WORLD BANK GROUP

SAWI SOUTH ASIA WATER INITIATIVE

UNLOCKING FLOATING SOLAR PHOTOVOLTAICS POTENTIAL IN INDIA

VOLUME 2: GUIDANCE DOCUMENT

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ABBREVIATIONS

AC	Alternating Current
ALS	Accidental limit state
API	American Petroleum Institute
ARC	Anti-Reflective Coating
ASCE	American Society of Civil Engineers
BOM	Bill of Materials
BoS	Balance of System
CFD	Contract for Differences
DAF	Dynamic amplification factors
DC	Direct current
DH	Damp Heat
DNV	Det Norske Veritas
DSC	Differential scanning calorimetry
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ESCR	Environmental Stress Crack Resistance
ESE	Early Streamer Emission
EY	Ernst & Young
EYA	Energy Yield Assessment
FPU	Floating Production Unit
FRP	Fibre reinforced plastic
FSPV	Floating Solar Photovoltaics
G	Earth gravity
GI	Galvanised Iron
GVI	General Visual Inspection
HDPE	High Density Polyethylene
HF	Humidity Freeze
HSE	Health Safety and Environment
HZ	Hertz
IALA	Industrial Area Local Authority

IAM	Incidence Angle Modifier
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IK	Impact Protection
IP	Ingress Protection
IR	Infrared
ISO	International Organization for Standardization
kV	Kilovolt
kW/m^2	Kilo Watt hours per square metre
LA	Lightning Arrester
LV/MV	Low voltage/Medium voltage
M	Meter
MC4	Multi-Contact, 4 millimetre
MM	Millimeter
MOU	Mobile offshore units
MPPT	Maximum Power Point Tracking
MS	Millisecond
NABL	National Accreditation Board for Testing and Calibration Laboratories
NM	Nanometer
O&G	Oil & Gas
O&IRM	Operation & inspection, repair, maintenance
O&M	Operation & Maintenance
OPEX	Operating expense
PA	Pascals
PE	Polyethylene
pH	Power of Hydrogen
PID	Potential-Induced Degradation
PV	Photovoltaic
PVEL	PV Evolution Labs LLC
RH	Relative Humidity
TC	Thermal Cycling
UV	Ultraviolet
WB	World Bank
XLPE/XL	Cross-linked polyethylene

1. INTRODUCTION

1 INTRODUCTION

This Guidance Document is Volume 2 of the 3 volumes on "Unlocking Floating Solar Potential in India". This Guidance document reviews the provisions of various technical provisions of various technical standards while adopting it for floating solar applications. The document provides a review of the technology, deliberations for technology selection for FSPV plant, challenges/issues which may arise during design, installation and operation & maintenance (O&M) of equipment in FSPV, mitigation to address the challenges and finally review of the technical standards and gaps in these standards while adopting it for FSPV applications. Recommendations/mitigations are suggested to overcome those gaps for each of the main equipment that comprise a floating solar project namely:

- Photovoltaic (PV) modules
- Floaters
- Anchoring and Mooring
- Inverter
- Balance of System (BoS) – Combiner box, cables and accessories, transformers and earthing and lightning protection

Additionally, the report covers guidance for Energy Yield Assessment (EYA) and safety principles to be followed during installation, commissioning, and O&M phases.

2. NOTE TO THE READER

2 NOTE TO THE READER

The goal of this guidance document is to provide an overview and guidance to the reader to make pragmatic decisions in the absence of specific regulations and standards especially for testing, design principles, safety factors and design loads for floating PV, with focus on inland and near shore waterbodies. It is to be noted that the content of this document can never overrule any local, national and international applicable standards and regulations.

The content presented is based on the publicly available information on the floating PV system and the reader needs to be aware that changes in technology, site conditions and learnings from actual installations could warrant a change in assessment, necessitating new solutions to ensure a reliable system.

This guidance document follows the narration as indicated below for each of the main equipment:

- Firstly, a brief overview of the technology is presented for main components like modules and inverters and for the new components of the floating PV plant like floaters, anchoring and mooring systems.
- A brief of specific considerations for the installation on water is presented next for each equipment, along with the possible mitigations for the issues.
- The next subsection presents an overview of the technical standards currently in use for ground mounted solar installations and gaps identified with respect to the floating application.
- The standards which are not referenced in the tenders floated for FSPV in India are identified with a superscript "**Add on**", with the intention to provide the reader with a quick reference of standards that could improve the technical characteristics of the project.

This guidance document is intended to make the reader acquainted with the broad requirements of components deployed in a FSPV system and is not envisioned to be a detailed document in itself. For further reading on requirements, recommendations and guidelines for design, development, operation and decommissioning of FSPV systems, DNV's Recommended Practice DNV-RP-0584 (Design, development and operation of FPV projects) [1] can be referred. The recommended practice focusses on the lifecycle of FSPV systems and has been developed in accordance with recognized and agreed best practices and collecting the most relevant requirements from existing standards, codes and guidelines, when present. World Bank's publication Where Sun Meets Water: Floating Solar Handbook for Practitioners [2] is also a good reference for practical guidelines on FSPV projects, evolved from lessons learned from early projects.

3. PV MODULES

3 PV MODULES

3.1. Solar PV Module Technologies

PV module is the main component of a solar power plant as it converts incident solar irradiation into electricity. Crystalline silicon (mono and multi) and thin film (Cadmium telluride or CT and Copper indium gallium (di)selenide or CIGS) are the two PV module technologies commercially available in the market. Crystalline silicon technology has been predominantly used in floating PV applications so far, majorly driven by the maturity of the market and advances in the module technologies. **Figure 3.1** shows the technological advancements in PV module technology over the years.

FIGURE 3.1: Solar PV module technologies [3]

2010: The Early

- P-Type mono and multi, thin film and CPV technologies
- All cells are 156 mm with 3 busbars
- Monofacial only

2012: Limited Cell Innovation

- Half-cut cells introduced for early-adopter testing
- Incremental cell design improvements
- New backsheet and encapsulant materials

2014: Significant cell

- 8 different cell technologies tested, including n-type PERT, p-type PERC, Heterojunction (HJT)
- 3 different cell sizes and 4 busbar combinations

2016: PERC begins to dominate

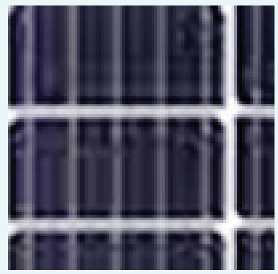
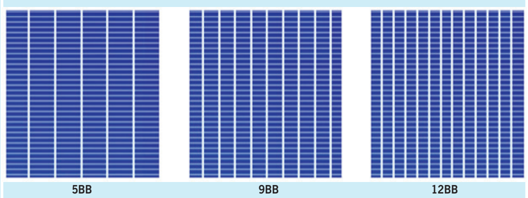
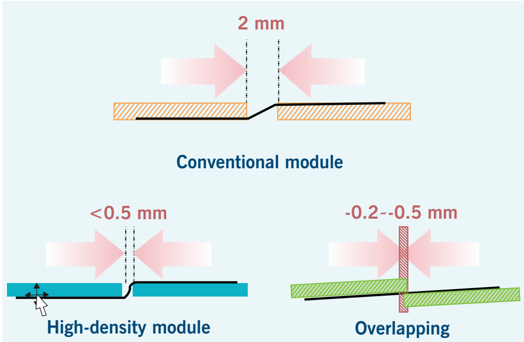
- Product mix tested is fairly consistent as manufacturers validate PERC cell technologies
- Larger cells are introduced (up to 161.7 mm)

2018 to present: Major cell and module advancements

- Different cell sizes (125 mm, 156 mm, 156.75 mm, 157.25 mm, 158.75 mm, 161.7 mm, 162 mm, 166 mm, 188 mm, 210 mm)
- 8 different cell technologies (p-type mono Al-BSF, p-type multi and mono PERC, n-type mono PERT, HJT n-type mono p-type bifacial mono PERC, n-type bifacial mono PERT, CdTe
- Cells with different counts of busbars- 3,5,6,9,12
- Monofacial and bifacial glass-glass modules
- Monofacial and bifacial glass-backsheet modules
- 4 different cell interconnection types- Standard ribbons, ECA (Shingled), interdigitated back contact (IBC), metal wrap-through (MWT)

Amongst all these module technologies, the present solar PV module market is majorly dominated by Passivated Emitter and Rear Contact technology. Owing to its higher efficiency, better temperature coefficient and better low light performance, this technology constitutes more than 70% of the market in 2020. **Table 3.1** presents the technological advancements commercially adopted by the PV module manufacturers to improve various aspects of the module such as efficiency, reliability, degradation etc.

TABLE 3.1: Commercialised technological advancements

Module type	Characteristics	Visualization	Remarks
Cut cell modules	Mitigates reliability issues like hot spot, fatigue, crack propagation and partial shading.		Recent innovation with little field history.
Multi-Busbar (MBB)	Higher number of busbars with reduced width essentially means reduced series resistance of the modules and smaller electrically isolated area in case of cracked cells. 9BB technology has necessitated transitioning from flat ribbon to round ribbon.		Ensuring reliability requires advanced soldering methods and machinery.
Tiling cell interconnection	Leads to effective utilization of the module area and thereby higher module efficiency.		There is concern that there is not enough space to accommodate thermal and mechanical stresses caused due to expansion and contraction of dissimilar layers of modules. Accelerated testing is envisaged to ensure long term performance.

Module type	Characteristics	Visualization	Remarks
Bifacial module	Bifacial modules can harness the reflected and diffused radiation from the rear ground, thereby increasing the energy generation.		Gain obtained with these modules in FSPV application might be limited due to less albedo of water surface, close packing of the modules and low tilt angle of installation.
Dual glass module	Well-made dual glass modules are highly resistant to corrosion and moisture ingress. However, these modules are associated with higher weight and increased cost. As the glass used is typically heat strengthened and of lower thickness, a lower mechanical strength can be expected compared to tempered glass which is important for impact resistance to hail and flying debris.		As compared to a module with a white backsheet, a dual-glass monofacial solar panel typically exhibits a slight efficiency loss on account of loss of reflected light between the cells. Some dual-glass monofacial modules have white reflectors between the cells.

The basis for selection of PV module will depend on a number of factors predominantly relating to the site conditions, the FSPV floater design and the philosophy of operation & inspection, repair, maintenance (O&IRM). Section 2.2 describes the important considerations for application of PV modules in FSPV projects.

3.2. Specific Considerations for FSPV

Unlike installations on land, modules are exposed to a harsher and more humid environment which raises concerns about corrosion, water ingress and Potential-induced degradation (PID) as shown in **Figure 3.2**. It should be noted that long-term field data of modules installed in floating plants are not sufficiently available to identify and quantify all the possible performance, safety, or degradation mechanisms.

The challenges and issues relevant to solar PV modules in floating applications are listed in **Table 3.2** along with possible mitigation measures.

FIGURE 3.2: Major issues with PV modules in FSPV

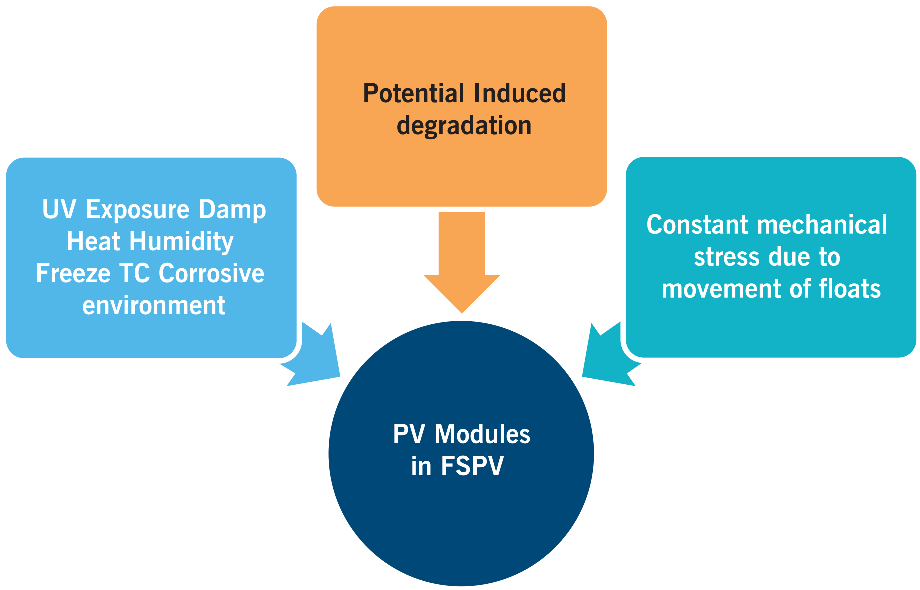


TABLE 3.2: Challenges with PV modules for floating solar applications

Parameter	Issue	Mitigation
Environment	Floating solar plant experiences humid, misty and salty environment depending on the site. This increases susceptibility to corrosion and water ingress. Chemical contaminants in water will also have an impact.	The frame of modules is generally made of anodized aluminium, 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 materials with low moisture and vapour transmission could be considered for manufacturing. Modules should be tested for International Electrotechnical Commission (IEC) 61215 and 61701 as a starting point for corrosion tests, damp heat, humidity freeze (HF) and temperature cycling tests. However, it is likely that long-term reliability testing would be necessary with an increase in the severity of the test conditions, depending on the learnings from field and characteristics of the installation site. It is also recommended that modules should be subjected to test as per IEC 60068-2-18 (Tests – Test R and guidance: Water) before and after the environmental testing with severity chosen depending upon the water body environment.
Mechanical	Modules would undergo dynamic loading due to wind, waves and water currents and also depending on the type of support system.	Modules should be tested as per IEC TS 62782:2016. The testing loads, points of application and cycles need to be revisited to reflect the actual site conditions and type of installation.

Parameter	Issue	Mitigation
Soiling	Water splashing, and condensation can be expected on the modules due to wind and other site conditions. Water collection can also happen at the bottom edge of the modules if the tilt angle is low. If the water is high in minerals, mineral deposition could occur in the long run due to evaporation, leading to changes in the optical properties of the glass.	Regular O&M should include visual checks, and infrared (IR) scans on modules. IR scans may be helpful in identifying diode failures due to chronic shading (for example due to bird droppings).
Connectors	The common issues that could be encountered with connectors are corrosion, water ingress and mechanical forces due to the movement of the floaters.	Connectors shall be tested for IEC 60068-2-52 and IEC 62852 with the test method chosen depending upon the application. However, it is likely that long-term reliability testing would be necessary with an increase in the severity of the test conditions, depending on the learnings from field and installation sites. IP 68 rating is recommended considering the possibility of immersion in water. The contact material of Multi-Contact, 4 millimetre (MC4) connectors is generally made of tin-plated Copper. A thicker tin coating is recommended to avoid corrosion as the connectors would be exposed to more humid environment and water splashing/immersion. It is desirable to ensure that the electrical connections are made immediately after installation of modules to prevent water ingress and corrosion and to maintain the IP rating of the connectors.
Grounding and electrical connections	As the floaters move with water, cables used for safety grounding of the module frames and electrical connections will be subjected to mechanical forces. The lugs, washers, nuts and bolts used for termination are prone to electrolytic corrosion and loose connections. Ageing of insulation of cables due to exposure to sun and water could happen.	Cables should be given enough slack to prevent undue stress on the cable and connections. Appropriate materials should be used for lugs, washers, nuts and bolts to prevent galvanic corrosion. Compatibility of lugs with the material of conductor of cables is to be ensured. If Copper lugs are to be used, tin plating is recommended. A periodic check of the tightness of connections should be mandatorily included in the maintenance plan. The insulation of cables should be UV stabilised and should be hydrolysis resistant and flame retardant/resistant.
Potential Induced Degradation (PID)	High humidity increases the risk of PID in modules.	Modules should be tested for compliance to IEC TS 62804-1:2015: PV modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon. However, it is likely that long-term reliability testing would be necessary with an increase in the severity of the test conditions, depending on the learnings from field and installation sites.

Parameter	Issue	Mitigation
		It is also recommended that modules should be subjected to test as per IEC 60068-2-18 before and after the PID testing with severity chosen depending upon the type of installation. The grounding of the Direct Current (DC) negative pole of the inverter should be done to mitigate PID issues. Alternatively, provision of anti-PID function in the inverter can be explored.
Installation	As the floating plants are generally assembled on the shore and then launched into the water, there are chances of proliferation of microcracks or physical damage to the modules.	Consent should be taken from the module manufacturer for the intended installation procedure and installation site conditions so as not to void the warranties. Additionally, manufacturing Quality Assurance Plan could be modified to have stringent acceptance criteria.

The following features could prove beneficial for reliability of modules in floating solar application.

3.3. Review of Existing Technical Standards

3.3.1. Overview of Technical Standards

The list of standards which the PV modules must comply with are provided in the **Table 3.4** and the list of National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited testing agencies in India having infrastructure to test against these standards are added in Appendix A.

3.3.2. Evaluation of Technical Standards

A brief description of the associated failure modes probed through the most common tests done on PV modules are described on next page.

TABLE 3.3: Desirable technological features

Characteristics	Benefit
Half-cut cell	Lower electrical resistance Reduced strain on the ribbons Lower hot-spot temperatures
Multi-busbar connector	Help in reducing impact of cell micro cracks
Thicker encapsulant	Limit the transmission of strain and reduce cell breakage rate
Anodised aluminium frame	Clamping is easy Reduced effect of corrosion

TABLE 3.4: List of key technical standards for PV modules

Standard	Title
IEC 61215 (All parts)	Terrestrial PV modules – Design qualification and type approval
IEC 60529	Degrees of protection provided by enclosures (IP Code)
IEC 61701	Salt mist corrosion testing of PV modules
IEC 62790 Add on	Junction boxes for photovoltaic modules - Safety requirements and tests
IEC 61730-1 & 2	PV module safety qualification
IEC 62716	Ammonia corrosion testing
IEC 62782 Add on	PV modules - Cyclic (dynamic) mechanical load testing
IEC 62759 Add on	PV modules transportation testing
IEC 62275 Add on	Cable management systems - Cable ties for electrical installations
IEC 62804-1-1	Test methods for the detection of potential-induced degradation – Part 1-1: Crystalline silicon – Delamination
IEC 63202 Add on	Light Induced Degradation test
IEC TS 63209 Add on (currently under development)	Extended-stress testing of PV modules

Ultraviolet (UV) Test

- PV modules are constructed with various polymers such as encapsulants, back sheets, and tapes. High energy UV photons can break polymer chains resulting in decreased optical transmission and degraded mechanical properties.
- Often the UV test is combined with a Damp Heat (DH) or Humidity Freeze (HF) test since polymer degradation is exacerbated in the presence of moisture.

