPV O&M activities, conduct site inspections to remove hazards and safely re-energize systems. Maintain detailed records of maintenance, incidents, and safety updates to enhance long-term system reliability and improve protocols.

7.3 Floating PV Technical Specifications

Technical Specifications Note for FPV Policy

Floating Solar PV (FPV) systems can be installed on water bodies such as water reservoirs, lakes, natural/artificial ponds/tanks, and hydropower dams. FPV projects are gaining significant traction in India due to land constraints. Developing robust technical specifications for these projects is crucial to long term performance, reliability, and cost effectiveness for achieving scale of economies. The FPV system shall consist of the following components:

1. Solar Photovoltaic (SPV) Modules
2. Floating Structure
3. Mooring and Anchoring System
4. Inverter / Power Conditioning Unit (PCU)
5. Cables
6. Combiner box
7. Switchgear
8. Transformers
9. Protection – Earthing and Lightning system
10. SCADA and PPC system
11. Operation & maintenance (O&M)
12. Other considerations

The components of a Floating Solar PV System shall essentially comprise but not be limited to solar PV panels/modules of the required number, inverters/PCU, floating platforms designed for buoyancy and stability, and mooring systems to anchor the structure. The system must include cables and conduits suitable for marine environments, submersible and floating cables with proper insulation, and array junction boxes that are waterproof and corrosion resistant. Additionally, DC and AC distribution boxes, various connectors, fasteners, and structural components must be included. Essential protection systems such as earthing, lightning protection, and surge arrestors should be in place. The package must also cover civil and mechanical works, an installation and operational manual, and a minimum of five years of comprehensive operation and maintenance (O&M). Other miscellaneous works necessary for the safe and efficient operation of the floating solar PV plant should also be incorporated.

1. Solar PV Modules

- PV modules deployed in Floating Solar Photovoltaic (FPV) systems shall conform to the latest BIS or IEC standards, including but not limited to those listed below, to ensure safety, reliability, and long-term durability. Modules shall meet design qualification and type approval requirements as per IS 14286 (Part 1): 2023 / IEC

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61215-1:2021 and IS 14286 (Part 1/Sec 1):2023 / IEC 61215-1-1:2021 for crystalline silicon modules. For thin-film modules, applicable requirements shall follow IS 14286 (Part 1/Sec 2/3/4): 2019, as applicable. Testing procedures shall be conducted in accordance with IS 14286 (Part 2): 2023 / IEC 61215-2:2021. Safety requirements must align with IS/IEC 61730-1:2016, which specifies requirements for construction, and IS/IEC 61730-2:2016, which outlines requirements for testing, to ensure photovoltaic (PV) modules are qualified for safety and to mitigate hazards such as fire and electric shock. ASTM D257 shall also be considered for determining surface resistivity and volume resistivity of insulating materials.

- The selection of PV modules shall be based on the following criteria:
 - a. **Monocrystalline PV modules** shall be the preferred choice due to their high efficiency, space optimization, and long-term reliability in marine environments.
 - b. **Polycrystalline PV modules** may be used where cost-effectiveness is a priority, offering a balance between affordability and energy output for large-scale FPV installations.
 - c. **Thin-film PV modules** shall be considered for specific applications requiring lightweight and flexible designs, despite their lower efficiency compared to crystalline silicon modules.
 - d. **PERC (Passivated Emitter and Rear Contact) modules** shall be utilized to enhance efficiency, by incorporating a reflective layer at the rear of the cell, improving light absorption and electron movement.
 - e. **Dual-glass modules** shall be considered for enhanced durability and longevity, as the rear glass replaces the conventional plastic back sheet, forming a glass-glass structure that resists UV degradation and environmental wear.
- FPV panel orientation shall align with site latitude for optimal energy yield to the extent possible, with an east-west orientation and a 5°-7° tilt angle to minimize shading and enhance efficiency. Tilt selection shall consider wind speed, wave conditions, and structural stability. Anti-reflective coatings shall be used to improve light absorption.
- Glass-glass PV modules shall be preferred for their superior resistance to environmental conditions and enhanced protection. Modules shall be equipped with robust frames to withstand both dynamic and static loads. Accelerated aging tests shall be conducted to ensure the effectiveness of the solar panel, frame, and mounting structures in highly humid and saline conditions.
- Mounting systems shall include flexible joints or vibration-damping measures to absorb wave-induced motions, designed to accommodate maximum amplitude and frequency based on site-specific hydrodynamic studies. Corrosion-resistant materials, such as anodized aluminum or coated metals, shall be used, with anodization thickness tailored to the type of water body (inland or marine).
- Modules shall be PID-resistant, incorporating materials that mitigate potential-induced degradation. To minimize energy losses due to Potential Induced Degradation (PID), all modules shall be tested in accordance with IS 17210 (Part 1): 2019 / IEC TS 62804-1:2015, ensuring their resistance to voltage-induced performance deterioration over time. Regular diagnostic tests like LID performance test, EL imaging, IR thermography, and IV Curve Tracing should be conducted to detect early faults and ensure long-term reliability. PV modules shall be capable of withstanding additional loads due to wind and water movement and may incorporate protective coatings to resist prolonged UV exposure. The option IV Curve testing protocols must be provided by Inverter OEMs in compliance to local rules.
- Module degradation varies depending on the manufacturer data sheet / power warranty terms, technology option, and site-specific conditions such as temperature, humidity, soiling, and environmental weathering. As a normative range, the average year on year degradation rate is 0.55% per year for monofacial / Mono PERC modules and 0.45% per year for bifacial modules, with an average annual degradation rate of 0.5%. These factors based on actual degradation studies must be considered when assessing the long-term performance and reliability of FPV systems.
- Modules intended for deployment in saline, humid, or corrosive environments shall be tested for salt mist corrosion resistance per IS/IEC 61701:2011 and for ammonia corrosion resistance per IS 16664: 2018/ IEC 62716:2013, ensuring robust performance under harsh environmental conditions typical of FPV sites.

2. Floating Structure

- The floating structure and its associated materials used in FPV systems shall comply with the latest editions of relevant BIS, IEC, ISO, or ASTM standards, including but not limited to those listed below, to ensure mechanical strength, environmental durability, and long-term reliability. This includes compliance with ASTM D1693, ASTM D1693-15 for environmental stress cracking of HDPE and ethylene plastics; ASTM D5397 for evaluation of stress crack resistance using Tensile load test; ASTM D790 / ISO 178 for flexural properties;

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ASTM D 792 / ASTM D 1505 for Density and Specific Gravity; ASTM D638 / ISO 527 for tensile strength; ASTM D695 for compressive properties; ASTM D2565 / ISO 4892-2 and ASTM D4329 / ISO 4892-3 for UV resistance; and the RoHS Directive 2002/95/EC for restriction of hazardous substances in materials used; and UL 94 or Equivalent IEC/ISO standard – Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing.

- Corrosion protection for steel structures within FPV systems shall conform to ISO 12944-2:2017 and ISO 12944-5:2019 to ensure effective performance in harsh aquatic environments. Additionally, structural design shall account for external loads such as wind, wave action, and water currents in accordance with IS 875 (Part 3):2015, and for seismic forces as per IS 1893 (Part 1):2016, ensuring overall structural resilience and safety under site-specific environmental conditions. IS 6685:2009 shall also be applicable for specifications related to life jackets used in operational and safety protocols on water-based installations.
- FPV systems may consider one of three floater technologies—Pure Float, Modular Raft, or Membrane—based on site conditions, technical requirements, and long-term performance needs.
 - a. **Pure Float** involves direct mounting of PV modules on HDPE floats connected by pins or bolts, offering modularity, low installation cost, and good corrosion resistance.
 - b. **Modular Raft** uses a structural frame made of HDPE and steel or buoyant rafts to support PV modules at optimal tilt angles, ensuring high buoyancy, ease of installation, and better stability.
 - c. **Membrane design** attach PV modules to a reinforced membrane with a tubular ring for buoyancy, offering ease of transport and reducing the impact of wave and wind forces on the structure.

Design selection shall consider environmental suitability, structural resilience, and operational efficiency to ensure long-term system sustainability.

- Floating structures in FPV systems must maintain buoyancy, stability, and structural integrity throughout their service life under site-specific wind and hydrodynamic forces. They shall support all equipment loads without failure, ensure secure mounting of PV modules, and allow safe, above-water access for maintenance. Design must enable easy inspection and replacement of components without impacting adjacent floats.
- Floats used in Floating Solar Photovoltaic (FPV) systems shall be made from single or composite materials that meet all applicable design and environmental requirements. The materials shall ensure durability, stability, and resistance to environmental stress. Acceptable materials include:
 - a. **Synthetic Polymers** such as High-Density Polyethylene (HDPE) and Polyethylene (PE), which are lightweight, corrosion-resistant, and suitable for modular assembly.
 - b. **Metals** such as Aluminum, Stainless Steel, or Carbon Steel with corrosion-resistant coatings, which offer high structural rigidity, particularly for modular raft configurations.
 - c. **Other Materials**, including Polyurethane Foam, Fiberglass reinforced with epoxy or polyester resin, Ferrocement, or other composite materials, may be used if they meet structural, performance and environmental requirements.

All float materials shall be tested and validated to ensure mechanical integrity, chemical stability, and long-term operational reliability in the intended water body environment.

- Materials used for floating structures in FPV systems must withstand stresses from waves, wind, operational loads, and the weight of PV panels throughout their design life. Floats and interconnections shall be robust enough to resist impacts during installation and operation, including contact with floating debris, docking boats, and submerged obstacles such as rocks.
- Floater selection shall be based on site-specific conditions and durability requirements. HDPE floaters offer a cost-effective option with high resistance to impact, UV radiation, and chemicals. Steel floaters provide superior structural strength, while combined steel-HDPE floaters offer enhanced robustness suitable for sites with high wind speeds and wave heights, eliminating the need for wave barriers.
- Steel floats require regular inspection and maintenance, particularly in saline environments, due to corrosion susceptibility. Galvanized aluminium or stainless steel shall be used for module mounting structures to ensure durability. For protection against corrosion, structures must comply to ISO 12944 with respect to selected corrosion category. In contrast, HDPE floats are corrosion-resistant and maintenance-free, with natural resistance to marine growth.
- Floats shall be free from toxic substances such as arsenic, chromium, and excessive chlorine at all stages of the FPV system lifecycle. When installed in drinking-water reservoirs, floats must be tested for turbidity, total dissolved oxygen (TDO), and total organic carbon (TOC) to ensure compliance with applicable drinking-water safety measures.