Thermal Cycling (TC)

- In response to temperature changes in the environment, PV module components expand and contract albeit at different rates. This creates interfacial stresses within the module which, over multiple cycles, may fatigue the adhesion between components and degrade the components themselves. Typical failure modes include cell breakage, solder bond failure, and junction box adhesion failure.

Damp Heat (DH)

- Environmental exposure to moisture can degrade adhesives, penetrate sealants, corrode metal components, and create electrical shunts.
- Typical failure modes include delamination, discoloration, junction box adhesion failure, and corrosion related short circuits.

Humidity Freeze (HF)

- In many environments, modules freeze. The expansion of moisture within the module can cause failures of adhered interfaces, such as in the junction box, frame adhesives, back sheets, and encapsulants. Additionally, freezing may also initiate corrosion and propagate cell cracks. The humidity - freeze test is used as part of sequential tests.

Mechanical Stress

- The purpose of the test sequence is to allow a comprehensive evaluation of module performance when installed in high stress conditions such as dynamic mechanical loading, changes in temperature, high temperature and humidity followed by sub-zero temperatures.
- Typical failure modes can include breakage of glass, interconnect ribbons or cells, solder bond failures, delamination, junction box adhesion failure, inadequate edge delamination, and degradation of electrical output.

Following table summarizes the test specifications and evaluates the appropriateness of the tests considering FSPV application.

TABLE 3.5: Summary of reliability tests

Stress Factor	Standard	Requirement as per standard	Remarks
UV Exposure	IEC 61215	UV preconditioning is done at 15 kWh/m^2.	The UV exposure tests undertaken for PV modules are low considering long term outdoor operation of PV modules. This is a limitation for installations in ground mount applications also.
TC	IEC 61215	200 cycles from –40°C to +85°C and current shall be injected to the PV modules through external supply. The min dwell time of 10 mins to be maintained at each cycle. and max ramp rate of 100°C/h increase or decrease is specified.	Typically, in many reputed labs one cycle duration is approx. six hours. Increased thermal cycles and constantly maintaining higher current injection near to Imax value will simulate stress condition to the modules.
DH	IEC 61215	1000 h at +85°C, 85% RH.	The DH test duration of 1000 hours is generally considered less and even for modules installed in ground mount installations higher number of cycles are used for extended reliability testing. Please refer subsection 3.3.3 for further details.
HF	IEC 61215	10 cycles from +85°C, 85% RH to –40°C (no RH at low temperature) with continuous current flow. Typical dwell time for the high temperature is 20 h and 30 mins for low temperature. The ramp rate for increase/decrease temperature is 100°C/h.	The HF test for 10 cycles is generally considered less and even for modules installed in ground mount installations higher number of cycles are used for extended reliability testing. Please refer subsection 3.3.3 for further details.
Corrosion	IEC 61701	Salt mist test in this standard refers to IEC 60068-5-52 with 5% NaCl solution at neutral pH. Depending on the installation location the corrosivity class can be defined by designer or purchaser.	Choice for corrosion category can be done based on the characteristics of the site. For e.g., the standard specifies that the floating solar installations in offshore should have CX category and test method prescribed is as per test method 7 and 8. So while accepting the PV modules for offshore application, it should be ensured that the compliance of PV module is as per test method 7 and 8.
	IEC 62716	Ammonia corrosion test in this standard refers to International Organization for Standardization (ISO) 6988 for operation in ammonia corrosive environment.	This standard allows test on a small size module with similar Bill of Materials (BOM) as the PV module to be supplied to the project. So, at the time of evaluating compliance it should be carefully reviewed that the BOM of PV modules used for the project and the test are the same.

Stress Factor	Standard	Requirement as per standard	Remarks
Mechanical	IEC 62759	Transport simulation with complete shipping unit as per ASTM D 4169 for a duration of 180 mins followed by shock, rotational edge drop test, 100 half sine shocks and horizontal impact as per ASTM D5277. After the impact tests on module packages, the modules inside package are tested for TC, DH test, HF test and mechanical load test.	Methods for the simulation of transportation of complete package units of modules and combined subsequent environmental impacts, it does not however include pass/fail criteria.
	IEC 62782	Uniform load of 1000Pa ±100 Pascals (Pa) shall be uniformly applied over the modules at a rate between 3 and 7 cycles per minute. Total of 1000 cycles to be performed.	IEC 62782 does not specify DH or TC tests to be done after mechanical load test. The tests do not cover the forces experienced by PV modules in floating installations.
PID	IEC 62804	Under maximum system voltage, module temperature: 60°C ± 2°C with RH 85% ± 3% for a duration of 96 h. For the recent PID induced delamination standard, DH test as per IEC 61215 shall be conducted 2-7 days prior to voltage stress test.	The PID duration of 96 hours may not represent the actual field condition of the floating solar plant as this standard was originally developed for PV modules in ground mount installations. Since the modules in floating solar installations will be subjected to operation in higher humid environment, the test duration and the test cycles would need to be increased. Please refer subsection 3.3.3 for further details.

3.3.3. Gaps in Technical Standards

The solar industry in India primarily follows IEC standards for qualification and testing of PV modules and its subcomponents. Recent IS standards like IS 14286:2019, IS 61730 Parts 1 & 2 are adopted completely from IEC 61215 and IEC 61730 Parts 1 & 2, respectively.

The IEC 61215 is the internationally recognized performance standard for flat plate PV modules. However, passing this qualification test should be considered a minimum requirement. The IEC 61215 testing only involves 8 engineering samples in relatively short-duration accelerated tests which is inadequate and not intended for making 25-year useful reliability assessments.

While the IEC 61215 qualification testing is valuable for rapidly uncovering well known failure mechanisms, it is insufficient for assessing long-term reliability risk or evaluating newer or less common materials and designs. BOM-specific extended-duration testing provides a better indication of the long-term reliability of a specific design and BOM. The IEC TS 63209 describes a suite of extended duration tests that are being adopted by the industry. For example, the PV Evolution Labs LLC's (PVEL) Product Qualification Program is largely based on the IEC TS 63209. These extended tests stress numerous well-known modes of failure over a longer period than IEC 61215 qualification testing. Because of the rapid pace of innovation in the PV module industry, a greater emphasis is placed on positive extended-duration test results to indicate module durability. A review of the BOM-specific extended-duration test reports as a means to understanding module reliability risks is recommended. The extended tests specified in IEC TS 63209 are described.

TABLE 3.6: Extended reliability tests as per IEC TS 63209

Stress Factor	Recommendation
UV Exposure	In a UV test, the module shall be exposed to UV radiation of a specified dose which is typically 45 or 60 Kilo Watt hours per square metre (kW/m^2). Often it is recommended to combine the UV test with a DH or HF test since polymer degradation is exacerbated in the presence of moisture.
TC	The IEC TS 63209 test places modules in an environmental chamber where the temperature is cycled between -40°C and +85°C for 600 cycles instead of the 200 cycles in the IEC 61215. Additionally, maximum power current is applied to the modules while the temperature is increased and decreased.
DH	DH test shall typically be conducted for 2000 hours compared to the 1000 hours specified in IEC 61215.
HF	The humidity-freeze test shall be used as part of sequential tests and the modules shall be exposed to cycles of temperatures of 85°C and a relative humidity (RH) of 85% for 20 hours followed by to -40°C for 30 minutes.
Mechanical stress sequence	The sequence begins with a static mechanical load (2400 Pa), followed by a dynamic mechanical load (cycles of +1000 and -1000 Pa). Subsequently the module undergoes TC50 test and a HF10 test.
Backsheet stress sequence	The PV industry has come to understand that back sheet degradation in the field occurs faster due to the synergies of multiple stresses. In the IEC TS 63209, a new extended-duration test has been developed to better probe the durability of the back sheets which begins with a DH200 exposure to inject moisture into the module. Subsequently the module is exposed to three cycles of UV60 + TC50 + HF10. This sequence is intended to better capture the combined effects of moisture, heat, and UV that had been missing in previous test sequences.

4. FLOATERS

4 FLOATERS

4.1. Floater Technologies used in India

Floaters can generally be classified into three main categories, namely pure floats, modular rafts, and membranes as presented in **Table 4.1**.

TABLE 4.1: Types of Floats

Floater type	Description	Visualization
Pure floats	Floaters on which the modules can be directly mounted and can be designed to support one or more PV modules. A sample image is provided for ready reference [4]	 Courtesy: Ciel et Terre
Modular rafts	Support structural frames on which the PV modules will be supported. A sample image is provided for ready reference [5]	 Citation: Citation: 'Rosa-Clot & Tina, 2018' or 'Rosa-Clot, M. & Tina, G. M., 2018. Submerged and floating photovoltaic systems: Modelling, Design and Case Studies, London: Academic Press.'
Membrane floats	A reinforced membrane that supports the PV modules with additional structures, such as tubular rings to provide buoyancy. A sample image is provided for ready reference [6]	 Courtesy: OceanSun

In addition to floaters that are used to support PV modules, they are also used for supporting walkways, cables, inverters, and transformers.

The floats used for PV mounting in India primarily consists of pure floats and modular rafts with the former gaining more traction in past 2-3 years. High Density Polyethylene (HDPE) is the most common material used for floaters, however other materials, particularly ferrocement, have been known to be used.

4.2. Guidance for Selection and Design of Floaters

Floaters of different size, shape and configuration are available in the market. The materials used for the floaters also vary from synthetic plastics such as HDPE and Polyethylene, to metals such as Aluminium, stainless steel and carbon steel. Other materials such as Polyurethane foam, fibreglass with epoxy or polyester resin, and ferrocement are also used.

In general, any type and material of the floater can be selected for the project, provided the strength, durability, and functional requirements of the project are met. The selection and design of floaters and the floater assembly should take into account the following key factors including, but not limited to the following:

- Site environmental conditions such as the following:
    - Wind
    - Wave and current
    - Temperature and humidity
    - Water level variation
    - Water quality
- Block size and layout
- Mooring arrangement
- Material strength and durability
- Equipment specifications
- Transportation and installation
- Operation and maintenance requirements

In general, the floaters shall be designed in such a way that the following functional and performance requirements are met:

- Floats shall provide adequate buoyancy and stability
- Floats shall be durable and maintain structural integrity for design life
- Floats shall have adequate strength and stiffness to support the PV module/equipment
- Floats shall allow access for unrestricted maintenance activities
- Floats shall minimise stresses on all cables
- Any other additional requirement based on functionality and/or supported equipment

4.3. Review of Technical Standards

4.3.1. Overview of Technical Standards

Since the development of floating solar technology is at a very early stage of maturity, there are no comprehensive standards that exist which cater to all the aspects of design and serviceability requirements of a system. **Table 4.2** provides a list of standards from established sectors like energy, oil and gas and maritime whose requirements may be applicable for design of floater for FSPV.

TABLE 4.2: Key technical standards for Floats

Standard	Description
General and Related Standards	
DNV-ST-0119 Add on	DNV – Standard: Floating wind turbine structures
DNV-ST-0164 Add on	DNV – Standard: Tidal turbines
ISO 2394 Add on	General principles on reliability for structures
Loads and Load Combinations	
IS 875	Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures
IS 1893	Criteria for Earthquake Resistant Design of Structures
American Society of Civil Engineers (ASCE) 7 Add on	Minimum Design Loads and Associated Criteria for Buildings and Other Structures
DNV-RP-C204 Add on	DNV – Recommended practices: Design against accidental loads
DNV-RP-C205 Add on	DNV – Recommended practices: Environmental Conditions and Environmental Loads
Structural design	
IS 456 Add on	Plain and Reinforced Concrete - Code of Practice
IS 800	General Construction in steel - Code of Practice
IS 801 Add on	Code of Practice for the use of Cold-Formed Light Gauge Steel Structural Members in General Building Construction
IS 8147 Add on	Code of Practice for the use of Aluminium Alloys in Structures
ASCE Manual Add on	Structural Plastics Design Manual
DNV-ST-C501 Add on	Composite components
Material testing for Plastics	
ASTM D543 Add on	Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
ASTM D570	Standard Test Method for Water Absorption of Plastics
ASTM D638	Standard Test Method for Tensile Properties of Plastics
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D1693	Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics
ASTM D2565	Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications
ASTM D3045 Add on	Standard Practice for Heat Aging of Plastics Without Load
ASTM D3895	Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry (DSC)
ASTM D6110 Add on	Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics

Standard	Description
ASTM D7774 [Add on]	Standard Test Method for Flexural Fatigue Properties of Plastics
ASTM D7791 [Add on]	Standard Test Method for Uniaxial Fatigue Properties of Plastics
ISO 75 [Add on]	Plastics - Determination of temperature of deflection under load
ISO 175 [Add on]	Plastics - Methods of test for the determination of the effects of immersion in liquid chemicals
ISO 178	Plastics - Determination of flexural properties
ISO 179 [Add on]	Plastics - Determination of Charpy impact properties
ISO 180 [Add on]	Plastics - Determination of Izod impact strength
ISO 306 [Add on]	Plastics - Thermoplastic materials - Determination of Vicat softening temperature
ISO 527	Plastics - Determination of tensile properties
ISO 4582 [Add on]	Plastics - Determination of changes in colour and variations in properties after exposure to glass-filtered solar radiation, natural weathering or laboratory radiation sources
ISO 4892 [Add on]	Plastics - Methods of exposure to laboratory light sources
ISO 6721 [Add on]	Plastics - Determination of dynamic mechanical properties
ISO 9370 [Add on]	Plastics - Instrumental determination of radiant exposure in weathering tests - General guidance and basic test method
IS 15410	Containers for Packaging of Natural Mineral Water and Packaged Drinking Water
ISO 22088 [Add on]	Plastics - Determination of resistance to environmental stress cracking
ISO 868:2003 [Add on]	Plastics and ebonite - Determination of indentation hardness by means of a durometer (Shore hardness)
RoHS Directive (European Union) 2015/863 [Add on]	Test for Restriction of Hazardous Substances
ASTM G7/G7M	Standard Practice for Natural Weathering of Materials
ASTM G155 [Add on]	Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials
ASTM G154 [Add on]	Standard Practice for Operating Fluorescent UV Lamp Apparatus for Exposure of Non-metallic Materials
ISO 11357-6:2018 [Add on]	Plastics - DSC - Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)
UL 94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

4.3.2. Evaluation of Technical Standards

4.3.2.1. Design Principles and Safety Factors

The two well established design methodologies that are generally followed in design of structural elements are Limit state method[1] (Partial safety factor method) and Working stress method[2] (Allowable stress method). Traditionally, designs were carried out based on working stress method, however, this has given way to Limit state method in the past two decades. Similar levels of reliability of structures may be achieved using both these methods.

The standards IS456 and IS800, used for design of concrete and hot rolled steel sections provide sufficient guidance for design using both methodologies. IS 801 and IS 8147 only support design in accordance with working stress method. However, the reliability of the structural element can be ensured, provided the design is performed in line with the requirements specified in the said standards, irrespective of the methodology used.

Although the design of floaters made using steel, concrete or aluminium can be established based on the above standards, there are no relevant Indian standard that covers the design of Plastics such as HDPE that is commonly used in construction for floaters. Structural Plastics Design Manual by ASCE provides guidance on design of plastics. Alternatively, the principles outlined in ISO 2394 may be used in determining the relevant safety factors for plastics.

It should be noted that unlike other components such as PV modules or mooring lines that can be designed to be replaced, the floaters and module mounting structure form the backbone of the entire system and hence are generally designed to act as permanent structures for the entirety of its design life. Hence these structures need to withstand the worst possible design actions that is expected to occur during its entire design life without failure, and without major repair or maintenance. Hence degradation/deterioration of the material needs to be accounted for at the design stage itself. This is generally done by including the loss of material due to corrosion or use of reduced design tensile/flexural strength due to UV degradation. Due to the same reason, only limited guidelines on operation and maintenance are provided in standards. Owing to novelty of technology and unique environmental conditions applicable to FSPV, regular inspection and maintenance may be required. Section 9.2.3 of WB's Where Sun meets water- Floating Solar Handbook for practitioners [2] provides general recommendations for operation and maintenance of floats and the same may be referred to in this regard.

4.3.2.2. Design Loads

The environmental loads and other operational and accidental loads acting on the floaters need to be considered for design of floaters. The dead load acting on structure may be taken based on provisions of IS875 part 1. The imposed live load may be taken in line with IS875 part 2.

The environmental loads acting on the floaters include wind loads, wave loads, current loads, snow loads, effect of water level variation and marine growth as well as seismic loads.

1 Limit state method is a probability-based design methodology which utilizes partial safety factors for both design actions and design responses to achieve the required level of reliability. Different limit states (ultimate, serviceability, accidental and fatigue) are defined with different partial safety factors (based on probability), and the design is said to be adequate if the design demands are less than the design capacity.

2 Working stress method is the conventional design methodology where the required level of reliability is achieved by limiting the stresses developed to a defined value. Increase in permissible stresses are used to account for the lower probability of different extreme design actions acting simultaneously.

TABLE 4.3: Indian standards for design loads

Load	Indian Standard	Remark
Dead Load	IS 875 Part 1	-
Live load	IS 875 Part 2	-
Wind load	IS 875 Part 3	Wind load coefficients specified in the standard may not be applicable and may need to be determined based on wind tunnel testing or CFD analysis validated using wind tunnel testing.
Wave load	-	No applicable Indian standard. Guidance provided in DNV-RP-C205 along with site specific data may be used to determine loads.
Current load	-	No applicable Indian standard. Guidance provided in DNV-RP-C205 along with site specific data may be used to determine loads.