3. Anchoring & Mooring System

- The anchoring and mooring system shall conform to the latest edition of BIS, IEC, or ISO standards, **including but not limited to** those listed below, to ensure structural safety, durability, and compliance. Wind load considerations shall be addressed in accordance with IS 875 (Part 3):2015. Concrete structures shall comply with IS 456:2000, and high-strength deformed steel reinforcement shall meet the specifications of IS 1786:2008. Corrosion protection of steel elements shall follow ISO 12944-2:2017, and the design and analysis of station-keeping systems for floating structures shall align with API RP 2SK.
- Within the floating system, hot-rolled structural parts shall conform to relevant standards including IS 800:2007 for general construction in steel, IS 2062:2011 for hot-rolled medium and high tensile structural steel, IS 1079:2017 for hot-rolled carbon steel sheet, plate and strip, IS 808:2021 for dimensions and properties of hot-rolled steel beam, column, channel and angle sections, and IS 3502:2009 for steel chequered plates. Cold-formed structural parts shall follow IS 801:2010 for the use of cold-formed light gauge steel structural members, IS 811:1987 for cold-formed light gauge structural steel sections and IS 4923:2017 for hollow steel sections for structural use and **IS 513** for cold rolled low carbon steel sheets and strips; and **IS 1239**: 2004 for mild steel tubes, tubulars, and other wrought steel fittings used in cable support systems and accessories.
- In addition, general applicable standards include IS 802:2016 for the use of structural steel in overhead transmission line towers (Part 1: materials, loads, and design strengths), IS 3370:2021 for concrete structures retaining aqueous liquids (Part 1: general requirements), IS 1161:2014 for steel tubes for structural purposes, IS 2629:1985 for hot-dip galvanizing of iron and steel, IS 4759:1996 for hot-dip zinc coatings on structural steel and allied products, IS 2633: 1986 for testing uniformity of coating on zinc coated articles, IS 9595: 1996 for Metal - Arc welding of carbon and carbon manganese steels, IS 4736:1986 for hot-dip zinc coatings on mild steel tubes, and IS 5624:2021 for foundation bolts. **IS 6745:1972** – *Methods for determination of mass of zinc coating on zinc coated iron and steel articles* and **IS 458:2021** – *Precast Concrete Pipes (with and without Reinforcement)* shall also be applicable wherever relevant in floating solar PV infrastructure works.
- Additional applicable standards for the design, inspection, and integrity of anchoring and mooring systems shall include **API Spec 2F** (Specification for Mooring Chain), **API RP 2I** (In-Service Inspection of Mooring Hardware for Floating Structures), **API RP 2MIM** (Mooring Integrity Management), **BS 6349-6** (Maritime Works – Part 6: Code of Practice for Design of Fendering and Mooring Systems), and **API RP 2A** for floater strength verification, spreader bar design, and pad eye design.
- Anchoring systems are critical to maintaining the stability and position of Floating Solar Photovoltaic (FPV) installations under varying environmental conditions. Permissible anchor types include:
 - a. **Gravity (Dead Weight) Anchors:** Suitable for rocky or hard seabed, these anchors rely on their own mass to resist movement. They are simple to install and effective under vertical and horizontal mooring loads.
 - b. **Drag Anchors:** Designed to embed into the seabed when tensioned, these are appropriate for soft soil conditions but are effective only for horizontal load applications.
 - c. **Screw and Pile Anchors:** Suitable for clay or silt beds with sufficient penetration depth, these provide high holding strength and are ideal for shallow water environments.

Anchor design and installation shall comply with applicable engineering standards and ensure the long-term structural integrity and safety of the FPV system.

- Dead weight anchor blocks shall be constructed with a minimum M-25 grade RCC as per IS: 456-2000. Reinforcement shall use corrosion-resistant Fe-500 TMT steel bars conforming to IS: 1786. Blocks must be properly sized to prevent slippage, and all inserts shall be made of stainless steel (SS 304 or site-suitable grade).
- Anchor selection shall be based on site-specific water depth, considering mooring line tension, environmental forces, and installation requirements:
 - a. **Shallow Water (<5 m):** Screw-type and gravity anchors are preferred for ease of deployment and effectiveness in low-depth conditions.
 - b. **Medium Depth (5–20 m):** Precursive earth-driven anchors are suitable for moderate depth and load conditions.
 - c. **Deep Water (>20 m):** Pile and drag anchors are recommended to withstand higher wind and wave forces.

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New anchoring technologies may be adopted if they meet strength, durability, and environmental sustainability requirements.

- Following the principles outlined in Clause □ regarding the selection of anchoring systems based on water depth, seabed characteristics shall be a key determinant in anchor type selection to ensure structural stability and environmental sustainability. The seabed directly influences anchor holding capacity, installation complexity, and seabed erosion. Anchors shall be selected based on the following seabed type conditions:
 - a. **Soft Soil:** Percussive earth-driven anchors are preferred, as they can be firmly embedded to minimize displacement caused by water currents or wind.
 - b. **Clayey Soil:** Screw (propeller-type) anchors are preferred for their ability to penetrate dense clay layers, offering a stable hold through increased surface engagement.
 - c. **Firm or Rocky Soil:** Gravity anchors are suitable due to their reliance on self-weight to maintain positional stability, even on hard or uneven substrates.

All anchoring solutions shall be designed to maintain structural integrity and operational reliability under site-specific hydrodynamic conditions, ensuring compliance with long-term environmental and engineering requirements.

- Anchor selection shall be based on the magnitude and direction of mooring line loads to ensure system stability. Gravity anchors are suitable for low to moderate mooring loads. Screw anchors offer high holding capacity and are ideal for moderate to high horizontal and vertical loads. Drag anchors are preferred where high horizontal loads are expected with minimal vertical uplift, as they provide effective resistance through soil penetration.
- The selection of mooring systems for Floating Photovoltaic (FPV) installations shall be determined based on site-specific water depth, wave conditions, and water level variations to ensure long-term stability and operational efficiency.
 - a. **Elastic Mooring System** can be considered for sites with extreme water level fluctuations due to its ability to stretch and absorb energy from waves, currents, and wind, ensuring balanced load distribution and enhanced durability in dynamic environments.
 - b. **Taut-Line Mooring System** can be considered for locations with deep water bodies or significant water level variations, offering a stable anchoring solution by maintaining constant tension between the FPV platform and anchors.
 - c. **Catenary Mooring System** may be considered for medium-depth reservoirs with moderate forces, utilizing heavy mooring lines that provide stability through tension and gravity. However, it faces challenges in vertical movements.
 - d. **Compliant Mooring Using Buoys** shall be used in areas with frequent tidal fluctuations or moderate currents, as it incorporates floating buoys to dissipate environmental forces and provide flexibility.

Use of elastic mooring components is encouraged to accommodate platform movement and reduce tension on anchor points.

- The selection of mooring materials must account for strength, fatigue resistance, environmental degradation, and the ability to absorb dynamic forces caused by wind, waves, and current variations. The following types of mooring lines may be considered based on-site requirements:
 - a. **Chain:** High tensile strength and mechanical robustness, suitable for high-load applications.
 - b. **Steel Wire Rope:** Strong load-bearing capacity with corrosion resistance when properly coated, ideal for long-term aquatic deployment.
 - c. **Fiber Ropes (Synthetic):** Lightweight and flexible, offering a favorable load-to-weight ratio and strong fatigue resistance.

Adjustable chain terminations shall be integrated into mooring systems by adding a small chain at the termination points. Buoyancy elements may be integrated into the mooring line design to minimize vertical loads on the floating structure, enhancing system protection and operational stability.

- Mooring lines must be resistant to UV exposure, saltwater corrosion, abrasion, and biofouling to ensure long-term performance. Materials such as **Polyethylene (PE)**, **Polypropylene (PP)**, and **Polyamide (PA)** offer UV resistance and flexibility, while galvanized or coated steel components help prevent corrosion. Anti-fouling

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coatings such as silicone or fluoropolymer-based options are recommended to reduce marine growth. Flexibility and wear resistance are essential to accommodate continuous movement from wind and waves.

- FPV installations shall be designed with secure mooring and positioning to prevent any obstruction to spillway gates, ensuring uninterrupted flood discharge capacity.
- Wave breakers shall be used in Floating Photovoltaic (FPV) systems where wave heights exceed the structural tolerance of the floating platform to ensure stability and efficiency. However, if the structure is designed to withstand wind and wave forces, wave breakers may not be required. Site-specific assessments shall determine their necessity.

4. Inverters / Power Conditioning Unit (PCU)

- The inverter or Power Conditioning Unit (PCU) used in Floating Solar Photovoltaic (FPV) systems shall conform to the latest BIS, IEC, IEEE, and other international standards, **including but not limited to** those listed below, to ensure high efficiency, environmental resilience, and operational safety. Efficiency measurements shall comply with IS/IEC 61683:1999 (for Inverter efficiency) and EN 50530 (MPPT efficiency). Safety of power converters shall be ensured through compliance with IS 16221 (Part 1):2016/ IEC 62109-1:2010 and IS 16221 (Part 2):2015 / IEC 62109-2:2011. Environmental testing shall be conducted as per IS/IEC 60068-1:2013, including IS/IEC 60068-2-1:2007 for cold testing, IS/IEC 60068-2-2:2007 for dry heat, IS/IEC 60068-2-14:2023 for temperature change, and IS/IEC 60068-2-30:2005 for damp heat cycle and **IS 9000 (Part 4):2020 / IEC 60068-2-78:2012** for steady state damp heat testing. Ingress protection shall align with IS/IEC 60529:2011, and anti-islanding protection shall conform to IS 16169:2019 / IEC 62116:2014.
- For electromagnetic compatibility and grid interface, the PCU shall meet IEC 61000 series standards for emission/immunity requirements, IEEE 519 for harmonic control, and IS/IEC 61727:2004 for grid interconnection. In addition, compliance with the prevailing Central Electricity Authority (CEA) regulations and the Indian Grid Code, as amended from time to time, is mandatory to ensure safe and reliable integration with the utility grid. Inverter sizing must comply to the requirements as stated as per latest CEA working group report dated July 2022¹⁰⁰ followed by directions issued with reference to minutes of discussions by CEA dated 05-10-2023¹⁰¹.
- In FPV systems, central or string inverters are typically used. For large installations or those far from shore, inverters and transformers should be mounted on floating platforms near the array, with cables to onshore interconnection points. For smaller systems close to shore, land-based placement may be considered. Deployment must address FPV-specific environmental and operational challenges to ensure reliable performance.
- Inverters used in floating solar PV systems must be designed to withstand continuous mechanical stress from platform movement and potential water ingress. For water-mounted installations and ground mounted installations, inverters shall have an adequate dust/ moisture protection IP rating complying to IS/IEC 60529. If installed on land, enclosures must be mounted on elevated platforms to prevent water splash damage and incorporate protective barriers such as metallic sheets to enhance durability and operational safety.
- Inverter enclosures shall be equipped with proper sealing, corrosion-resistant materials, and adequate ventilation or dehumidification systems to prevent moisture accumulation and ensure long-term reliability.
- Inverters deployed in FPV systems, particularly in humid or marine environments, shall be equipped with corrosion-resistant enclosures. To mitigate condensation-related risks, space heaters, dehumidifiers, and relative humidity (RH) sensors shall be installed within inverter enclosures to maintain internal environmental stability and ensure long-term operational reliability.
- Inverters deployed in FPV systems shall be tested for resistance to ultraviolet (UV) radiation and treated with UV-resistant coatings to safeguard against material degradation, thereby ensuring long-term performance and reliability under continuous solar exposure.
- Moist and conductive environments increase the risk of insulation, ground, and arc faults. Inverters should include residual current monitoring, insulation resistance monitoring, arc fault protection, and anti-PID kits.