IS875 part 3 provide the basic design wind speed (3-sec gust for 50-year return period) to be considered for the location. The code also provides force coefficients to be used for inclined slopes. However, the force coefficients provided are applicable for roof structures rather than FSPV, and hence may not be valid. Wind tunnel testing in an atmospheric boundary layer wind tunnel is recommended to determine the relevant force coefficients for the floater. DNV-RP-C205 provides guidance on modelling of wind data. The same can also be used to determine the wind load acting on the floaters, where applicable given the required level of accuracy and complexity of the component shape. It should be noted that the wind load calculation methodology proposed in DNV-RP-C205 is based on a 10-min average wind speed rather than 3-sec gusts[3]. If Contract for Differences (CFD) analysis is performed to determine wind force coefficients, it is recommended that the results are validated using results from wind tunnel tests.

There are no Indian standards that provide guidance on wave and current loads applicable for the floaters. DNV-RP-C205 provides guidance on modelling of wave and current data based on met-ocean study results, as well as determination of wave and current loads acting on the floaters. DNV-RP-C205 along with DNV-ST-0437 provides guidance on estimation of loads due to ice and snow as well as marine growth. The effect of water levels may be taken into consideration by performing design calculations at different water levels including the maximum and minimum water levels.

4.3.2.3. Structural Design of Floaters

A global load and response assessment of the floater assembly is recommended to be performed to determine the extreme responses for applicable load cases. However, this is not directly covered by any code/standard. An ideal global model should represent the individual floating elements that constitutes the complete structure as realistically as possible, include realistic connections between floats, capture all relevant loads, and include the mooring system. An ideal model should also perform both static and dynamic load assessment with a realistic representation of the environmental actions in time domain and should be used to assess the global motions, mooring tension, forces in connection between floats and inputs (e.g., float accelerations) for detailed structural assessments. However, this can be very computationally intensive and hence difficult to perform, especially during preliminary

3 If basic design wind speed based on IS 875 Part 3 (which uses 3-sec gust) is used *without conversion* when calculating loads based on DNVGL-RP-C205 (which uses 10-min average), the loads may be overestimated and vice versa.

design phases. Simplified assessment such as equivalent static assessment may be performed during preliminary design stages, by considering appropriate dynamic amplification factors (DAFs).

The following general principles shall be applied to a global load and response assessment:

- It shall be documented that all relevant physical effects are included.
- Justifications for any assumptions or simplifications shall be made and it shall be documented that they are accurate or conservative.

The response from the global analysis can be used for detailed structural analysis, where the suitability of each floater and its connections can be determined to be in line with the requirements of relevant code/standard as discussed in section 4.3.2.1. Localized increase in stress in areas such module mounting points, connection points, mooring line connection points, etc. should be considered in the detailed structural design checks.

4.3.2.4. Material Strength and Durability

The materials used for the floaters shall have sufficient strength, durability and should have sufficient resistance to degradation.

The material strength and durability requirements for metals and concrete will be met, provided the design is performed in line with the relevant standards and the grade of material complies with relevant standards as discussed in section 4.3.2.1. The said standards also include corrosion protection measures to be employed for the material based on the corrosivity levels applicable at site.

Due to unavailability of such standards for plastics, additional care should be taken to ensure durability of the floaters. The standards available for commonly used plastic materials such as HDPE and and Fibre reinforced plastic (FRP) pertain to requirements of products used frequently rather than those that can be used in design of floaters. Such standards include IS 4984 (high density polyethylene pipes for potable water supplies) and IS 14856 (Glass Fibre Reinforced Plastic Panel Type Door Shutters for Internal Use). However, DNV-ST-C501 provides guidance on design of composite materials and could be used for the design of FRP floaters.

Table 4.4 includes list of tests that are typically performed for plastics used for floats or on finished product. Accelerated testing is recommended to be performed to determine the susceptibility of material to degradation. Although direct correlation between accelerated

TABLE 4.4: Summary of mechanical and reliability tests

Test	Standard	Description	Recommendation
Tensile strength	ASTM D638	As the floater assembly is expected to withstand the load for the design life while subjected to continuous UV exposure, design should ensure that the tensile strength is sufficient to withstand the loads acting at its weakest point.	The reduction in tensile strength should be assessed before and after UV exposure (minimum 2000 hrs). Reduction in strength is recommended to be less than 5% of initial value.
Compressive strength	ASTM D695	Plastics have generally poor compressive strength due to their brittle nature. In FSPV application, the cross sections at various points of the floater are subjected to bending stresses and shear stresses due to the action of environmental loads.	The reduction in compressive strength should be assessed before and after UV exposure (minimum 2000 hrs). Reduction in strength is recommended to be less than 5% of initial value.

Test	Standard	Description	Recommendation
Elongation at break	ASTM D638	It is practically difficult to specify tests to reflect 25 years of life with full confidence owing to practical issues in manufacturing (failures can manifest even if tests pass). It is noted that in general, HDPE blends exhibit high elongation.	The test is recommended to be conducted before and after UV exposure. With an initial high value for elongation, the residual value after UV exposure should provide better margin for protection against crack propagation.
Fatigue strength	ASTM D7791 and ASTM D7774	The floater platform components together with connectors are frequently subjected to complex loading conditions including static-long term loading, impact loading and dynamic loading.	Required fatigue strength depends on frequency and value of cyclic load the connectors are subjected to during service life. A higher factor of safety gives higher durability.
Flexural strength	ASTM D790	Normally, blended HDPE has good flexural strength for applications like float assembly. The upper surface of the individual floats and the connectors will be subjected to flexural loading.	While it is difficult to specify exact values, assessing change in value before UV exposure and post UV exposure is advised to ensure durability.
Charpy notched Impact Test	ASTM D6110	The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test that determines the amount of energy absorbed by a material during fracture.	Rather than a single value, establishing ductile - brittle transition is more useful. In addition to the energy absorbed, the mode of failure and fracture mechanics of the material are recommended to be studied to gain better understanding of material behaviour and strength.
EPC Resistance	ASTM D1693 and ISO 22088	This test is applicable to assess impact of environmental changes like irradiation from Sun, ambient temperature and humidity changes on the material. A variety of test methods are available for assessing the environmental stress crack resistance (ESCR) of thermoplastics and they can be divided into two groups: tests at constant strain and tests at constant load (stress). Any test that involves the application of a constant strain is less severe than the equivalent test involving the application of a constant load, as the stress is not maintained constant during the test.	It is recommended to develop custom testing methods for a specific location using expertise gained from many other sites and practical experience from different applications. As variation across laboratories for same specimen are high, this test should be used to compare results of samples (approx. 10 can be considered a good sample size).
Environmental exposure Testing	ASTM G7/ G7M and ISO 9370	The relative durability of materials can be very different depending on the location because of differences in UV radiation, time of wetness, temperature, pollutants, and other factors. Therefore, it cannot be assumed that results from one exposure in a single location will be useful for determining relative durability in a different location.	Exposures in several locations with different climates which represent a broad range of anticipated service conditions are recommended. Control materials (at least one control material of similar composition and construction compared to test specimen is recommended) included as part of a test shall be used for the purpose of comparing the performance of test materials relative to the controls.

Test	Standard	Description	Recommendation
Water absorption analysis	ASTM D570	The test method for rate of water absorption has two main functions: ▪ Assess effects of exposure to water or humid conditions on electrical or mechanical properties, dimensions, or appearance. ▪ As a control test on the uniformity of a product, particularly if the test is made on the finished product.	If water absorption is found significant, mechanical tests should be re-performed to assess the change in properties.
Flammability Rating	UL 94	HDPE, like many plastics are highly flammable.	A rating of V1 is a reasonable requirement to be met, without any permanent damage to floater. Required flammability rating can be determined depending on regulatory or owner specific requirements. In the absence of both, a risk-based approach can be adopted by evaluating fire hazards in the near vicinity, detection mechanisms available, likelihood and consequence of a fire happening. Designing for extreme events like a catastrophic event, example sabotage, or fire from floating oil are advisable, but is generally not mandatory due to economic reasons.
Resistance to chemicals, acid, lye, mineral oil, benzene	ASTM D3895	Pure HDPE is known to be resistant to many chemicals, except a few. HDPE floater if used in chlorinated water can result in degradation of physical properties over time. Liquids immiscible with water and of lower specific gravity will float on the water surface and only the contact at the waterline area of floater is expected. The corrosion effect can be reduced substantially with additives.	The water where the plant is to be installed can be analysed for presence of oil contaminants, benzene and harmful chlorine compounds. Oxidation levels through ASTM method shall be performed after immersion of the sample for different durations. Normally, if after exposure of 30 days, no significant oxidation is reported, the material can be used in same waters. The masterbatch manufacturer should be consulted to assess risk of exposure to known chemicals and undertake mitigation measures. Painting the floaters with chemical resistant paints can be considered if the situation demands.
Corrosion test	ASTM D543	HDPE has excellent corrosion resistance and is virtually inert. It offers better overall resistance to corrosive acids, bases and salts and organic substances, such as solvents and fuels.	The water quality where the plant is to be installed may be analysed and depending on presence of any specific chemicals, reference test be used to evaluate the material's resistance to chemical agents,

Test	Standard	Description	Recommendation
			if continuous exposure to high concentrations is expected. If the water quality is likely to vary during the lifetime due to presence of effluents or contaminants, retests may need to be conducted to affirm resistance.
UV exposure rating	ISO 4892 and ASTM D2565	Photodegradation causes change in appearance and deterioration in properties like impact strength, tensile strength and elongation. UV inhibitors are added to the blend of HDPE to slow down such degradation.	Testing of required properties of each blend of HDPE before and after UV exposure can be conducted to assess effect of UV protection.
Floater drop test	-	Drop test is conducted by dropping the finished float sample from a height which can nearly simulate conditions of accidental dropping while transportation and handling.	Test procedure should be developed to reflect conditions in handling, transportation, storage and deployment where accidental drop is expected. The drop height and the procedure shall be agreed depending on needs of the site.
Heat ageing temperature test	ASTM D3045	Thermal degradation of polymers can lead to physical and optical property changes like reduced ductility and embrittlement, chalking, colour changes, cracking and general reduction in most other desirable physical properties. This eventually results in shorter service life and reduced factor of safety for design. Plastics can be protected from thermal degradation by incorporating stabilizers into them. This test is recommended for sites where ambient temperatures are consistently high (greater than 40°C) almost throughout the year.	Development of an approach wherein a stress strain diagram is drawn out for a few operating temperature ranges for a given masterbatch can be done. Examinations through Fourier transform infrared spectroscopy combined with mechanical tests are to be correlated to make a judgement on extent of influence of additives. Experimental studies on samples are required to be conducted after exposing samples to similar environment. Further, some pre-identified floaters in service could be considered for replacement at regular intervals with new ones and subjected to different examinations and tests to derive practical data to support conclusions.
Float bending test	-	This test reflects the strength of the designed float and not material alone. No standard test procedure exists for this test and the procedure would depend on geometry of the floater.	This test is recommended only if mandated by regulatory requirements or if used to further validate the design considerations.

testing and design life cannot be established at this time, testing for a minimum of 2000 hrs is recommended. For acceptable resistance to degradation, the change in physical properties is recommended to be less than 5% of initial value.

4.3.3. Gaps in Technical Standards

The checklist below provides the key gaps based on the review of the technical standards.

TABLE 4.5: Gaps identified and recommendations

Parameter	Limitations and Recommendations
Design principles and safety factors	Clear design principles are available for materials such as a steel concrete and Aluminium, However, lack of such standards for plastics particularly in the Indian context makes design for plastics difficult. However, similar factor of safety may be adopted by using principles outlined in Plastics Design Manual by ASCE and ISO 2394.
Design loads	Estimation of dead and live loads are covered adequately by IS 875 part 1 and 2, respectively. Basic design wind speed to be considered can also be adopted from the current standards. However, the wind force coefficients specified may not be appropriate for FSPV. Coefficients based on wind tunnel testing and/or CFD analysis validated using wind tunnel testing may be considered for wind loads. There are no Indian standards that cover wave and current loads. Also, wave and current parameters to be considered need to be determined based on-site specific data. Wave and current loads may be determined based on-site specific data collected using appropriate standards such as DNV C205.
Structural assessment	Ideally, the structural assessment should be performed based on a global model, which can be computationally intensive and hence difficult to perform. Other simplified assessments could be undertaken, especially during preliminary design, however, limited guidance is available on the same.
Inspection and Maintenance	As per general design practice structural frame and floaters are designed to be passive elements that should remain functional for expected life without repair/ maintenance. Given the novelty in technology and unique nature of FPV projects, regular inspection and maintenance may be required. Section 9.2.3 of WB's Where Sun meets water-Floating Solar Handbook for practitioners provides general recommendations for operation and maintenance of floats and the same may be referred to in this regard.

5. ANCHORING AND MOORING

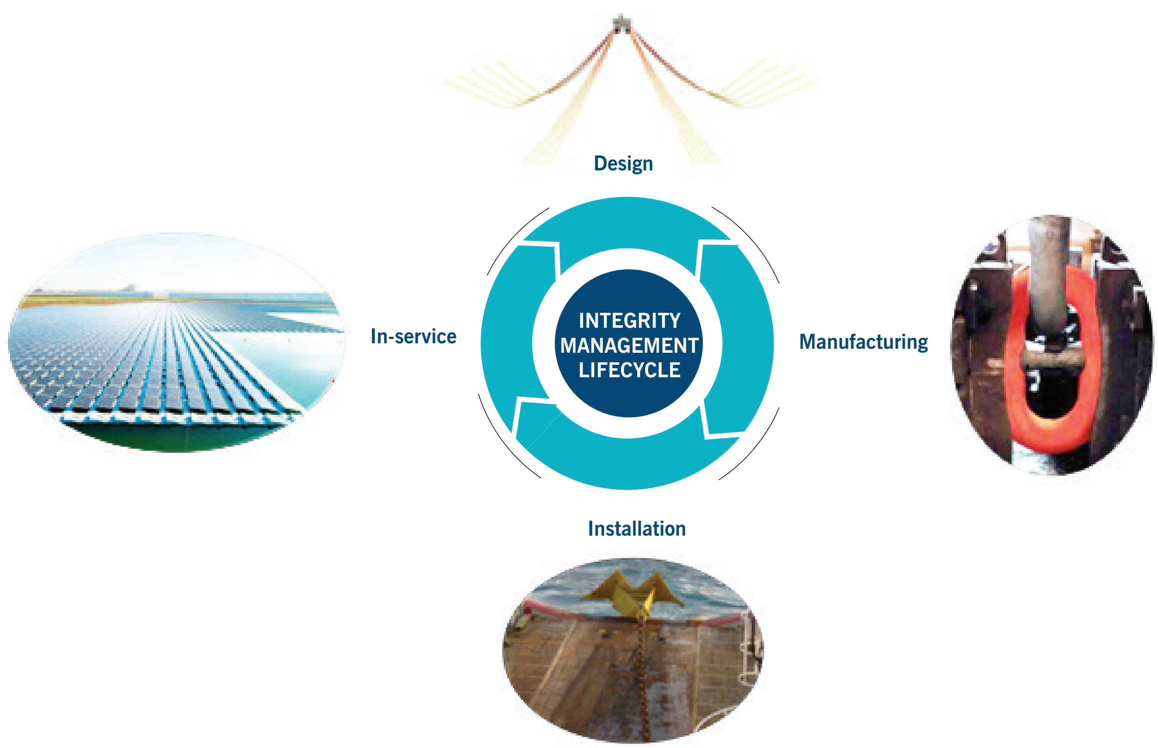
5 ANCHORING AND MOORING

This section will review the existing technical standards for mooring equipment for FSPV application, considering the lifecycle phases shown below; the lifecycle phases are design, supply (or manufacturing), installation, operations, and maintenance.

There are not yet a specific set of standards covering the application of mooring equipment in FSPV. Therefore, technical standards from other industries (mainly Oil & Gas [O&G] and floating offshore wind) are referred to. As such this section also identifies gaps in the technical standards and provides guidance (and a summary checklist) on bridging of these gaps, in the Indian context.

This section starts by setting the scene of typical mooring technology used in FSPV application (mainly in India) and important design considerations relating to this equipment as well as the factors that might influence material/component selection. This is important as it provides background information and reasoning regarding the important aspects that should be covered by technical standards for FSPV mooring system design and equipment selection.

FIGURE 5.1: Mooring system lifecycle phases



5.1. Floating Solar Mooring Technologies used in India

Almost all the floating solar projects developed so far in India implement typical short catenary mooring systems comprising of hundreds of mooring lines. The typical composition of these mooring systems is further detailed in the table below.

As explained above, there are a number of mooring line component types that can be used for floating solar applications, both in-land and in the sea (in-shore/near-shore and offshore). The basis for selection will depend on a number of factors predominantly relating to the site conditions, the FSPV floater design and the philosophy for O&IRM. Sections 5.1.1 and 5.1.2 below describe the different anchor and mooring line types and important considerations for their application in FSPV.