5. Cables

¹⁰⁰CEA, https://www.srdc.in/UploadFiles/NewsAndUpdate/Final_Report_of_the_Working_Group_July_2022.pdf

¹⁰¹CEA, https://cea.nic.in/wp-content/uploads/gm_and_npc/2023/10/Minutes_of_Meeting_held_on_23.08.2023_06.09.2023__25.09.2023.pdf

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- Cables used in Floating Solar Photovoltaic (FPV) systems shall conform to the latest BIS, IEC, EN, IEEE, and ASTM standards, including but not limited to those listed below, to ensure electrical safety, environmental resilience, and long-term durability. For DC cables, used for Interconnecting SPV Modules and from SPV Modules to (SCB), compliance with IS 17293:2020 and IEC 62930:2017 is mandatory, along with **either EN 50618:2014 or TÜV 2PFG 1169**, based on the specific project requirements. The **bidding authority shall have the flexibility to choose between EN 50618 or TÜV 2pfg 1169**, depending on site conditions, design needs, and desired thermal performance. EN 50618 mandates that cable conductor and insulation must withstand temperatures up to 120°C, whereas TÜV 2pfg 1169 specifies insulation requirements up to 90°C.
- AC and DC power cables shall conform to IS 7098 (Part 2):2011 for voltages from 3.3 kV to 33 kV. AC cables shall comply with IS 7098 (Part 1):1988, IS 1554 (Part 1):1988, IS 3961:2016 for current ratings, IS 3975:1999 for cable armoring, IS 5831:1984 for PVC insulation and sheath, and IS 8130:2013 for conductor specifications. Where applicable, IS 513 shall be considered for cold rolled low carbon steel sheets and strips, and IS 1239: 2004 for mild steel tubes, tubulars, and other wrought steel fittings used in cable support systems and accessories.
- Cables shall be tested as per IS 10810:1984 and its relevant parts, including flame retardance (IS 10810 Part 62 / IEC 60332-3), smoke density (ASTM D2843), oxygen index (ASTM D2863), gas evolution (IS 10810 Part 59 / IEC 60754-1), and IEEE 383 for type testing. Compliance with IS 4905:2015 / ISO 24153:2009 for random sampling procedures and IS 10418:2024 for cable drums is mandatory. Additionally, installation and maintenance of power cables up to and including 33 kV shall follow the guidelines provided in IS 1255. Connectors for DC applications in photovoltaic systems shall comply with IS 16781:2018 / IEC 62852:2014. Where applicable, IS 9537:1981 (Specification for conduits for electrical installations), IS 8309:1993 (Compression type tubular terminal ends for aluminium conductors of insulated cables) and IS 13573:2011 (Cable accessories for extruded power cables) and IS 3809:1979 – reviewed in 2017 (Fire resistance test for structures), and DIN 46329 (Cable lugs for compression connections, ring type, for Aluminium conductors) and IS 694 (Specification for PVC insulated unsheathed and sheathed cables for working voltages up to and including 450/750 V, used in electric power and lighting including flexible cords) shall be adhered. All cable components must ensure high performance under FPV operating conditions, including exposure to moisture, UV, and mechanical stresses.
- Cables used in FPV systems shall be copper, dual-insulated, and fitted with IP68-rated connectors. Cable trays and conduits must be UV-resistant and made of durable materials like PVC, HDPE, or fiberglass. Cables on floating platforms shall be classified as static or dynamic, with dynamic cables designed to withstand mechanical stress. Floating or submerged cables shall use XLPE/XLPO insulation and corrosion-resistant conductors, and be resistant to UV, hydrolysis, and marine conditions.
- Cables in FPV systems shall be routed to avoid contact with water to prevent corrosion and degradation. UV-resistant materials and wiring trunks must be used to shield cables from sunlight. AC and DC cables shall be securely fastened using cable ties or clamps, kept above water, and installed in cable trays, ladders, or conduits to prevent mechanical damage and ensure long-term reliability.
- Cables shall be installed with adequate slack to accommodate the movement of floating platforms, preventing undue tension that could lead to snapping or wear over time.
- Waterproof and dustproof IP68/69 complying to IS/IEC 60529 rated connectors should be used, and if cables are joined without connectors, proper marine-grade protection must be ensured. Suitable insulation protection and treatment should be provided to meet the cable laying requirements in trays / ladder / conduits.
- Water-blocking tapes should be used to prevent water ingress in case of insulation damage, and floating cables must be enclosed in flexible conduits or covered trays for added protection.
- Cables must be UV-stabilized, hydrolysis-resistant, and flame-retardant to endure harsh environmental conditions, and copper cables with anti-fouling properties should be used to minimize marine organism growth.
- Regular diagnostic tests must be conducted to detect and mitigate cable degradation, preventing insulation failures, mechanical wear, and electrical faults. Key tests include insulation resistance checks for moisture ingress and aging, high voltage testing for insulation breakdown, infrared thermography for detecting hotspots, and continuity testing for circuit integrity. These measures enhance energy efficiency, system safety, equipment lifespan, and cost-effectiveness while ensuring stable power generation and reliable operation under floating conditions.

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- All FPV installations must use biofouling-resistant cables, along with marine-grade and rubber-sheathed cabling, to withstand harsh environmental conditions. Proper installation, cable management systems, and regular monitoring through thermal imaging are recommended to prevent degradation, enhance reliability, and minimize failures, ensuring sustained plant efficiency, reduced downtime, and maximized energy output.
- All Cables used in FPV systems shall comply with ISO 12944 C5 and C5-M standards for very high corrosive environments suited as per site conditions, marine-grade specifications, and rubber-sheathed designs to ensure superior durability and performance in aquatic environments.

6. String Combiner Box (SCBs)

- The combiner box shall conform to the latest editions of international or equivalent national standards, including but not limited to those listed below, to ensure electrical safety, environmental protection, and durability. The enclosure shall comply with IS / IEC 61439-3(2012) reviewed in 2024 for low voltage switchgear and control gear assemblies, UL 94V for flammability resistance, UL 746C for UV resistance, IS 17050:2023 / IEC 62262:2021 for protection against external mechanical impacts and IS/IEC 60529:2001 for ingress protection (IP rating). Surge protection devices within the combiner box shall meet the requirements of IS 16463 (Part 12):2017 / IEC 61643-12:2008 and IEC 61643 (Part 11):2016 / IEC 61643-11:2011. The enclosure shall also comply with IEC 62208. Additional applicable standards include IEC 60269/60269-1 :2024 for low-voltage fuses and IS/IEC 60695-2-11:2021 for fire hazard testing and IS/IEC 60068-2-5:2018, which provides guidance on testing resistance to simulated solar radiation and weathering.
- String combiner boxes shall be equipped with enclosures specifically suited for high-humidity and variable conditions typical of reservoir and lake environments. Enclosures for combiner boxes shall be made from FRP, polycarbonate, polyamide, or galvanized iron (GI) sheet metal, with polycarbonate-based enclosures preferred for marine environments offering superior durability, better fire resistance, and chemical protection. To further enhance durability and performance, the installation of protective covers or canopies should be used to minimize direct UV and solar radiation exposure, ensuring longevity in floating solar PV systems.
- Combiner boxes used in floating solar PV systems shall be designed to prevent water ingress due to exposure to splashes or partial immersion. Bottom-entry cable configurations shall be adopted to minimize water stagnation, and installation height shall ensure clearance above the minimum cable bending radius. All enclosures must have a minimum ingress protection rating of IP65 to ensure durability and system safety in aquatic environments.
- The combiner box shall be installed on HDPE floats near PV modules or walkways and must be supported by cable management systems such as cable trays or conduit pipes. Adequate slack shall be provided in the connected cables to prevent mechanical stress on the combiner box and ensure reliable electrical performance under dynamic floating conditions.
- The combiner box shall be constructed using fire-resistant materials and designed to prevent the propagation of fire, both horizontally and vertically. Given the presence of flammable components such as HDPE floats and electrical cables in floating solar plants, the combiner box must not contribute to fire spread and shall comply with relevant fire safety standards to ensure operational safety and risk mitigation.
- The enclosures should be periodically replaced due to prolonged exposure to UV, salt, and humidity, based on manufacturer recommendations to maintain structural integrity.

7. Switchgear

- All switchgear and control gear used in floating solar PV systems shall comply with latest applicable BIS or IEC standards, **including but not limited to** those listed below: IS/IEC 60947-1:2020 for general requirements and IS/IEC 60947-7-1:2009 for terminal blocks for copper conductors. The selection, installation, and maintenance of switchgear and control gear shall conform to IS 10118 (Parts 1 to 4). Current transformers and voltage transformers shall meet the specifications of IS 6949:1973 and IS 4146:1983, respectively. Earthing systems shall be designed and implemented in accordance with IS 3043:2018. Electrical relays for power system protection shall comply with IS 3842 (Part 1–12):1967 / IEC 60255:2009/ IS/IEC 60255-1:2009/ IEC 60255-100 series, IEC 60255-26, and IS/IEC 60255-27:2013, **IS/IEC 60255-21-1:1988, IS/IEC 60255-21-2:1988, and IS/IEC 60255-21-3:1993**. The following standards shall also be applicable: **IS/IEC 60947-2:2016** for circuit breakers, **IS/IEC 60947-3:2020** for switches, disconnectors, and fuse-combination units, IS 13703 (Part 4): 1993/ **IEC 269-4** for low-voltage fuses, **IS/IEC 60947-4-1:2018** for contactors and motor starters and

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IS/IEC 60947-5-1:2016 for electromechanical control circuit devices and **IS 15086: Part 4:2017** for metal-oxide surge arresters without gaps for AC systems.

- Circuit breakers and metal-enclosed switchgear assemblies shall conform to IS/IEC 62146:2013, IS/IEC 62271-100:2021, and IS/IEC 62271-200:2021. Indoor post insulators shall meet IS 9431:2024 / IEC 60660:1999, while porcelain post insulators for voltages exceeding 1000 V shall comply with IS 5350:1970. Materials used in switchgear assemblies shall adhere to IS 6005:1998 for phosphate coatings and IS 5082:1998 for aluminium and aluminium alloy components to ensure mechanical integrity and corrosion resistance in the floating environment.
- Additionally, compliance shall be ensured with IS/IEC 61439-1 & 2:2020 for power switchgear and control gear assemblies, IS/IEC 62271-1:2017 for common specifications related to high-voltage switchgear and control gear and IS/IEC 62271-102:2018 for AC disconnectors and earthing switches, IEC 60376:2018, IS/IEC: 62271-206 for Voltage presence indicating systems for rated voltages above 1 kV and up to and including 52 kV to uphold system integrity and operational safety under floating solar conditions.
- Measuring instruments and meters shall comply with IS 11448:2000, IS 9792 (Part 1):1987, and IS 1248 (Part 1):2021 / IEC 60051-1:2016. Terminal and conductor identification shall follow the provisions of IS 11353:2023 / IEC 60445:2021 for consistent and safe system interfacing. IEC 62052-11, IEC 62053, and IS 14697 shall also be applicable for electricity metering equipment. Communication and automation for numerical relays shall adhere to IEC 61850 and IEC 61131-3 standards, ensuring compatibility with digital protection and control systems. The degree of protection for enclosures used in switchgear systems shall comply with IS/IEC 60947.