5.1.1. Guidance for Selecting Mooring Line Anchors

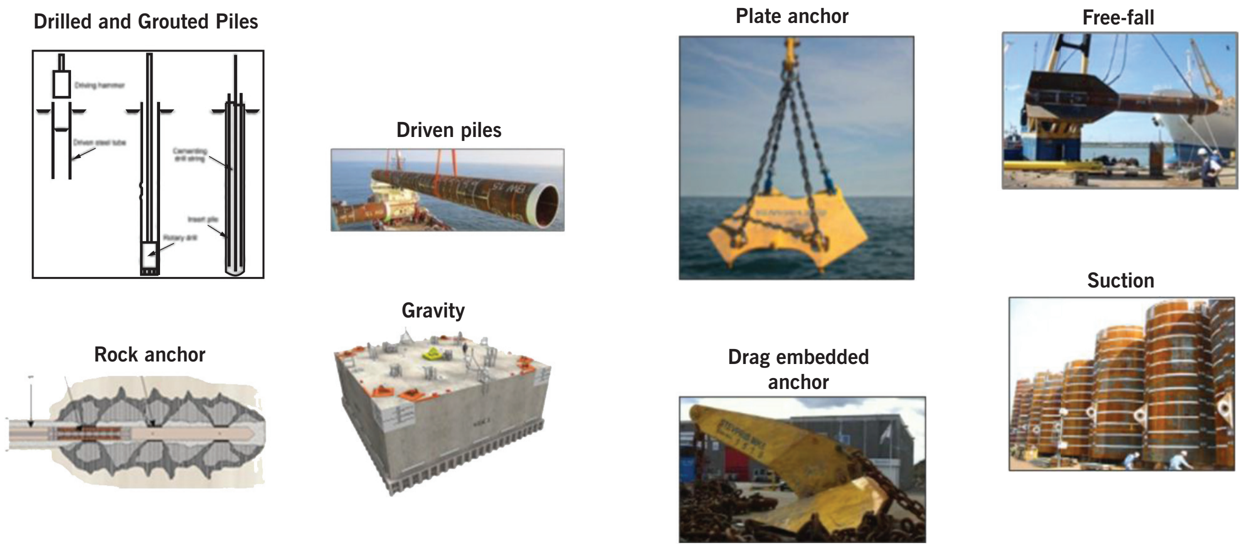
The seabed, lakebed, quarry bottom, etc. (collectively referred herein to as "ground") type governs the anchor selection. Therefore, anchor choice is in general an early decision to be made in the concept design. The diagram below presents a number of anchor types that are widely used for offshore mooring in the O&G and floating wind sectors. The organisation of these from left to right reflects the hardness of the ground, hard soil on the left and soft soil to the right.

TABLE 5.1: Anchoring and Mooring technology in India

Type of mooring systems	Connection with the structure	Mooring line components	Anchors	Tensioning mechanism	Typical features/issues
Short catenary mooring systems comprising of hundreds of mooring lines	Typically consists of a steel spreader mounted on an edge float; connected using shackles	Chain/Wire/Polyester or a combination of these	Gravity based concrete anchors/helical screw anchors depending on seabed type	None	These short lines in shallow waters generally get taut for the high-water level cases, or with small offsets of the array, leading to possibility of considerable dynamic loadings which at present is not properly accounted for in the designs.* Considering the number of lines and lack of tensioning mechanisms, the implicit uncertainty in installation tolerances is bound to create uneven loading in the lines.

* There are some proposals under consideration which involve taut mooring systems incorporating elastic components such as those from Sea flex or similar, which claim to reduce peak tensions considerably.

FIGURE 5.2: Mooring anchor types (left to right reflects the hardness of the ground, hard soil on the left and soft soil to the right)



The most common anchors used for offshore mooring are suction and drag anchors whilst the most common anchors used for FSPV applications are gravity anchors and helical screw anchors. Therefore, these anchor types are expanded below.

Gravity anchors are relatively simple to install (requiring least extensive ground investigations) with reasonably good accuracy with respect to position/orientation. They can be relatively cheap and use local supply chains as they comprise of a simple concrete structure. Gravity anchors have not been commonly used in offshore mooring application (O&G or floating wind) because very large anchors would be required to counteract the large mooring forces, which may be impractical to install. As such FSPV provides a better market for gravity anchors where mooring loads are comparatively smaller leading to smaller anchors that can also be readily designed for anchor sharing through having multiple connection points on the anchor. However, load sharing on an anchor increases the required weight, consequently this may lead to limitations with regards installation and retrieval – e.g., lifting of large/heavy anchors requires larger vessels which may not be able to operate in very shallow waters. Whilst less information is needed on the ground conditions, detailed knowledge of bathymetry at anchor position is needed.

Drag embedded anchors have a high capacity, are widely used in the O&G industry and on several floating wind projects. They are cheap, well-developed and have a proven installation process. However, they require larger position tolerance and cannot take large uplift loads. As a result, the mooring footprint of such systems can be large. Also, the predominant loading should be horizontal and along the centreline axis of the anchor, as such lateral loading should be minimal making it challenging to have multiple mooring lines connecting to the anchor which is desired for FSPV due to the large number of mooring lines per array. Drag anchors need to be proof loaded, usually to the ultimate limit state load to assure capacity through sufficient drag and penetration, which has installation implications in particular for FSPV where the marine spread may have limited bollard pull capacity.

Suction, driven pile and screw anchors are forms of embedded anchor. Suction anchors are widely used in O&G and floating wind applications due to their high capacity and reasonably good accuracy with respect to position/orientation. However, suction anchors are more expensive than drag anchors, and also have some transportation and installation challenges – e.g., they require large cranes due to their weight and height and given their size, fewer anchors can be shipped per vessel. These anchors have in general high holding capacity and are quite large, therefore are not expected to be required for in-land FSPV applications. Driven/Screw anchors are more common in FSPV applications and are in general flexible with respect to soil type and load angles. However, these require a good understanding of the soil conditions through ground investigations.

The anchor solution should be selected on a case-by-case basis depending on the site conditions. The following factors are of importance for selection of anchor type:

- Mooring line loads, i.e., vertical and horizontal load capacity and load sharing needs
- Ground and soil profile constraints
- Bathymetry/topology constraints
- Installation and recovery constraints
- Precision requirements
- Behaviour under sustained loading

Environmental impact should also play a role in the anchor selection. In general piles and other driven anchors which are noisy to install and/or more complex to remove are considered to have a greater environmental impact. As such, gravity anchors, if particularly large may also be considered to have environmental impact due to the large area of soil disturbance. Suction and drag anchors are easily removed with generally less ground impact however drag anchors may have a higher environmental impact during installation, as they need to drag and penetrate the soil to achieve the capacity.

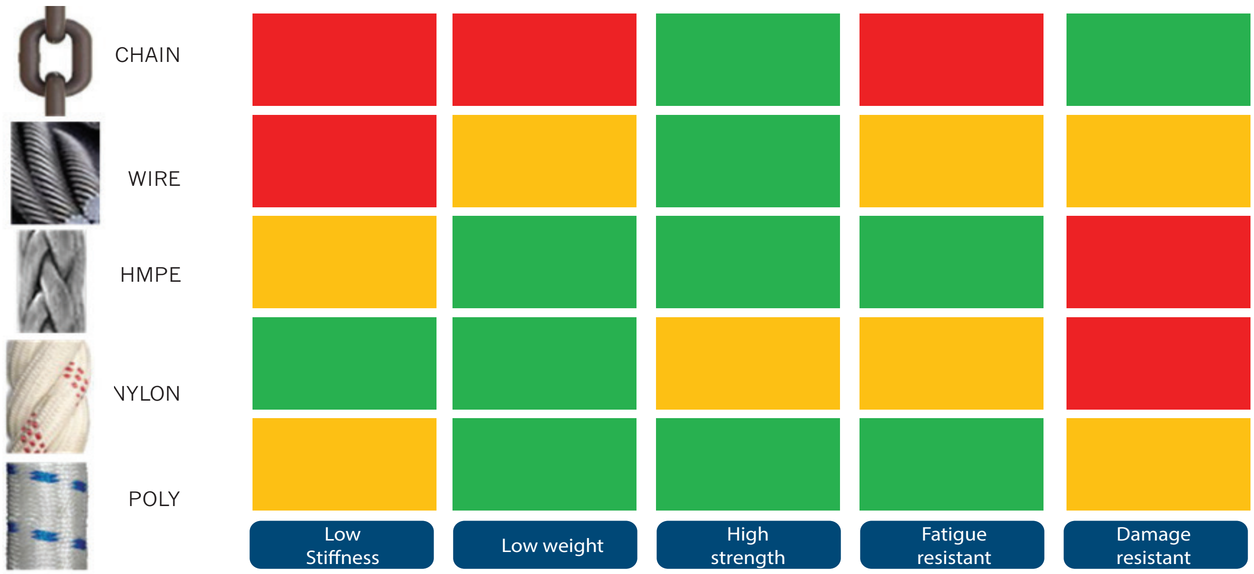
5.1.2. Guidance for Selecting Materials of Mooring Line Anchors

The most conventional mooring line types are chain, wire, and polyester. Dyneema and nylon are becoming increasingly popular in floating renewables applications due to their low weight and high strength properties.

The comparative attributes of each line type are shown below. These are stiffness, weight, ultimate strength, fatigue strength, and durability which are all key properties for mooring components:

- Low material stiffness is attractive as it lowers loads and may be particularly important for shallow water moorings which require material compliance; in shallow water a catenary has less geometric compliance than in deeper water.
- Low weight is attractive as it lowers transportation and installation costs and is particularly important for deep water, where excessive mooring weight would require adding buoyancy to the platform (and therefore cost).
- High ultimate and fatigue strength capacities are particularly important for severe conditions with large extreme loads and high wave occurrences.
- Damage resistant mooring line types should be placed at connections (e.g., fairlead/anchor) and at the touchdown points with the ground. Components with poor damage resistance require careful installation surveillance.

FIGURE 5.3: Guidance on material selection for mooring lines



Whilst chain is generally considered to be more robust than other mooring components, it is particularly susceptible to corrosion and also wear. Most recorded failures in the O&G floating production sector are due to a combination of fatigue combined with corrosion or wear. Most design standards account for uniform corrosion allowance however, there have been examples where localised pitting corrosion has occurred which has led to excessive weakening of the chain component. For FSPV application in fresh/brackish water in-land, the corrosion profile and type will be different to the experience from seawater application.

Steel wire rope is generally protected from corrosion (combination of grease and cathodic protection) but can be damaged due to contact and over-bend, therefore is particularly sensitive to installation/handling and also designers should consider the in-service dynamic behaviour (e.g., minimum bend radius, contact points, etc.). In FSPV applications where there are significant water level variations, to the extent that the mooring lines become grounded, wire ropes may not be suitable unless properly qualified for this due to failure modes such over-bend and particle ingress.

Fibre ropes (polyester, nylon and Ultra-high-molecular-weight polyethylene) have in general very good MBL to weight ratio and also good fatigue performance, though for nylon rope, the fatigue resistance depends on the construction of the rope and the environmental temperature. All fibre ropes are sensitive to slack-snatch loading which may lead to compression fatigue and rapid weakening of the mooring rope, with Aramid being the worst affected and polyester being the least affected [7]. This may be an important consideration for FSPV systems placed in dynamic environments. As well as being light, nylon has a good MBL to stiffness ratio, providing a strong but compliant mooring line, however nylon is a relatively novel component yet to be proven with many years of service in long term offshore mooring application.

Adopting the guidance from the O&G sector, fibre ropes should in general not come into contact with the ground during in-service condition so in FSPV applications where there are significant water level variations, to the extent that the mooring lines become grounded, this becomes a major consideration. Protective jackets can be placed on fibre ropes however, this may obstruct being able to inspect the fibre rope itself for damage. It is noted that fibre ropes are particularly sensitive to installation/handling with most recorded failures/incidents in O&G stemming from the installation phase. This is an important consideration for FSPV where there may be several hundred mooring lines installed per array and therefore it is more difficult to ensure robustness in the installation process.

The 3-T (Time-Tension-Temperature) endurance of the fibre rope should be considered in design. 3-T is the load bearing capability of the yarn material over time in response to tension and temperature. The criticality of each parameter depends on the other two parameters. For FSPV applications in India, it is expected that temperature may be a more important consideration than offshore locations, due to use of the fibre rope close to the water surface and in general warmer locations. It is recommended that the 3-T performance characteristics are established by testing. Specific operational experience should be fed back to refined O&M procedures and improved design procedures.

The following site condition factors should be taken into consideration when designing the mooring system arrangement and will influence the mooring line types selected:

- Topography
- Ground conditions
- Bathymetry
- Water depth
- Water level variation
- Environmental conditions
- Marine growth

In addition to the site condition factors, functional and performance requirements defined for the FSPV system must be considered.

5.2. Review of Technical Standards

5.2.1. Overview of Technical Standards

An FSPV mooring system should be defined as a permanent mooring system. The typical life of permanent moorings (or long-term mooring, LTM) is 25 years and it is normally expected that there is minimal intervention during the operating life of the asset. As such, based on this definition, the list below provides a range of industry technical standards that are applicable to the design, manufacturing, installation, and operation of permanent mooring systems.

The HSE regulatory expectations on moorings for floating wind and marine devices, provides general guidance on the requirements of the duty holder regarding design, manufacturing, installation, and operation. Referring to the applicability of O&G standards to floating wind and marine devices it says that "*ISO 19901-7:2013 provides standards for station keeping systems for floating offshore structures and MOUs in the oil and gas sector, principles and guidance within can be used in the renewable sector to the duty holder's advantage*". Following this principle, the technical standards selected for further evaluation of their applicability to FSPV are the API, ISO, DNV and NORSOK standards from the **Table 5.2**. The reason for this decision, is that these are the most mature and most widely used standards for mooring, and while they are not directly applicable to FSPV, the underlying principles and philosophies are valid. In addition to these, the IEC standard is also reviewed as this is developed to be applied to floating marine energy converters in a general sense. These are expanded on below, and the evaluation is in Section 5.2.2.

Several designers of moorings for FSPV application use API-RP-2SK as the basis for undertaking the mooring analysis. The benefit of this is that both international standards on moorings, ISO19901-7 and IEC-TS-62600-10

TABLE 5.2: Key technical standards for Anchoring and mooring

Body	Reference	Title
American Petroleum Institute (API)	API RP 2SK Add on	Design and analysis of station-keeping systems for floating structures
	API Spec 2F Add on	Specification for mooring chain
	API RP 2I Add on	In-service Inspection of Mooring Hardware for Floating Structures
	API RP 2MIM Add on	Mooring integrity management
BS	BS 6349-6 Add on	Maritime Structures – Part 6: Design of inshore moorings and floating structures
DNV	DNV-ST-0119 Add on	Floating wind turbine structures
	DNV-OS-E301 Add on	Position mooring
	DNV-OS-E302 Add on	Offshore mooring chain
	DNV-OS-E303 Add on	Offshore fibre ropes
	DNV-OS-E304 Add on	Offshore mooring steel wire ropes
	DNV-RP-E301 Add on	Design and installation of fluke anchors
	DNV-RP-E302 Add on	Design and installation of plate anchors in clay
	DNV-RP-E303 Add on	Geotechnical design and installation of suction anchors in clay
	DNV-RP-E304 Add on	Damage assessment of fibre ropes for offshore mooring
	DNV-RP-E305 Add on	Design, testing and analysis of offshore fibre ropes
	DNV-ST-N001 Add on	Marine operations and marine warranty
	DNV-OTG-18 Add on	Guidance for long-term nearshore mooring systems
	DNV-CP-0100 Add on	Type approval: Synthetic fibre ropes for towing, mooring, and anchoring
	DNV-CP-0255 Add on	Approval of manufacturers: Wire ropes
	DNV-RU-OU-0512 Add on	Floating offshore wind turbine installations (classification rules)
Health Safety and Environment (HSE)	N/A	Regulatory expectations on moorings for floating wind and marine devices
Industrial Area Local Authority (IALA)	Guideline Add on	Plastic buoys
	Guideline Add on	The Design of Floating Aid to Navigation Moorings
	Guideline Add on	Hydrostatic design of buoys
IEC	IEC TS 62600-10:2015 Add on	Wave, tidal and other water current converters Part 10: Assessment of mooring system for marine energy converters
ISO	ISO 19901-7 Add on	Station keeping systems for floating offshore structures and mobile offshore units (MOUs)
NORSOK	NS 9415.E:2009 Add on	Marine fish farms Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation

have a similar structure and analysis philosophy as API-RP-2SK and also the same load factors, though the IEC standard also applies additional consequence factors. The API recommended practice and ISO standard are widely used for mooring assessment, however it is noted that these were developed for offshore floating production units (FPUs) and MOUs. Therefore, their application to FSPV, and in-particular inshore an in-land location, is debatable. The ISO19901-7 and IEC-TS-62600-10 standards have some minimal information on installation and in-service requirements, referring to API-RP-2I for further guidance. API-RP-2I is one the first documents in the O&G sector addressing in-service inspection of mooring hardware for floating structures. However, this was predominantly written for MOUs which retrieve their moorings between deployments (that may last a few months to a few years) and perform in-air equipment survey. The integrity management philosophy of in-service permanent moorings is different and therefore, whilst AP-RP-2I provides useful guidance for assessing the fit-for-purpose of mooring components, its underlying philosophy is not the most relevant to FSPV application.

DNV-ST-0119 is developed specifically for floating offshore wind turbines. The benefit of applying this standard is that it is developed with target reliability levels that are suitable for offshore renewables. In this context, it provides a better match to FSPV. It also provides guidance for shared anchors which is a particularly relevant for FSPV. DNV-ST-0119 is not standalone and refers to the relevant standards/recommended practices for the following:

- The mooring hardware (chain, wire, fibre rope, anchors, etc.)
- The installation (DNV-ST-N001)
- In-service integrity management (offshore Class rules)

As such these provide a comprehensive set of technical guidance for designing most types of mooring systems. As with the API and ISO documents, the DNV standards/recommended practices are predominantly developed for offshore moorings. To increase the coverage, DNV-OTG-18 provides useful guidance for in-shore permanent moorings drawing attention to load effects that may not be present in offshore conditions. However, application to an in-land location is debatable.

The NORSOK standard for marine fish farms provides requirements for site survey, risk analyses, design, dimensioning, production, installation and operation. It may seem odd to suggest a fish farm standard, but fish farm units (pens, floats, moorings, etc.) are more similar to FSPV in terms of location, scale, materials and access-practice by personnel, than offshore O&G and floating wind platforms.

The IALA guidelines for mooring buoys provide the minimum requirements for a navigation buoy, however, are not as extensive as the API, DNV and NORSOK requirements. The British Standard for inshore moorings and floating structures has been withdrawn. Therefore, these standards are not selected for the evaluation.

5.2.2. Evaluation of Technical Standards

The following table reviews the most relevant and well-developed industry technical standards for moorings against the following topics:

- Design principles:
  - Limit states
  - Type of analysis
  - Return period
  - Safety factors
  - Environmental design loads
  - Corrosion
  - Marine growth
- Site survey

- Installation
- Monitoring
- Inspection
- Maintenance

For each topic, the key principles of the technical standards are described collectively, and in some cases distinguishing certain details between them. For each topic, comments are provided on the applicability to FSPV and the main gaps.