8. Transformers

- Transformers in floating photovoltaic (FPV) systems shall comply with the latest edition of relevant international or equivalent national standards, **including but not limited to** those listed below, to ensure safety, reliability, and efficient performance. General requirements for power transformers, including design, testing, and performance criteria, shall conform to IS 2026:2011 and its applicable parts, including IS 2026 (Part 1):2011 / IEC 60076-1 for voltage ratio, phase displacement, and winding resistance; IS 2026 (Part 3):2018 / IEC 60076-3 for insulation levels and dielectric testing; IS/IEC 60076-4 : 2002 for Lightning Impulse and Switching Impulse Testing of power transformers; IS 2026 (Part 5):2011 / IEC 60076-5 for short-circuit withstand capability; IS 2026 (Part 7):2009 / IEC 60076-7 for transformer loading guide; and IS 2026 (Part 11):2021 / IEC 60076-11 for dry-type transformers.
- Transformers and accessories shall also conform to IS 3639:1966 for fittings and accessories, IS 11333:1985 for flameproof dry type transformers, and IS 2705:2017 / IEC 60185 for current transformers. Requirements for bushings shall be in accordance with IS 2099:1986, IS/IEC 60137:2017, IS 3347:1988 for porcelain bushings, and IS 12676:1989 for oil-impregnated paper insulated condenser bushings. Insulating oils shall meet the standards of IS 335:2018 / IEC 60296. **IS 16081:2013 / IEC 61099:2010** shall apply for specifications of unused synthetic organic esters and **IS 16659:2017 / IEC 62770:2013** for unused natural esters used in transformers and similar electrical equipment and IEC 61869/ IS 16227 series for Instrument transformers. Additionally, **IS 17050:2023 / IEC 62262:2021** shall be followed for degrees of protection provided by enclosures against external mechanical impacts. **IS 3637:1966** shall be adhered to for **gas-operated relays**, **IS 9434:2019 / IEC 60567:2011** shall be followed for **sampling and analysis of gases in oil-filled electrical equipment** and **IS 10593:2023 / IEC 60599:2022** shall be followed for **guidance on the interpretation of dissolved and free gases in mineral oil-filled electrical equipment**. Selection, installation, and maintenance of transformers shall conform to IS 10028 / IS 1646. Compliance with the Indian Electricity Act 2003, BEE guidelines, and CEA notifications is mandatory.
- Transformers in floating photovoltaic (FPV) systems may be installed as standalone units or as part of a compact substation. They shall be equipped with adequate ventilation and shall comply with minimum ingress protection (IP) ratings suitable for the environmental conditions. Selection of transformers must consider site-specific risks such as oil spillage, proximity to sensitive water bodies (especially used for drinking or aquaculture), and potential for corrosion. Dry-type transformers are preferred in locations subject to high wave action, wind loads, or structural movement.
- Transformers used in FPV applications must be designed with appropriate protective coatings, corrosion-resistant materials, and mechanical reinforcements to withstand prolonged exposure to humidity, vibrations, and dynamic stresses. For improved electrical safety and system reliability, the use of an IT (Isolated Terra)

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earthing system is recommended, providing superior fault protection and higher availability in floating power installations.

- Transformers in FPV systems shall be designed to withstand hydrodynamic forces and vibrations through reinforced mechanical design, enhanced mooring, and use of dampeners. Nitrogen injection fire protection systems (NIFPS) may be installed as per site specific requirements and capacity criteria as per local rules regulations. Real-time monitoring of transformer parameters shall be enabled through SCADA systems to ensure operational safety and reliability. Adequate protection must be provided in the transformer design for adequate protection against spillage of oils deposits preventing to flow into the water bodies. Additionally replaceable oil collection tanks must be provided along with transformer designs to accommodate ease of maintenance during operation period.
- In offshore FPV installations, transformers shall be protected against salt deposition, which can elevate the risk of phase-to-ground faults. Bushings shall have increased breakdown voltage and adequate creepage distance. For medium-voltage transformers, cable boxes with a minimum ingress protection rating of IP65 or better IP rating complying to IS/ IEC 60529 (2001)/ latest revision shall be used to shield bushings from salt accumulation and ensure system reliability.
- To prevent contamination of waterbodies and protect marine life, transformers installed in FPV systems shall be hermetically sealed and use natural, biodegradable insulating oils such as usage of natural ester oil. Where environmental sensitivity is high, dry-type transformers with corrosion-resistant and water-resistant construction shall be preferred.
- Inverters and transformers installed on floating platforms shall be mounted with vibration-resistant fixtures to accommodate movement from waves, wind, and currents. They must be housed in protective enclosures to prevent environmental exposure. Post-installation, all loose items must be removed, unused terminals sealed, and durable safety labels affixed. For oil-filled transformers, measures to mitigate oil leaks should be taken. Inverters and transformers should be transported to the installation location on the water using appropriate methods, following standard industry practices.

9. Earthing and Lightning Protection Systems

- Earthing and grounding in FPV systems shall comply with latest national or international standards, **including but not limited to** those listed below: IS 3043:2018 for solar field grounding and IEEE 80 for substation and power evacuation system grounding, IEEE 837 for qualifying permanent connections used in substation grounding. Lightning protection shall follow IS 17978:2022 / IEC TR 63227:2020, with ESE-type systems installed as per approved design to ensure full plant coverage. **UL 467 – Grounding and Bonding Equipment** shall also be adhered to for grounding hardware and components. All measures shall align with the CEA Electrical Safety Regulations, 2010, the Indian Electricity Rules, and the Indian Electricity Act. Special provisions for earthing and lightning are to be done in a Floating PV project due to presence of water bodies thereby avoiding any adverse impact of fault current flowing into water bodies.
- Grounding of FPV systems shall be essential to ensure electrical safety and protection of equipment. Given the unique environment of floating solar installations, the earthing and lightning protection system shall be designed considering the challenges associated with water-based platforms, and in alignment with evolving best practices and applicable standards.
- Any of the following earthing methods may be employed in FPV projects, based on site conditions and technical feasibility:
 - a. **Shore-Based Earthing:** Earthing conductors from the floating platform may be extended to the shore and terminated using conventional grounding techniques.
 - b. **Waterbed-Based Earth Pits:** Dedicated grounding electrodes may be installed on the waterbed and connected to the FPV electrical system.
 - c. **Suspended Electrodes in Water:** Earth electrodes may be suspended at calculated depths to utilize the water body as a grounding medium. This method shall be used with caution, accounting for variations in water conductivity and ensuring no risk to personnel or aquatic life.

The earthing system shall be designed based on site-specific resistance measurements and environmental parameters. Design shall include functional earthing for the DC system, where required, to prevent Potential Induced Degradation (PID) and ensure compliance with relevant national and international standards.