The technical standards included are the following:

- API-RP-2SK and other relevant API recommended practices
- ISO19901-7
- IEC-TS-62600-10
- DNV-ST-0119 and other relevant DNV standards and recommended practices
- NS9415

TABLE 5.3: Evaluation of key technical standards for Anchoring and mooring

Description of requirement		Commentary
Design principles		
Limit states	All have requirement for: ▪ Ultimate strength design for intact and one-line broken scenarios (referred to as "damaged" in API, "redundancy check" in ISO or "accidental limit state, ALS" in DNV, IEC and Norsok) ▪ Fatigue design considering mooring system in intact condition NS9415 has additional ALS case with spring flood and intact mooring system	Strength and fatigue design of moorings is required for FSPV in offshore, inshore, and in-land locations. Fatigue is expected to be more important in locations where waves are more significant (i.e., offshore). Damage condition considers one line failure only with reduced safety factors. Considering an FSPV array may be composed of several hundred mooring lines, there is increased probability of a single line failure, and it is questionable whether this requirement for one line failure is considered to be adequate to reflect a mooring damage event of significance for FSPV, e.g., cluster/group of mooring lines fail.
Type of analysis	All require dynamic analysis for permanent moorings, with time domain and frequency domain being acceptable. ISO19901-7 and IEC-TS-62600-10 also allow for quasi-static approach. NS9415 also allows for both static and quasi-static approach, with corresponding escalation applied to the load factors.	An FSPV array may be composed of several hundred mooring lines, with the array dimension in the order of km's. The floats have only a few centimetres draught and are hinged, consequently the complete structure has flexibility. These factors mean that a traditional rigid body dynamic analysis may not be appropriate and may be too computationally intensive e.g., to undertake in the time domain. The NS9415 offers the option for static and quasi-static mooring analysis with corresponding escalation applied to load factors, which is attractive for FSPV.

Description of requirement		Commentary
Return period	DNV-ST-0119 and NS9415 require 50yr extremes, typically 50yr waves with associated wind and current. Note if 50yr wind (with associated wave and current) or 50yr current (with associated wind and wave) is more critical this shall be considered. ISO19901-7, IEC-TS-62600-10 and API-RP-2SK require 100-year extremes considering the following combinations: a. The 100-year waves with associated winds and currents b. The 100-year wind with associated waves and currents c. The 100-year current with associated wave and wind	100-year return period is applicable to O&G offshore FPUs and MOUs. 50-year return period is better suited to floating renewables application.
Safety factors	ISO-19901-7, IEC-TS-62600-10 and API-RP-2SK safety factors are paired with 100yr return period and are applied considering total force/tension: ▪ Safety factor for mooring line tension: intact 1.67; damaged 1.25 ▪ Safety factor for drag anchor: intact 1.50; damaged 1.00 ▪ Safety factor for suction/pile/gravity anchor: intact 1.60; damaged 1.20 ▪ Safety factor for fatigue for chain and six strand wire is 3.00 (increase applies if bending fatigue is present)	Most technical standards cover the range of mooring lines and anchor equipment expected for FSPV application. NS9415 also distinguishes material factors for different line types (e.g., chain and synthetic). This is relevant and recommended for FSPV where there may be more variability in mooring line type reliability due to the large number of lines manufactured and installed. An FSPV array may be composed of several hundred mooring lines, therefore it is unavoidable to have significant uncertainties with FSPV mooring systems (e.g., anchor position, line pretension, bathymetry, different mooring make-ups between lines, uncertainties in metocean conditions, etc.). Such uncertainties, which are particular to FSPV, are not accounted for by the existing safety factors described here.
	DNV-ST-0119 partial safety factors are paired with 50yr return period and are applied considering mean and dynamic tension for the mooring line, and total for the anchor: ▪ Safety factor for mooring line tension (consequence class 1): intact mean 1.30/ intact dyn 1.75; damaged mean 1.00/ damaged dyn 1.10 ▪ Safety factor for mooring line tension (consequence class 2): intact mean 1.50/ intact dyn 2.20; damaged mean 1.00/ damaged dyn 1.25 ▪ Material factor for drag anchor: intact 1.30; damaged 1.00 ▪ Material factor for suction/pile/gravity anchor: intact 1.30; damaged 1.20	

	Description of requirement	Commentary
	▪ Safety factor for fatigue (consequence class 1): 5 ▪ Safety factor for fatigue (consequence class 2): 10 (increase applies if bending fatigue is present)	
	NS9415 safety factors are paired with 50yr return period and are applied considering total force/ tension. Total safety factor is the load factor * material factors. ▪ Load factors ◆ 1.60 for static analysis; ◆ 1.15* Dynamic amplification factor (DAF) for quasi-static analysis ≥1.1 and the choice of DAV value shall be justified and documented) ◆ 1.15 for dynamic analysis. ▪ Material factors ◆ 2.0 for chain and shackles; ◆ 3.0 for synthetics and rock bolts; ◆ 5.0 for used chain and synthetics with knots ▪ The holding power of the anchor shall exceed the dimensioning force in the mooring line ▪ Safety factor for fatigue is 5.00 (increase applies if bending fatigue is present)	
Env. Loading	Wind loading applied as fluctuating 1 hour mean plus time-varying component calculated from a suitable empirical wind gust spectrum. Alternatively, wind load applied as constant 1 min average. Waves defined by Hs and Tp with appropriate spectrum. The wave height versus wave period relationships for the design sea state should be accurately determined from oceanographic data for the area of operation. For fatigue analysis, the long-term joint distribution of wave heights and periods (scatter diagram) is required, and a single best estimate of the associated wave period can be used for each sea state. Current should consider combined effect of tidal currents, circulation currents (loop and eddy currents), storm-generated currents, and soliton currents as applicable. The speed and direction of the current at different elevations should be specified.	In addition to wind, wave, current and water depth variation load effects, FSPV should also consider waterbed movement and scour, and earthquake loading. DNV's Recommended Practice DNV-RP-0584 and DNV-RP-C205 can be further referred for detailed understanding of impact of environmental loads on design and also for different water bodies. In general snow/ice accretion should also be considered, which may impact draught and therefore hydrodynamic loading, though this may not be applicable for the Indian context.

Description of requirement		Commentary
	The design water depth for the mooring system should account for sea level variations due to tides, storm surges, and seafloor subsidence, if applicable.	
Corrosion	All have requirement of about 0.4 mm corrosion allowance per service year in the splash zone and in the dip or thrash zone on hard bottom, though for ISO19901-7 corrosion and wear allowance for these locations is given as a range (0.2 mm to 0.8 mm). For the remaining length API-RP-2SK and ISO19901-7 have 0.1 mm to 0.2 mm per service year, and DNV-ST-0119 has 0.3 mm per service year (for regular inspections). DNV has more stringent requirements for the splash zone and touchdown point for the Norwegian Continental shelf and tropical locations.	For FSPV application in fresh/brackish water in-land, the corrosion type and profile will be different to the experience from seawater application.
Marine growth	The type and accumulation rate of marine growth at the design site may affect weight, hydrodynamic diameters, and drag coefficients of vessel members and mooring lines should be taken into consideration in the design. All have requirement for inclusion of marine growth in the mooring analysis. DNV provides some general guidance for recommended values.	N/A - guidance is suitable for FSPV application.
Survey	Site investigation survey to determine local wind, wave, and current conditions. For permanent moorings, bottom soil conditions should be determined for the intended site to provide data for the anchoring system design especially in case of tidal or sifting seabed. Shape of the seafloor should be properly accounted for in the mooring analysis. A bottom hazard survey should be performed.	N/A - guidance is suitable for FSPV application.
Installation	After installation, the mooring should be test loaded to ensure adequate holding capacity of the anchoring system, eliminate slack in the grounded portion of the mooring lines, detect damage to the mooring components during installation, and ensure that the mooring line's inverse catenary is sufficiently formed to prevent unacceptable mooring line slacking due to additional inverse catenary cut-in during storm conditions.	An FSPV array may be composed of several hundred mooring lines which may make load testing all the lines prohibitively expensive. The as laid/post-installation survey is recommended. This survey provides the basis for undertaking future mooring integrity management decisions and is essential to create a risk-based framework to inspections (see inspection).

Description of requirement		Commentary
	ISO, IEC and API require that for permanent moorings with drag anchors, the mooring lines should be test loaded to at least 80% of the maximum storm load determined by a dynamic mooring analysis for the intact condition. For pile anchors and suction caissons, a test load should be determined based on the consideration of eliminating the slack in the grounded mooring lines, forming reverse catenary in the mooring line below the seafloor, and detecting damage to the mooring components during installation. Duration of the test load should be at least 15 minutes. DNV requires that the anchor installation loads tension shall be equal to the extreme line tension based on an environment with a 100 year return period considering both ULS and ALS. Norsok does not have any requirement for load testing of anchors. DNV and Norsok require post-installation surveys (also referred to as-laid survey), for example 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 it shall be verified that the change has not led to significant weakening of the mooring (through the as-laid analysis). DNV also requires an expanded first annual survey after the bed-in phase considering that within a year in operation the mooring system has settled, lines have settled in seabed, trenching, if this is an issue, will now clearly appear and other deficiencies like component misalignments and twists should be visible. DNV-ST-N001 has special requirements for managing the risk of marine operations and technical requirements for mooring line installation (e.g. proximity to other floating or subsea assets, etc.).	Shallow water may introduce additional load testing and survey challenges due to the vessel size, associated winch capacity and DP limitations.
Monitoring	API, ISO and DNV standards require that moored floating units should be equipped with a system for monitoring the position of the vessel and mooring line failure detection system. For moored floating where operations require mooring line adjustment, units should be equipped with a system for measuring mooring line pay-out. It is advised that moored floating units should be equipped with a calibrated system for measuring mooring line tensions.	An FSPV array may be composed of several hundred mooring lines which may make tension monitoring on all the lines prohibitively expensive, and it would be challenging to ensure reliability on all hundreds of tension monitoring sensors on each array. Tension monitoring sensors on selected critical lines in the system may be considered.

Description of requirement		Commentary
Inspection	All have requirement for regular inspection program which is essential to monitor the integrity of the moorings. API chain discard criteria is 10% reduction in MBS. API-RP-2MIM provides risk-based framework to develop, evaluate, plan, and implement a mooring integrity management program for the unit. DNV has specific survey requirements given in the Offshore Class rules: ▪ Annual survey which consists of documentation review and General Visual Inspection (GVI) of above-water components (e.g., top chains, wire ropes visible from inboard the facility, winches/windlasses, deck sheaves, etc.). ▪ Complete 5-year survey which consists of the annual survey scope, GVI of complete mooring system (e.g., looking for anomalies such as damage, local loss of marine growth, corrosion, misalignment, twists, and trenching) and Close Visual Inspection (CVI) + measurement of key components including underwater connectors etc. and representative portion of mooring line.	Regular inspection of mooring lines in water may be prohibitively expensive, considering a solar farm may consist of several arrays, each with hundreds of mooring lines. Annual GVI of above water parts may be feasible (e.g., undertake a walk-around the floats and record observations). 5-year inspection of complete mooring system including underwater parts may be too demanding on Operating expense (OPEX). A risk-based inspection framework is required, which aims to optimize the frequency and scope of inspection to balance cost with component failure risk, where we differentiate risk based on location and component. Less frequent or no inspection at low-risk regions and more frequent inspection and possibly measurement at higher risk. This means available inspection resources can be utilized more efficiently than for a purely prescriptive approach leading to greater reliability and OPEX reduction. It does require a management system and to have competence in moorings and risk analysis. Installation survey is essential to form the basis against which the condition can be compared in subsequent inspections.
Maintenance	Mooring systems are typically designed for 25 years design life with preferably minimal intervention. As such the mooring system should have sufficient fatigue capacity for the full design life. In some cases, mooring line change-out operations are required (e.g., localised corrosion in chain above assumed design criteria) and change-out criteria including the component level specifications are developed on a case-by-case basis and verified by the Classification Society (if classed). Therefore, there are no standard industry technical requirements with regards to mooring component change-outs. Marine procedures for change-out operations are developed on a case-by-case basis and comply with regulatory requirements (e.g., safety, responsibilities, refreshment windows etc.) and component level Class requirements (if classed).	FSPV in-land/inshore locations are more accessible than offshore locations therefore maintenance/mooring component change-out may be a more feasible strategy with regards to OPEX. For example, if the water depth is within limitations for standard diving operations it may be more feasible to plan for component replacement (e.g., every 10 years) than if in water depths that would require a remotely operated underwater vehicle.

5.2.3. Gaps in Technical Standards

The checklist below provides the key gaps based on the review of the technical standards.

TABLE 5.4: Gaps identified in technical standards of anchoring and mooring when adopted for floating solar plant

Design principles	Main gaps
Basis for design analysis of FSPV mooring system efficiently	FSPV arrays may be composed of several hundred mooring lines. This makes the traditional approach for mooring analysis of permanent moorings (by time domain dynamic analysis) challenging with regards to computational effort required. It would be favourable that options are available to enable mooring designers to undertake mooring analysis in more efficient ways, e.g., quasi-static analysis with appropriately calibrated safety factors. Due to the scale of the array and number of lines installed per array, significant uncertainties are expected with FSPV mooring systems (e.g., anchor position, line pretension, bathymetry, different mooring make-ups between lines, uncertainties in metocean conditions, etc.). These uncertainties can significantly impact the mooring loads (e.g., un-balanced pretension leads to poor load distribution between mooring lines) hence it is essential that the mooring analysis addresses these uncertainties. A basis for undertaking FSPV mooring analysis efficiently will enable mooring designers to study the uncertainties as well as studying various damage scenarios. At present the technical standards require consideration of only one line failure, which is questionable whether this requirement adequately reflects a mooring damage event of significance for FSPV.
Alignment of technical standards return period (e.g., to 50 years)	100yr return period is applicable to O&G offshore FPUs and MOUs. 50yr return period is better suited to floating renewables application, whilst some FSPV mooring designers in India are using 25yr return period (for wind based on IS 875-3 (1987): Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 3: Wind Loads).
Alignment of technical standards on material factors	Only NS9415 distinguishes material factors for different types of line type (e.g., chain and synthetic). This is relevant and recommended for FSPV where there may be more variability in mooring line type reliability due to the large number of lines manufactured and installed.
Additional load effects for FSPV	In addition to wind, wave, current and water depth variation load effects, FSPV should also consider waterbed movement and scour, and earthquake loading.
Recommendations for chain corrosion allowance for FSPV locations	For FSPV application in fresh/brackish water in-land, the corrosion type and profile will be different to the experience from seawater application.

Other areas for improvement of industry guidance which can help accelerate the commercialisation of FSPV mooring are suggested below:

TABLE 5.5: Suggested areas of improvement during installation and O&M phase of Anchoring and Mooring

Areas	Suggested improvement
Installation	**Alignment on requirement for as laid survey** The as laid/post-installation survey is recommended. This survey provides the basis for undertaking future mooring integrity management decisions and is essential to create a risk-based framework to inspections.
Inspection	**Guidance on risk-based inspection framework for FSPV** Regular inspection of mooring lines in water may be prohibitively expensive, considering a solar farm may consist of several arrays, each with hundreds of mooring lines. Annual GVI of above water parts may be feasible (e.g., undertake a walk-around the floats and record observations). A risk-based inspection framework is required.
Maintenance	**Guidance for maintenance** For certain FSPV in-land/inshore locations which are accessible and have water depth within limitations for standard diving operations it may be commercially feasible to plan for maintenance/mooring component change-out. More industry guidance and requirements for this are required (e.g., component procurement, testing and quality assurance, installation and service vessel requirements, crew competency, positioning requirements, requirements for inspection contractors, emergency response management, change management, etc.).

6. INVERTER

6 INVERTER

6.1. Inverter Technologies

The inverter is the component of the PV system that converts the DC electricity produced by the PV array into Alternating Current (AC) electricity for the utility grid. It implements a maximum power point tracking (MPPT) algorithm that draws the maximum power from the connected PV array. The inverter also provides the interface to the utility grid including functionality for meeting power quality requirements and safety.

Broadly, the inverters can be classified into two categories:

1. **String Inverters:** These are the inverters with direct DC string input from the PV array, as the name suggests. Typically, these inverters are rated from 1 kW to 250 kW and have a maximum system voltage rating of 1000 V or 1500 V. String inverters typically have multiple MPPTs, thereby resulting in better tracking of current and voltage of the PV arrays exposed to dissimilar conditions.
2. **Central Inverters:** These are inverters with connection from multiple DC combiner boxes which combine the PV strings. Typically, these inverters are rated from 500 kW to 5000 kW and have a maximum system voltage rating of 1000 V or 1500 V. Central inverters typically have a single MPPT.

The following table presents the comparison of string and central inverters considering utility scale solar application:

TABLE 6.1: Inverter comparison

Design Aspect	String Inverter	Central Inverter
Visualization *[Source:* [8]*]*		

Design Aspect	String Inverter	Central Inverter
Rating	1 kW to 250 kW	500 kW to 5000 kW
No. of MPPTs	Multiple	Single
Grounding	Ungrounded (floating) system	Grounded system
Typical DC Cabling Loss	0.7%	1.5%
Typical AC Cabling Loss	1%	0.5%
Labour Cost	Higher	Lower
Material Cost	Higher	Lower
Energy Output	Comparatively lower	Comparatively higher
Redundancy of system	High	Low
Warranty & Service	Typically, 5 years replacement warranty, not serviceable on-site	Typically, 5 years on-site repair/ replacement warranty

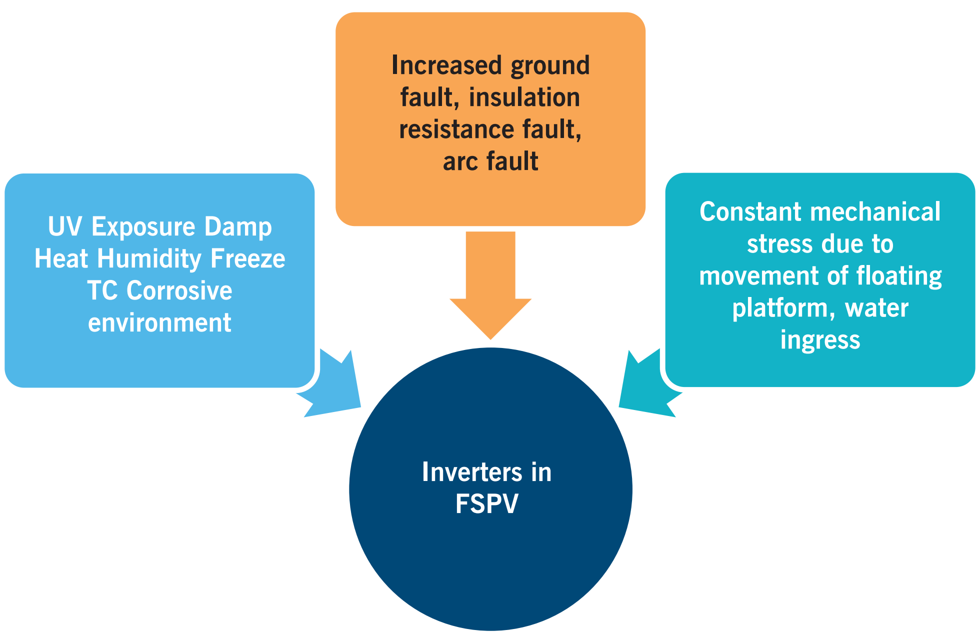
Apart from these mainstream inverters, module-level inverters have been recently introduced in the market. Micro-inverters and power optimizers monitor the module performance at individual module level rather than system level. Such module level equipment assists in reducing module mismatch losses. However, these inverters are yet to become cost-competitive with the central and string inverters.

6.2. Specific Considerations for FSPV

The inverters can be subjected to the following conditions in a FSPV installation as depicted below.

In case of floating solar application, the inverters along with the transformer and switchgear equipment may also be located on

FIGURE 6.1: Major issues with inverters in FSPV



the floating structure near the PV array. Hence, the inverters should be designed for wet and humid environment and also to withstand the wind speeds at site. As the floats would be in motion on the water surface, additional mechanical stress should be considered for the design of components and cable terminations. The ingress protection (IP) class of inverter shall be IP55 or higher for floating installations. Suitable provisions to avoid splashing of water on inverter should be made, if mandated by the manufacturer. Paints and coatings for the inverter enclosure/container should be considered keeping in mind the risk of corrosion. The cable entry should be kept at the bottom side of the inverter to avoid moisture ingress.

TABLE 6.2: Challenges with Inverters for floating solar environment

Parameter	Issue	Mitigation
Environment	Inverters used in FSPV application are subject to additional mechanical stress due to the cyclic motion on water surface.	The vibration tests which are presently defined for inverter in IEC 62093 is focused on vibrations occurring during shipping and transportation. As the vibrations induced due to cyclic motion could be different, a suitable test criterion would need to be defined considering the site conditions.
Environment	Inverters may be subject to higher electromagnetic interference. Some of the activities in waterbodies are fishing by local community, inland waterways, recreational activities like boating and adventure sports, sea airplanes services etc. Depending on the activity, there is a possibility that radio or microwave frequency for communication and navigational purposes like radar and GPS may be used in the vicinity of the project site.	The Electromagnetic interference (EMI) and Electromagnetic Compatibility (EMC) of the inverter shall be suitably evaluated considering the factors specified. Also, the water body owner can be consulted to understand planned recreational activity or inland waterways in future.
Protection features	Inverters used in FSPV application have high susceptibility to insulation resistance faults, ground and arc faults. Most of the inverters available in the market do not offer arc fault protection as a default.	Though the following protection features are not enforced by any local or national code presently, it is to be ensured that inverters for FSPV application are provided with: ▪ Residual current monitoring device ▪ Insulation resistance monitoring ▪ Arc fault protection ▪ Anti PID kit
Water ingress	Inverters used in floating solar application; especially central inverters require a dedicated separate island with raised platform to avoid splashing of water.	IP rating of enclosures and internal electronic components should be minimum IP55. Handrails can be installed along the periphery of the barges where inverters will be installed. Additionally, barricades using metallic sheet may be provided to further avoid splashing or water entering the inverter floating platform.

Parameter	Issue	Mitigation
Water condensation	For installation in marine environment external air intake for ventilation will result in exposure of components to humid or moist air. Depending on ambient temperature condensation may occur. Inverter enclosures can be made corrosion resistant suitable for withstanding marine environment.	Extended DH cyclic test as per IEC 62093 with RH>95% can be conducted to determine any condensation inside the enclosures at the end of test. Inverters supplied for floating applications shall be installed with space heaters, dehumidifiers, and RH sensors. Additionally, silica gel desiccant may also be placed inside the inverter enclosure which can aid in moisture absorption but need to be regularly inspected during routine maintenance. Inverter enclosures (both inside and outside) and the cooling fan shall be given corrosion resistant coating and choice of material can also be done to suit the site environment. The circuit boards shall be given conformal coating.

6.3. Review of Existing Technical Standards

6.3.1. Overview of Technical Standards

TABLE 6.3: List of key technical standards for Inverters

Standards	Title
Institute of Electrical and Electronics Engineers (IEEE) 1547 1547	Standard for Interconnecting Distributed Resources with Electric Power Systems
IEC 61439-1 & 2	Low-voltage switchgear and control gear assemblies
IEC 62109-1 & 2	Safety of power converters for use in PV power systems
IEC 62116	Utility-interconnected PV inverters - Test procedure of islanding prevention measures
IEC 61683	Procedure for measuring efficiency
IEC 61000-6-2 & 4	EMC
IEC 62477 Add on	Safety requirements for power electronic converter systems and equipment
IEC 61727 Add on	Characteristics of utility interface
IEC 62093 Add on	BoS Components for PV systems - Design qualification natural environments
IEC 62208 Add on	Empty enclosures for low-voltage switchgear and control gear assemblies – General requirements
IEC 62262	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (Impact Protection or IK code)
IEC 62920 Add on	PV power generating systems - EMC requirements and test methods for power conversion equipment

6.3.2. Evaluation of Technical Standards

TABLE 6.4: Key observations on technical standards of inverters

Stress Factor	Standard	Requirement as per standard	Remarks
UV Exposure	IEC 62093	7.5 kWh/m² in the wavelength range between 280 nanometer (nm) and 320 nm, and 15 kWh/m² in the wavelength range between 320 nm and 400 nm. Equipment under test shall be maintained at 60°C ± 5°C dry condition.	The most critical side will be mounted facing the UV source. And 10% of irradiation level shall be applicable for back side.
TC	IEC 62093	For outdoor unprotected inverters TC from +85°C to -20°C for 250 cycles is specified. The minimum dwell time at each temperature extremities are 10 min and the maximum ramp rate for time rise and down time is 100°C/hr.	This test is performed to test the ability to withstand thermal fatigue and stress due to repeated temperature changes. Each cycle shall be of six hours minimum. Current continuity is checked throughout the test.
DH test	IEC 62093	For outdoor unprotected environment, the test duration is 1000 hrs at + 85°C, 85% RH. For outdoor unprotected equipment DH cyclic test at RH>95% for three cycles of 12 hrs each, with the inverter in load condition.	The test is performed to determine the ability of inverter to withstand effects of long-term penetration of humidity. The cyclic tests are performed to inspect any condensation inside the enclosure.
HF	IEC 62093	10 cycles from +85°C, 85% RH to –20°C (no RH at low temperature). Typical dwell time for the high temperature is 20 h and 30 mins for low temperature. The ramp rate for increase/decrease temperature is 100°C/hr.	This test induces 54 hermos mechanical stress on the internal components. Current continuity is checked throughout the test.
Shipping vibration	IEC 62093	This test is in turn referred from IEC 60068-2-6: ▪ Frequency range: 10 hertz (Hz) to 11,8 Hz; 11,9 Hz to 150 Hz, ▪ Constant amplitude: 3.5 millimeter (mm) ▪ Constant acceleration: 2 Earth gravity (g) ▪ Cycling: 1 octave/min ▪ Duration on each axis: 2 hr ▪ Total test duration: 6 hr	To simulate conditions of vibration during transportation. Tests are done on the inverter unit and not on the package itself. The inverter is not energized, and continuity checks are not performed.
Shock test	IEC 62093	This test is in turn referred from IEC 60068-2-27: ▪ Amplitude of acceleration: 15 g ▪ Type of shock: half-sine ▪ Duration of shock: 11 millisecond (ms) ▪ Sequence of shocks: 1 second (s) ▪ Number of shocks: 18 (6 × 3)	To simulate conditions of any impact during transportation. Tests are done on the inverter unit and not on the package itself. The inverter is not energized in this test.

Stress Factor	Standard	Requirement as per standard	Remarks
Mechanical impact	IEC 62262/IEC 62208	The impact energy applied shall be three times the impact energy for enclosures with dimension less than 1 meter (m) and five times the energy for dimensions more than 1 m.	This test is generally performed on empty enclosures and not on the complete assembly.

6.3.3. Gaps in Technical Standards

As specified for PV modules, the inverter testing can be made sequential and extended reliability tests can be undertaken. The following table tabulates the gaps identified in technical standards for application in floating solar plants.

TABLE 6.5: Applicability of technical standards of Inverters in floating environment

Parameter	Limitations and Recommendations
Extended reliability tests	Duration of reliability tests like UV exposure can be increased. Corrosion test is not part of the recommended test in the standard. A sequential test plan for inverter wherein the same inverters will undergo series of tests is not currently practised. Combination of corrosion tests like salt mist test as per IEC 60068-2-52 with other reliability tests like DH test, TC can be defined.
Developing mechanical load test to make it suitable for floating environment	IEC 62093- vibration test and shock test are primarily intended to simulate the conditions occurring during transportation. The tests do not cover the forces (e.g., effect of waves) experienced by inverters in floating installations. Also, the inverters are not maintained in load condition during test which may not be the case for FSPV application.
Electromagnetic compatibility and interference (EMC/ EMI)	The IEC standards against which the inverters are tested for EMC/EMI are basically for ground mount-based installations considering interferences from radio wave, microwave for mobile communication and interference with some equipment or appliances used in household or industries. For marine environment, the compatibility and interference are not yet established for the inverters available in the market presently. Suitable offshore standards for EMC/EMI of power electronics components shall be adopted for inverters and the testing capability of the same needs to be developed in the country.
Fire resistance	Presently most of the inverters available in the market are not compliant with respect to resistance to fire, fire propagation in horizontal/vertical direction. Compliance to these standards can be made mandatory for inverters installed in floating solar plants.
Testing Infrastructure	To perform reliability and durability tests for large size inverter, a large environmental chamber will be required. Presently there are only a few facilities across the world to carry out such tests for large inverters. Some inverter manufacturers have environmental test facility, but they are not open for third party testing. The test lab of inverter manufacturer is generally not accredited with any agency like NABL as is the expected norm in India. Most of the tests for ensuring protection features of inverter are performed in a simulated environment which may not be representative of the actual site conditions.

7. BALANCE OF SYSTEM

7 BALANCE OF SYSTEM

7.1. Combiner Box

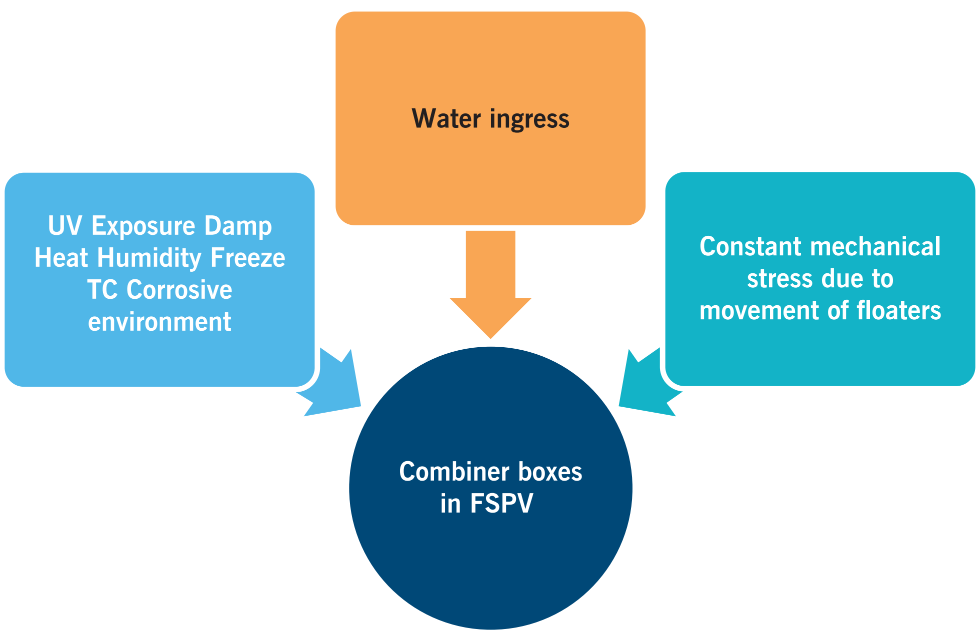
In a central inverter system, DC combiner boxes are used to combine multiple strings into one output which is then connected to the inverter input. In a string inverter system, AC combiner box would be used to combine outputs of multiple string inverters into one single AC evacuation point.

Typical enclosure materials used for combiner boxes are FRP, polycarbonate, polyamide and galvanised iron (GI) sheet metals. Polycarbonate has the best durability for external applications and has better fire and chemical resistivity compared to its other polymer and metal-based peers.

7.1.1. Specific Considerations for FSPV

For floating solar applications, the combiner boxes can be subjected to the following conditions as depicted below.

FIGURE 7.1: Major issues with combiner boxes in FSPV



The challenges with combiner boxes and possible mitigation measures have been elaborated on next page.

TABLE 7.1: Challenges with combiner boxes for floating solar environment

Parameter	Issue	Mitigation
Environment	Material degradation or physical damage to its integrity may occur if the combiner box is not properly designed to withstand the UV exposure, DH, humidity and mechanical stresses.	Extended reliability test shall be considered for combiner boxes in FSPV application. Combiner boxes with UV exposure rating of >2000 hrs can be considered.
Combiner box material and build quality	String combiner boxes are not specifically built to be installed over a lake/reservoir or in a marine environment where it may operate under much more pronounced DH and humid conditions.	Polycarbonate based enclosures can be readily used for marine environments and it offers good durability. Protective covers or small canopy arrangement can be provided to reduce direct exposure to UV and solar irradiation to some extent.
Water Ingress	Combiner boxes in case of FSPV applications are subject to water ingress through water splashes or partial immersion.	It is recommended that the combiner boxes are provided with bottom entry cable design to avoid water stagnation. The installation height of the combiner boxes shall be sufficient and should be greater than the minimum bending radius of respective cables terminated in it. Minimum IP65 rated enclosures shall be used for these applications.
Insulation protection	For floating solar application, the combiner boxes are installed over the HDPE floats near to PV modules or walkway.	Cables are recommended to be installed through cable trays or through conduit pipes with enough slack to avoid stress on the combiner box.
Fire resistance	Since the floating solar plant constitutes much equipment like HDPE floaters, cables etc. which are flammable, the combiner boxes are susceptible to fire incidents.	Combiner boxes shall have adequate fire resistance and shall not aid in propagation of fire in horizontal and vertical direction. Compliance to UL94 standard can be verified prior to use.

7.1.2. Review of Technical Standards

The current standards available are based on experience from onshore applications. So, these standards should be used as a starting point, and more rigorous tests should be performed (including water intrusion tests) based on the application and learnings from the field.

7.1.2.1. Overview of Technical Standards

TABLE 7.2: List of key technical standards for combiner boxes

Standards	Title
IEC 61439-1 & 2	Low-voltage switchgear and control gear assemblies
IEC 62208 Add on	Empty enclosures for low-voltage switchgear and control gear assemblies –General requirements
IEC 62093 Add on	BoS Components for PV systems - Design qualification natural environments

Standards	Title
IEC 60364 Add on	Low-voltage electrical installations
IEC 62548 Add on	PV arrays - Design requirements
UL 94	Tests for Flammability of Plastic Materials for Parts in Devices and Appliances
IEC 62262	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)

7.1.2.2. Evaluation of Technical Standards

IEC 62093 is common standard which covers the reliability tests related to BoS components like Inverters and combiner/junction boxes. The evaluation of IEC 62093 made in subsection 6.3.2 can be referred for further details.

7.1.2.3. Gaps in Technical Standards

The following are the gaps identified in the technical standards governing combiner boxes.

TABLE 7.3: Applicability of technical standards of combiner boxes in floating environment

Parameter	Limitations and Recommendations
Extended reliability tests	Duration of reliability tests like UV exposure can be increased. Corrosion test is not part of the recommended test in the standard. A sequential test plan wherein the same combiner boxes will undergo series of tests is not currently practised. Developing a sequential test plan with series of stress tests like combination of corrosion tests like salt mist test as per IEC 60068-2-52 with other tests like DH test, TC can be undertaken.
Developing mechanical load test to make it suitable for floating environment	IEC 62093- vibration test and shock test are primarily intended to simulate the conditions met during transportation. The tests do not cover the forces experienced by combiner boxes in floating installations.