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- All exposed conductive parts shall be interconnected and either terminated to the waterbody at appropriate depth or to the waterbed using grounding electrodes. For IT earthing systems, connection to the electrical earthing network may be omitted if justified by a site-specific risk assessment.
- In FPV systems employing non-conductive floating materials, equipotential bonding may be exempted if adequately justified by safety analysis. However, the grounding system shall ensure that no hazardous potential difference exists between the water surface and any accessible conductive component.
- Floating solar PV installations shall be equipped with an effective Lightning Protection System (LPS) to mitigate the risks of direct lightning strikes and lightning-induced overvoltages. This requirement extends to all electrical infrastructure, including onshore substations associated with FPV projects, which must comply with applicable building codes and safety standards.
- Developers shall carry out a location-specific lightning risk assessment, considering historical lightning data from local meteorological services. The outcome of this assessment shall guide the design and implementation of both external and internal lightning protection systems appropriate for the site conditions.
- An External Lightning Protection System (LPS) shall be installed to intercept and safely conduct lightning strikes to earth, preventing physical damage to the FPV infrastructure. This system shall comprise air-termination devices, down-conductors, earth-termination systems, and equipotential bonding. Design methods such as the rolling sphere or protective angle technique shall be applied. Sufficient separation distance between the LPS and PV system must be maintained to prevent flashover risks.
- An Internal LPS shall be implemented to protect electrical and electronic equipment using Surge Protection Devices (SPDs), equipotential bonding, and optimized cabling design. Type II SPDs shall be installed on both AC and DC sides. Cable routing shall be designed to minimize loop areas, especially over water, and bonding conductors shall run in parallel with DC/AC cables to ensure effective current dissipation during lightning events.
- All lightning protection components shall be securely mounted and designed to withstand environmental stresses including wind, wave motion, and thermal cycling. Special attention shall be given to the flexibility and mechanical protection of bonding elements to avoid fatigue and mechanical failure over time.

10. Weather monitoring system - WMS (including SCADA & PPC Requirements)

- The Weather Monitoring System (WMS) shall include all necessary meteorological instruments, along with appropriate software and hardware, to ensure seamless integration with the SCADA system for real-time data acquisition.
- Auxiliary power for all instruments and data loggers shall be sourced from an uninterruptible power supply (UPS) to ensure continuous operation. The data logger must have the provision to receive redundant power supply for enhanced reliability. All meteorological instruments shall be supplied with valid calibration certificates. A single integrated sensor capable of measuring wind speed, wind direction, relative humidity, and rainfall is acceptable, provided it meets the performance specifications outlined in subsequent sections.
- The weather monitoring system shall comply with all applicable regulations related to telemetry and ensure seamless transmission of weather data to designated control centers such as State Load Dispatch Centre (SLDC) and Regional Load Dispatch Centre (RLDC).
- The SCADA system for Floating Solar PV (FPV) installations shall incorporate the following instrumentation and control components to enable real-time monitoring, data acquisition, and compliance with regulatory and operational requirements:
 - a. **Pyranometers:** One pyranometer shall be installed for every 50 MW capacity to measure solar irradiance. Class-A pyranometers (ISO 9060:2018) with necessary accessories shall be provided for measuring incident solar radiation on horizontal and inclined plane of array.
 - b. **Temperature Sensors:** Adequate numbers of ambient and module temperature sensors shall be installed in accordance with IS/IEC 61724-1: 2021 to ensure accurate performance monitoring. Additionally, temperature sensor for measuring water temperature is to be installed as per suitable site condition.

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- c. **Wind Sensors:** Install wind sensors as per detailed system design to monitor wind speed and direction. Wind sensors are also needed to ensure protection of the floats against unwanted dynamic movements. Necessary provisions must be ensured for different types of site sensitivity and as per Wind speed zones in compliance to IS 875 Part 3.
- d. **Additional Meteorological Sensors:** Measurement instruments for sunrise/sunset, rainfall (rain gauge), cloud cover, and air density shall be installed based on site-specific design requirements.
- e. **PV Analyzer:** PV analyzer(s) must be deployed as per the system design to enable performance analysis and fault detection.
- f. **Water Level Sensors:** Install water level sensors to continuously monitor reservoir/lake levels, especially important in reservoirs used for irrigation or hydropower. This supports predictive maintenance and safe mooring design.
- g. **Mooring Tension Sensors:** Deploy strain gauges or load cells to monitor the tension in mooring lines. This enables proactive maintenance and prevents anchor failures due to excessive stress, especially in high-wind or fluctuating water conditions.
- h. **Humidity and Condensation Sensors:** Especially for floating inverters or junction boxes—monitor internal enclosure humidity to detect early signs of condensation or ingress that could damage electrical components.
- i. **Optical sensors for monitoring algae growth:** Optical sensors may be installed for early detection of potential algae development over bottom parts of floats which then will trigger a mechanism for regular maintenance of floaters based on site condition.
- j. **Corrosion detection sensors:** Corrosion detection sensors for all structural parts (mooring / anchoring/ other parts) must be installed to detect early signs of cracks and necessary preventive correction. This must be installed in alignment of a site-specific O&M plan.
- k. **SCADA system along with Servers:** SCADA along with adequate number of Engineering Workstations and Operator Workstations shall be installed with server configurations capable of handling current data loads with a 50% design margin to accommodate future scalability. SCADA shall provide real time performance monitoring according to IS/ IEC 61724-1: 2021 standard.
- l. **Dedicated power plant controller (PPC) along with Phasor Measurement Unit:** A dedicated Power Plant Controller (PPC) shall be installed to manage plant output (both active and reactive power controls) and grid compliance. It must be integrated with a Phasor Measurement Unit (PMU) as per detailed design and in alignment with applicable local grid codes and regulations. It must be of suitable configurations for telemetry and data communication with SLDC / RLDC as per applicable local rules.

June 2025

Published by

Deutsche Gesellschaft für

Internationale Zusammenarbeit (GIZ) GmbH

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