7.2. Cables and Accessories

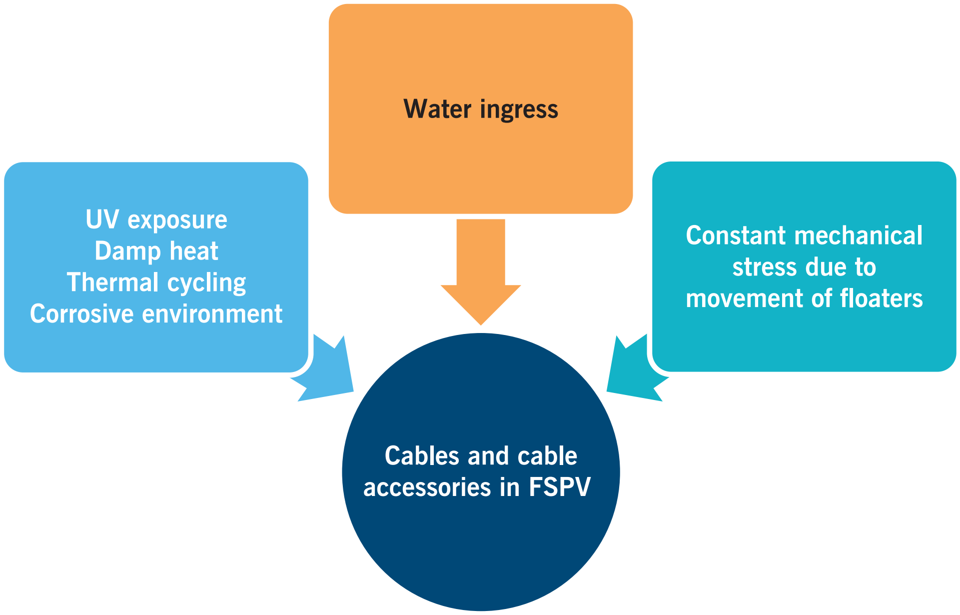
Cross-linked polyethylene (XLPE/XLPO) insulation with Copper/Aluminium conductor is preferred for DC/AC Low voltage/Medium voltage (LV&MV) cables. Direct laying of cables on the floaters will expose the cables to a humid environment and solar irradiation apart from mechanical forces. The cables should be aptly designed for such conditions and should be hydrolysis resistant, UV resistant, flame resistant/retardant and armoured for mechanical strength as a minimum

Presently, Nylon and Polyamide are the most common materials used for cable glands, cable ties and MC4 connectors. Depending on indoor or outdoor installation, GI sheet metal, HDPE or FRP are commonly used for cable cleats, cable conduits and cable trays. Nylon and polycarbonate have excellent resistance to UV and has good material durability for operating in a marine environment.

7.2.1. Specific Considerations for FSPV

Unlike ground mount systems, cable has specific challenges in a floating solar plant.

FIGURE 7.2: Major issues with cables and accessories in FSPV



The challenges and issues relevant to cables in floating applications are listed in **Table 7.4** along with possible mitigation measures.

TABLE 7.4: Challenges with cables and cable accessories for floating solar environment

Parameter	Issue	Mitigation
Environment	Cables in FSPV installations are in continuous contact with the water surface. As the inverters have ground fault detection, even minor protective sheath damage can result in frequent ground fault errors in the damp environment, leading to system interruptions.	For submerged installation in water, marine grade cables are recommended to be used. Specially designed XLPE cables are also available for such installations. Use of water blocking tapes also help to prevent the progression of water into the cable in case of insulation damages or faults. Floating cables shall be suitably protected by flexible conduits or covered cable trays. The insulation of cables should be UV stabilized and should be hydrolysis resistant and flame retardant.
Cable routing	Movement of floaters result in mechanical stress on the cables.	For DC/AC cables many floater manufacturers provide grooves in the floaters or a floater path to route the cables. It is recommended to route the cables on separate floats and not along the walkway with provision for enough slack to avoid tension. Routing of cables through flexible conduits or cable trays fitted on floats (preferably covered) can also be beneficial.

Parameter	Issue	Mitigation
Water ingress	Water ingress is a major issue with cable accessories in floating solar installations	IP68 rated connectors are recommended considering the possibility of immersion in water. Appropriate materials should be used for lugs, washers, nuts and bolts. Compatibility of lugs with the material of conductor of cables is to be ensured. If Copper lugs are to be used, tin plating is recommended. A periodic check of the tightness of connections should be mandatorily included in the maintenance plan.
Mechanical stress on cable and cable accessories	Due to cyclic movement caused by waves there will be mechanical stress acting on the cable and accessories.	Appropriate slack can be left for cables which will reduce the stress. The mechanical stress test conditions may be re-evaluated for floating solar applications. While deriving technical specification for cable glands, cleats and lugs the safety factor for pull forces can be developed/evolved based on modelling and field experiences.

7.2.2. Review of Technical Standards

7.2.2.1. Overview of Technical Standards

Standards that are applicable to cables to be installed in air or ground are also applicable for cables to be installed on floaters.

TABLE 7.5: List of key technical standards for cables and cable accessories

Standards	Title
IEC 62930 Add on	Electric cables for PV systems with a voltage rating of 1.5 kilovolt (kV) DC
IS 7098	Crosslinked Polyethylene Insulated. Thermoplastics Sheathed Cables
IEC 63026 Add on	Submarine power cables with extruded insulation and their accessories for rated voltages from 6 kV (Um = 7.2 kV) up to 60 kV (Um = 72.5 kV) - Test methods and requirements
IEC 60068	Environmental testing
IEC 60364 Add on	Low-voltage electrical installations
IEC 62444 Add on	Cable glands for electrical installations
IEC 61537	Cable management - Cable tray systems and cable ladder systems
IEC 61914 Add on	Cable cleats for electrical installations
IEC 62275 Add on	Cable management systems - Cable ties for electrical installations
IEC 61238-1 all parts (cable lugs) Add on	Compression and mechanical connectors for power cables - Part 1-3: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages above 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) tested on non-insulated conductors
IEC 62852 Add on	Connectors for DC-application in PV systems - Safety requirements and tests
IEC 60183 Add on	Guidance for the selection of high-voltage A.C. cable systems

7.2.2.2. Evaluation of Technical Standards

TABLE 7.6: Key observations on technical standards of cables and accessories

Stress Factor	Standard	Requirement as per standard	Remarks
Environmental factors for cables	IEC 62930	UV, Vibration, Ozone resistance, DH, Smoke tests and assessment of halogen for all non-metallic materials for low smoke halogen free cables is covered.	While it is specified in the standard that cables can be used in corrosive environments where intermittent or accidental subjection to corrosive or polluting substances is possible, the cables are not rated for continuous use in corrosive environment. Test requirements for corrosion like salt mist or ammonia corrosion etc. are not covered in this standard.
Environmental factors for cable accessories- Cable glands	IEC 62444	Corrosion tests, mechanical tests like cable retention, anchor test are covered.	Cable glands rated as per IEC 62444 is passive to EMC & EMI. Generally, IP65 rating or more can be specified for the glands. Corrosion test is specified for steel only and non-metallic materials like nylon, polyamide, polycarbonate etc are not covered under the corrosion tests. UV exposure, DH, HF tests are not specified.
Environmental factors for cable accessories- Cable tray and ladder systems	IEC 61537	The cable trays and accessories made of metallic (steel) materials are specified for corrosion protection by galvanization. The standard covers requirement of resistance to fire propagation for metallic materials.	Corrosion protection requirements and resistance to fire propagation is not covered for other non-metallic or composite materials. UV exposure and operation for marine or offshore environment is not specifically covered in the standard.
Environmental factors for cable accessories- Cable cleats and intermediate restraints	IEC 61914	The tests for lateral and axial retention are specified to check the integrity of the cleat. The loads are considered to be uniform and applied for a period of 1 hour. The pass criterion is mandrel movement less than 50% on lateral load and less than 5mm in axial load test. Adequate resistance to flame propagation as per IEC 60695-11-5 shall be applicable for non-metallic and composite materials.	UV exposure test is covered for various materials. Corrosion test and salt spray test are covered for metallic components.

Stress Factor	Standard	Requirement as per standard	Remarks
Environmental factors for cable accessories- Cable ties	IEC 62275	Cable ties: metallic, non-metallic, or composite complying to this standard should having the following features: 1. Passive to EMC & EMI 2. Adequate resistance to flame propagation 3. Resistance to corrosion and UV exposure.	1000 hours of UV testing is covered under this standard. 192 hours of salt spray test is undertaken for testing corrosion resistance.
Environmental factors for cable accessories- MC4 connectors	IEC 62852	Two types of tests for contact corrosion are covered under this standard for corrosive environment. DH test covered is similar to IEC 61215. Temperature rise test is also specified.	UV exposure test and TC are not covered in the standard.
Environmental factors for cable accessories- Cable lugs	IEC 61238-1 all parts	With respect to reliability and environmental conditions only mechanical tests are covered. 1000 heat cycle tests are specified.	The standards recommend additional test for installation in environments where connector is raised to high temperature and external mechanical stresses like vibration and corrosion.

7.2.2.3. Gaps in Technical Standards

TABLE 7.7: Applicability of technical standards of Cables and Cable accessories in floating environment

Parameter	Limitations and Recommendations
Reliability test for cable accessories	UV exposure test for cable glands and MC4 connectors is not covered in their respective standards. Corrosion tests for non-metallic and composite materials are not covered for cable, cable cleats and cable tray in their respective standards.
Cable retention test for IEC 61238-1 all parts (lugs), IEC 61914 (cleats and intermediate restraints) and IEC 62444 (glands)	The pull forces for cable retention and cable anchorages for armoured and unarmoured cables is primarily derived for application in land-based environment. The cables, cable glands, and lugs in FSPV may experience additional mechanical stress due to cyclic motion from waves and water level variation may also increase the mechanical stress leading to development of fatigue overtime. Vibration test can be added along with mechanical stress test as this will represent a realistic operating condition for these components. The aforementioned tests can be developed to test the cable under electrical load conditions, as this will provide insights on the overall safety of the cables and its accessories.
IEC 61914 (cleats and intermediate restraints)	Smoke emission and toxicity is not presently considered in the standard since its mentioned in standard that typically cable cleats are small in size and less in quantity. For PV modules a large number of cleats shall be required. Since the installation is in marine environment the details of smoke toxicity and interaction with local environment shall be considered.

7.3. Transformers

Transformers are critical components in the solar PV installations that "step-up" voltage in the plant in two levels from low voltage output of inverter (typically 400 V-800 V) to medium voltage level (typically 11/33 kV) (Inverter Duty Transformer) and from medium voltage level to grid interconnection level (typically 66/132/220 kV) (Power transformers).

The different types of transformers are presented in **Table 7.8**. In FSPV installations, the transformer can be supplied as an independent unit or as part of an enclosed compact substation.

TABLE 7.8: Types of transformers

Transformer Type	Brief description	Visualization [Source: Schneider Electric]	Remarks
Hermetically sealed type	Hermetically sealed transformers are said to be maintenance free transformers as the dielectric insulating fluid in it is completely sealed, thereby experiencing zero contact with the atmosphere. Expansion of the oil is compensated with fins radiator. These transformers tend to be costlier and have high repair cost.		These transformers are suitable for FSPV application considering reduced risk of oil spillage, safety and low maintenance aspects.
Sealed type with gas (N2) cushion	These transformers are partially filled with oil and are filled with inert gas (typically Nitrogen) in the space above the oil. This allows not only for the expansion of oil but also prevents oxidization of the oil. However, these transformers will require continuous supply of inert gas and monitoring of air pressure.		These transformers need high maintenance and hence are difficult to use in FSPV applications.
Breathing type with conservator	Oil immersed transformers with breathers have a conservator tank on top of the main tank to allow for oil expansion. However, oil in this case is continuously exposed to air. Oxidization of oil is prevented using silica gel.		Transformers in FSPV application being exposed to high humidity, these transformers may not be ideal. Use of natural oils like ester oil will reduce impact on waterbody in case of spillage.

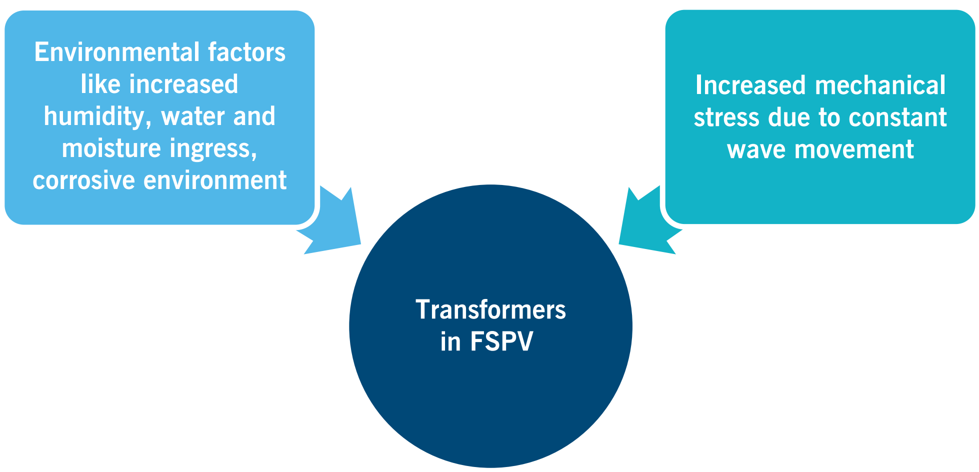
Transformer Type	Brief description	Visualization [Source: Schneider Electric]	Remarks
Dry type	These transformers do not use any insulating liquid and use air as the cooling medium.		These transformers tend to be bigger in size compared to oil filled transformers, less efficient, noisier, costlier and have lesser life which might limit its use in FSPV applications.

7.3.1. Specific Considerations for FSPV

The installation of transformers can be done either on land adjacent to the waterbody or on rafts/barges. If the installation is done on water, sufficient clearances need to be maintained for maintenance access.

For floating solar applications, the transformers can be subjected to the following conditions as depicted below.

FIGURE 7.3: Major issues with transformers in FSPV



Specific issues pertaining to transformers in floating solar installations and their mitigation measures are provided below.

TABLE 7.9: Challenges with Transformers for floating solar environment

Parameter	Issue	Mitigation
Environment	Transformers in FSPV are prone to corrosion due to the high humidity.	For an offshore application, specifically C5-M atmospheric corrosivity category can be specified as per ISO 12944-2, and for inland lakes, the corrosivity category needs to be decided depending on the site location. Stainless steel could be used for parts like radiator fins, instruments, nameplates, and hardware.

Parameter	Issue	Mitigation
		Use of a fully enclosed substation has advantages in terms of minimized exposure of the transformer to the environment.
Protection	Seepage of oil into the water body might affect the marine life and water quality.	Hermetically sealed oil-filled transformers with natural oils which is environment friendly can be considered. Dry type transformers with special construction could also be explored in very specific cases.
Water ingress	Transformers placed offshore are prone to water ingress due to splashes.	It is recommended to have suitable clearance from water surface to prevent splashes.
Design	Transformers in offshore applications are subject to additional stress due to movement of the floats.	The mechanical design of the transformer should ensure the desired operation of the transformer in the foreseen installation conditions where it is constantly subjected to hydrodynamic forces. Floater layout is to be designed such that sufficient space for maintenance access is provided. Movement of transformer floater may be brought down by having increased mooring and anchoring. Some dampeners arrangement may be added to reduce the mechanical stress due to vibration. Nitrogen injection fire protection systems (NIFPS) can be installed as needed. Supervisory control and data acquisition based connectivity to monitor parameters like Winding Temperature Indicator, Oil Temperature Indicator, Detection of Gas, Pressure and Temperature and oil level can be provided.
Breakdown voltage of Bushing	In offshore environment where salt deposition is expected to happen, a phase to ground fault is highly probable.	Breakdown voltage of bushing may be increased, and the creepage distance may be chosen adequately. For MV transformers, cable boxes on LV & MV side for cable terminations can be considered with IP65 and above, to prevent salt deposition on bushing.

7.3.2. Evaluation and Gap Analysis of Technical Standards

TABLE 7.10: List of key technical standards for Transformers

Standards	Title
IEC 60076	Power transformers – Parts: 1, 2, 3, 4, 5, 7, 8, 10, 10-1, 11, 12, 13, 14 and 20
IS 2026 series	Power transformers

The commonly referred standards like IEC/IS specifically catered to land based installations. There are presently no standards which can be referred for offshore floating installations.

7.4. Earthing and Lightning Protection

The grounding of a solar plant is vital for the protection of the equipment and operational safety. Compared to ground mount installations, the earthing and lightning protection for floating solar is complicated and is still evolving to determine a best practice. Presently there are three techniques which are being followed as depicted below.

Shore based

- Earthing connections of various equipments from the floating island are taken to the shore and are earthed using conventional practice.

Sea/River bed based earth pits

- The earthing connections are taken under water to dedicated earth pits which are located on the river/sea beds.

Using earth electrodes suspended in water at certain depths

- In this technique the water body is used as ground path. The earth electrodes are suspended in the water and any leakage current is dissipated in water. This method poses risk for personnel and marine life and also requires precise data related to the historical water conductivity and the variation of conductivity with respect to depth and temperature of water.

The earthing design shall always be based on a risk assessment and shall consider the different floating technologies used. It would be advisable to create an equipotential earthing grid at different inverter locations and for floater blocks. This equipotential ring should be connected to multiple earthing rods determined by calculation. The water and the exposed conductive parts of the solar installation shall not have a potential difference which can be a hazard for human or animal life.

Lightning protection of a floating solar plant is very vital as in a ground mounted plant. It is typical in solar plants to use Early Streamer Emission (ESE) based Lightning Arrester (LA) for lightning protection. All conductive paths are recommended to be equipotential bonded and connected to earth.

7.4.1. Specific Considerations for FSPV

TABLE 7.11: Challenges with Earthing and Lightning protection system for floating solar plant

Parameter	Issue	Mitigation
Environment	Electrodes are susceptible to corrosion in the marine environment.	Earth flats or electrodes used shall be corrosion free or have suitable allowance for corrosion considering the marine environment. The welded and bolted joints of the earthing strip shall be suitable for marine environment where water immersion or contact with water will be frequent or permanent. Also, the bolted joints shall consist of similar or compatible materials, to avoid galvanic corrosion.

Parameter	Issue	Mitigation
		ESE based LA shall be used for DC field lightning protection as per NFC 17-102. The air terminal, down conductors and the lightning pole shall be corrosion resistant and suitable for operation in marine environment. Lightning risk assessment can be carried out specific to the site as per IEC 62305.
Mechanical stress	Earthing cables/electrodes in FSPV application are subject to stress due to movement of floats.	Earthing strips should be designed and installed in such a way that any lateral or vertical movement of the floaters do not stress the connection points and damage the cables/strips.
Water quality	Corrosion of earthing electrodes may potentially affect the water quality.	Impact of the earthing electrodes on water quality must be assessed.
Earthing underwater	For earthing using earth pits in seabed or riverbed, the earth strips or electrodes needs to be taken down till the bed level. Some of the issues in using this approach are: ▪ The mooring lines may allow some displacement of the floating island under hydrodynamic forces. This lateral movement may add mechanical stress on the suspended earth strips. ▪ Variation in water level may add mechanical stress to the earth strips. ▪ Historical record of earth resistivity of the seabed or riverbed. There are chances that sedimentation may occur, which may alter the earth resistivity.	Clarity can be sought from relevant authorities regarding underwater earthing. Strategy to be developed for periodic inspection of earthing electrodes and earth pits.

7.4.2. Evaluation and Gap Analysis of Technical Standards

The following standards can be referred to for designing the earthing and lightning protection.

TABLE 7.12: Key technical standards for Earthing and Lightning protection systems

Standards	Title
IS 3043	Code of practice for earthing
IEC 60364 [Add on]	Low-voltage electrical installations
IEC 62548 [Add on]	PV arrays - Design requirements
IEC 61936 [Add on]	Power installations exceeding 1 kV AC
IEEE 80	Guide for Safety in AC Substation Grounding
NFC 17-102 [Add on]	Protection against Lightning - Early Streamer Emission Lightning Protection Systems
IEC 62305 [Add on]	Protection against lightning

The standards mentioned above are particularly devised for guiding the earthing design in ground mount-based installations. There are no national or international standards available for earthing of floating solar plant. There is also lack of clarity in the acceptance of underwater earthing or suspended earth electrode under water from the statutory bodies.

8. ENERGY YIELD ASSESSMENT

8 ENERGY YIELD ASSESSMENT

This section covers the brief of EYA approach for floating solar project in comparison to ground mounted project.

TABLE 8.1: Key approach to EYA methodology for FSPV

Section of EYA	Approach
Solar resource assessment	Existing approach of using most representative long-term satellite-based data can be adopted. If site measured data is available, site adaption can be undertaken to improve the accuracy.
Technology selection	Technology selection process of PV modules and Inverters does not change much between the ground mount installation and floating solar installation. Specific considerations for floating solar applications are provided in section 2 and 3.
Optical losses	Optical losses like Incidence Angle Modifier (IAM), shading loss (near & far shading) and soiling losses shall be based on the similar approach used for ground mount installation. IAM loss shall be dependent on module BOM like glass type and the Anti-Reflective Coating (ARC). Far shading will be based on local condition of any obstruction and near shading shall depend on system engineering considerations. Soiling losses depend on the local conditions like dusty environment, frequency of module cleaning planned, annual rainfall data, proximity to avian migratory paths etc. In general, soiling losses due to bird droppings can be significant in floating solar projects compared to ground mount systems.
Loss parameters	Loss parameters estimation shall be based on the similar considerations applied for ground mount systems depending on module technology, inverter technology and engineering consideration, except the temperature loss variation due to cooling effect in floating environment and wave mismatch. **Wave induced mismatch** For FSPV systems, string mismatch and PV module mismatch due to float motions from waves and water current shall be considered. Wave-induced mismatch will occur when the PV modules in one string or multiple strings connected to one inverter are tilted at different angles and/or oriented at different azimuths due to wave movement. Changing the tilt angle and/or azimuth will affect the global in-plane irradiance received by the PV module. As a result, each PV module in the string may exhibit different voltage and current characteristics, and thereby introduce an additional mismatch loss. In order to understand the mismatch losses incurred when a PV module or string of PV modules are positioned at different relative angles, it is recommended to run a batch of simulations varying the azimuth and tilt over a given interval to gain an understanding of how the system may respond to different magnitudes of wave motion.

Section of EYA	Approach
	Rigidity of the structure, mooring and anchoring solution may have an impact on the expected change in PV module azimuth and tilt angles due to wave motions. This may have the effect of reducing or increasing the wave-induced mismatch losses. As floating structure size (single body or multi-body) and float connection types (steel/plastic and flexible/solid) may have material impact on wave-induced mismatch, additional care should be taken when assessing wave-induced mismatch on annual energy estimates. **Module temperature and cooling effect** The temperature coefficient of power for a given PV module expresses the reduction of module output power with increasing module temperature. The temperature of the module is typically calculated from its thermal balance. The thermal behaviour of the field, which strongly influences electrical performance, is determined by a thermal balance between the ambient temperature and the cell heating, due to incident irradiation. Depending on the main equipment float structure coverage of solar panels on back side, the air circulation behind the solar panels can be determined. For higher coverage of more than 65%~70% there will be low air flow under the modules due to the presence of floater structure and low tilt and not much decrease in module temperature losses can be expected. **Module Degradation** Presently there is limited long-term data available for analysing FPV performance degradation, and when sufficient long-term data is available, it might be relevant to apply a different degradation methodology compared to ground-mounted PV. DNV also recommends collecting onsite data by in-situ measurement techniques like flash test or IV curve tracing method which may later be applied to the EYA.
Uncertainty analysis	Typical EYA shall consider the following parameters for the uncertainties: ▪ Resource uncertainty (for satellite data and on-site measurements) ▪ Solar resource variability (yearly variability for irradiance) ▪ Soiling variability (yearly variability for soiling) ▪ Model uncertainty (uncertainty for model inputs) Additionally, for FSPV related uncertainties the following specific attributes can be considered: ▪ Wave induced mismatch ▪ Change of azimuth due to water current ▪ Thermal loss factors

9. HEALTH, SAFETY AND ENVIRONMENT (HSE)

9 HEALTH, SAFETY AND ENVIRONMENT (HSE)

9.1. General

The HSE recommendations presented in this section is based on the DNV's Recommended practice through the Joint Industry Project for floating solar. As a minimum, the following site-specific documents shall be developed covering the risks in FSPV projects:

- HSE Risk assessment
- HSE Management plan
- Fire safety plan
- Lifting plan for works requiring equipment to be lifted

9.2. Hazard Identification and Risk Assessment

The project specific HSE risk assessment shall cover various risks encountered in activities related to plant installation, commissioning, operations and maintenance of each equipment, with activities broken down to task level to identify appropriate mitigation measures. Various risks identified shall be documented and consolidated into the HSE management plan. The fire safety plan and lifting plan shall also be developed and made part of HSE management plan. The HSE management plan shall be implemented by the Engineering, procurement, and construction/O&M and all contractors or sub-contractors working at the FSPV site.

HSE risk assessments shall be conducted using appropriate methodologies such as failure mode and effects analysis (as per IEC 60812), bowtie analysis, or equivalent alternatives. Complementary processes which may be used to implement the HSE risk assessment include hazard and operability study (as per IEC 61882) and hazard identification (as per ISO 17776). Guidance on risk mitigation measures may be applied as per the European Union Directive 2016/425 or the American Occupational Safety and Health Administration Standard 1926 on personal protective equipment.

9.3. Walkways

The floats with function of walkways shall provide enough width to allow workers to move without difficulty to carry equipment and parts. Walkways should be clearly indicated with physical markers (e.g., stickers) that prevent workers from setting foot on fragile elements of the installation. The walkways shall have adequate anti-slip surfaces. It is recommended to avoid cavities within or in close proximity of the walkways in order to prevent stumbling or accidental falls.

9.4. General Health and Safety Recommendations

For all personnel working at site, it is to be ensured that life vests are always worn, and workers shall never work alone. Properly trained and certified divers should be considered for installation. All personnel should have a swimming certification and lifebuoys should be positioned throughout the FSPV array. Risk of drowning and injury shall be mitigated with supervision by trained personnel for performing first aid.

Communication systems within the floating platform and from the floating platform to shore shall always be available. Installation work, inspection or maintenance on the FSPV system shall be avoided during adverse conditions like high wind speed, thunderstorms, etc. A shelter for providing shade should be planned if the FSPV system location is expected to present high ambient temperatures.

10. BIBLIOGRAPHY

10 BIBLIOGRAPHY

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APPENDIX

APPENDIX A: LIST OF NABL ACCREDITED TEST LABS IN INDIA

NABL Link for accessing scope of accreditation of individual labs: https://nabl-india.org/nabl/index.php?c=searchlab&m=index&Itemid=177#

Sl. No.	Lab Name	Field	Address	Lab Id
1	MITSUI Chemicals India Pvt. Ltd. (Solar Pv Lab)	Solar PV modules	Plot 5 and 6, Swastik Industrial Estate Ahmedabad, Gujarat, INDIA	T-5176
2	Central Power Research Institute	Combiner box, Transformers	Regional Testing Laboratory (RTL) No. 3A, Institutional Area, Sector-62 Noida, Uttar Pradesh, INDIA	T-1980
3	Electrical Research & Testing Organisation	Testing	Plot No. 747; Manjusar Village Savli-Vadodara Road; Taluka: Savli, Vadodara Gujrat, INDIA	T-3560
4	Electrical Research and Development Association	Solar PV modules, Inverters, Combiner box, Transformers	ERDA Road, Makarpura Industrial Estate, Makarpura, Vadodara, Gujrat, INDIA	T-0099
5	TUV Rheinland (India) Private Limited	PV modules, Inverters, Combiner box, MC4 connectors	#27/B, 2nd Cross Road, Electronics City Phase1, Bengaluru, Karnataka, INDIA	T-1075
6	PV Test Facility, National Institute of Solar Energy	PV modules, Inverters	19th Milestone, Gurgaon-Faridabad Road, Gwalpahari, Gurgaon, Haryana, INDIA	T-1124
7	ACE Test Lab	PV modules, Inverters	Industrial Plot No.69, Kashra No-54, Opp. Jain Mandir G.T. Karnal Road, Nangli Poona Delhi, DelhI, INDIA	T-4995
8	Conformity Testing Labs Pvt. Ltd.	Inverter (only safety standard)	WH-52, Mayapuri Industrial Area, Phase-1 New Delhi, Delhi, INDIA	T-1957
9	Swen Konformity	Inverters, Combiner box	# Gokul RH 1 Sr. No. 22, Vishal Nagar Pimple Nilakh Pune, Maharashtra, INDIA	T-2501
10	Central Electronics Centre, Indian Institute of Technology-Madras	Inverter (efficiency measurements)	Chennai, TAMIL NADU, INDIA	T-0404
11	Electronics Regional Test Laboratory (North)	Inverter (efficiency measurements) EMC compatibility	S-Block, Okhla Industrial Area, Phase-II New Delhi, Delhi, INDIA	T-0014
12	Nisaki Technology Services	EMC compatibility	# 46, Park Road, 2nd Main, 10th Cross Wilson Garden, Bengaluru Rural, Karnataka, INDIA	T-1016
13	AA Electromagnetic test laboratory private limited	EMC compatibility	Plot No 174, Udyog Vihar, Phase 4, Sector 18, Gurgaon, Haryana, INDIA	T-4843
14	Electronics and Quality Development Centre	EMC compatibility	B 177/178, G.I.D.C. Electronics Estate, Sector-25, Gandhinagar, Gujrat, INDIA	T-0074
15	Electronics Regional Test Laboratory (West)	EMC compatibility	Plot No. F 7 & 8, MIDC Area, Andheri (East), Mumbai-City, Maharashtra, INDIA	T-0043

Sl. No.	Lab Name	Field	Address	Lab Id
16	Institute for Design of Electrical Measuring Instruments	Combiner box	Swatantryaveer Tatya Tope Marg, Chunabhatti, Sion, Mumbai, Maharashtra, INDIA	T-0774
17	International Centre for Automotive Technology	EMC compatibility	Plot No. 26, Sec-3, HSIDC, IMT Manesar, Gurugram, Haryana, INDIA	T-1392
18	Rishabh Testing and Calibration Laboratory	EMC compatibility	Rishabh Instrument Pvt Ltd, C-6 NICE Trishla Unit Nasik Satpur, Nashik Maharashtra, INDIA	T-4612
19	Tarang-Product Qualification and Compliance Planet, Wipro Technologies	EMC compatibility	Survey No. 70, 77, 78/8A, Dodda Kannelli, Sarjapur Road, Bengaluru, Karnataka, INDIA	T-1022
20	Yadav Measurements Private Limited	EMC compatibility	Plot No. 373-375, RIICO Bhamashah Industrial Area, Kaladwas, Udaipur Rajasthan, INDIA	T-0267
21	Transrail Lab, Transrail Lighting Limited	Combiner box	Survey No. 227/1/1/1/1/1, Village Kherdi, Khanvel Kherdi Road, Silvassa, Dadra and Nagar Haveli, INDIA	T-4807
22	Testing Laboratory, NSIC-Technical Services Centre (A Govt. of India Enterprise)	Combiner box	Japanigate, P.O. Balitikuri, Howrah West Bengal, INDIA	T-0601
23	Godrej busbar temperature rise & impulse test laboratory, Godrej & Boyce Mfg Co Ltd.	Combiner box	2D, KIADB Industrial Area, Bengaluru Karnataka, INDIA	T-4943
24	GIGA Labs, Schneider Electric Pvt. Ltd.	Combiner box	Sy. No. 63/38, Gorvigere Village, Bidarahalli Hobli, Bengaluru Urban Karnataka, INDIA	T-2528
25	C and I Calibrations Pvt. Ltd.	Transformers	J-448, Sitapura Industrial Area Jaipur, Rajasthan, INDIA	T-2152
26	CG Power and Industrial Solutions Limited, (Transformer Division)	Transformers	29, 31, 32, New Industrial Area, Mandideep, Raisen, Madhya Pradesh INDIA	T-2870
27	Ghaziabad Testing Laboratories Private Limited	Transformers	AO-150, Amrit Steel Compound, South Side, G.T. Road, Industrial Area, Ghaziabad, Uttar Pradesh, INDIA	T-1379
28	Mahati Electrical Testing Laboratory	Transformers	Gat No. 233 & 175/2, NH-9, Pune-Solapur Road, At & Post Yawat, Tal. Daund, Dist. Pune, Pune, Maharashtra, INDIA	T-3763
29	National High-Power Test Laboratory Pvt. Ltd.	Transformers	Powergrid Complex, 765/400 kV S/S, Khimlasa Road, Bina, Distt.-Sagar, Sagar, Madhya Pradesh, INDIA	T-3711
30	Transformer Testing Laboratory	Transformers	Raychem RPG (P) Limited, Gat No. 426/2B, Chakan-Talegaon Road, Mahalunge Village, Taluka Khed, Pune Maharashtra, INDIA	T-3336

Sl. No.	Lab Name	Field	Address	Lab Id
31	Transformer Testing Laboratory, Tesla Transformers Global Pvt. Ltd.	Transformers	Transformer Testing Laboratory Tesla Transformers Global Pvt. Ltd., Bhopal, Madhya Pradesh, INDIA	T-4392
32	Transformer Testing Laboratory-TBI, Schneider Electric Infrastructure Limited	Transformers	Milestone 87, Baroda-Halol Highway, Kotambi Village, PO Jarod, Vadodara, Gujrat, INDIA	T-1351
33	Ultra-High Voltage Research Laboratory, Central Power Research Institute	Transformers	Medipally PO, Hyderabad Telangana, INDIA	T-0126
34	Atmy Analytical Labs Pvt. Ltd.	Polymer materials	Plot No. I-30, DLF Industrial Area, Phase-1, Faridabad, Haryana, INDIA	T-1332
35	Enviro Remediation & Research Laboratory LLP	Polymer materials	Gala No. 7, Ground Floor, HDIL Industrial Park, Building No. 14. Chandansar, Virar East, Thane, Maharashtra, INDIA	T-2571
36	Faurecia Chennai test laboratory	Polymer materials	Plot No. 1,2,5,6 CMDA Industrial Complex Kanchipuram, Tamil Nadu, INDIA	T-4813
37	Intertek India Private Limited	Polymer materials	No. 607, 608, 6th Floor, TICEL Bio Park, Phase-II, CSIR Road, Taramani, Chennai Tamil Nadu, INDIA	T-2867
38	SGS India Private Limited, Testing Laboratory - Transportation, Consumer and Retail	Polymer materials	Gat. No. 624/2, Chakan, Kuruli, Taluka-Khed, Pune, Maharashtra, INDIA	T-1554
39	Trustin Analytical Solutions Pvt. Ltd.	Polymer materials	R.K. Complex, First Floor, Plot No. 303/B, 'B' Block, Thiruneermalai Road, Parvathy Puram, Chrompet, Chennai, Tamil Nadu, INDIA	T-3452
40	Central Institute of Plastics Engineering & Technology (CIPET)	Polymer materials, ESCR and mechanical tests for HDPE	Across India at multiple test labs	T-0141
41	UL India	PV modules & Inverters	Kalyani tech park, Bengaluru, Karnataka	

APPENDIX B: LIST OF STRUCTURAL RESEARCH AND TEST LABS IN INDIA

Sl. No.	Lab Name	Capabilities	Address
1	RWDI	Wind tunnel testing, CFD modelling, Wind and wave forecasting	KINFRA (IT/ITES), SEZ, KINFRA Film & Video Park, Sainik School, P.O. Kazhakoottam, Thiruvananthapuram, Kerala - 695585, India
2	National Aerospace Laboratories (NAL)	Structural design, analysis and testing, Structural dynamics and integrity	HAL Airport Road, Bengaluru - 560017, India
3	National wind tunnel facility (NWTF), IIT Kanpur	Wind tunnel testing	Aerospace Engineering, Indian Institute of Technology Kanpur - 208016
4	Department of Ocean Engineering, IIT Chennai	Wave basin, Random Wave Flume, Wave cum current Flume, Shallow water wave flume, Towing tank, Structural Testing Facility (loading frames, test beds, loading device), Marine Geotechnical Engineering Laboratory, Materials Laboratory for Ocean application	Indian Institute of Technology Madras, Chennai - 600036
5	IIT, Kharagpur	Vibration test, Structural Dynamics and Aeroelasticity, Bending test, Tensile and compressive test	Department of Aerospace Engg, IIT Kharagpur, Kharagpur - 721302, India
6	IIT, Kharagpur	Hydrodynamics laboratory, Hydroelastic analysis	Department of Ocean Engg. and Naval Architecture, IIT Kharagpur Kharagpur - 721302, India
7	National Institute of Ocean Technology (NIOT)	Marine sensors, Ocean structures	Velacherry-Tambaram Main Road, Narayanapuram, Pallikaranai, Chennai - 600100

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