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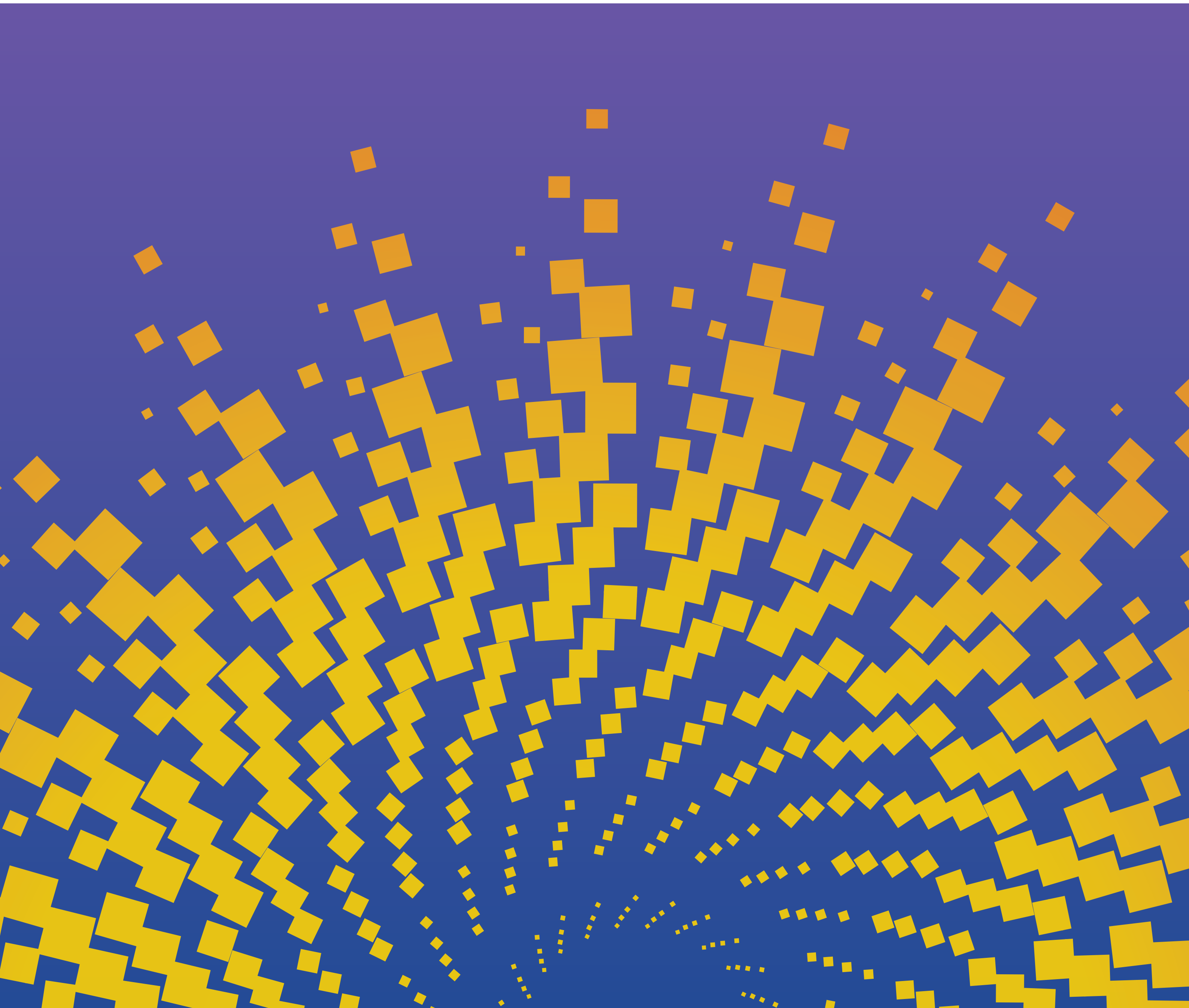
TECHNICAL STANDARDS FOR BALANCE OF SYSTEMS IN SOLAR PROJECTS



Concept

International Copper Association India and BRIDGE TO INDIA

Disclaimer

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Acronyms

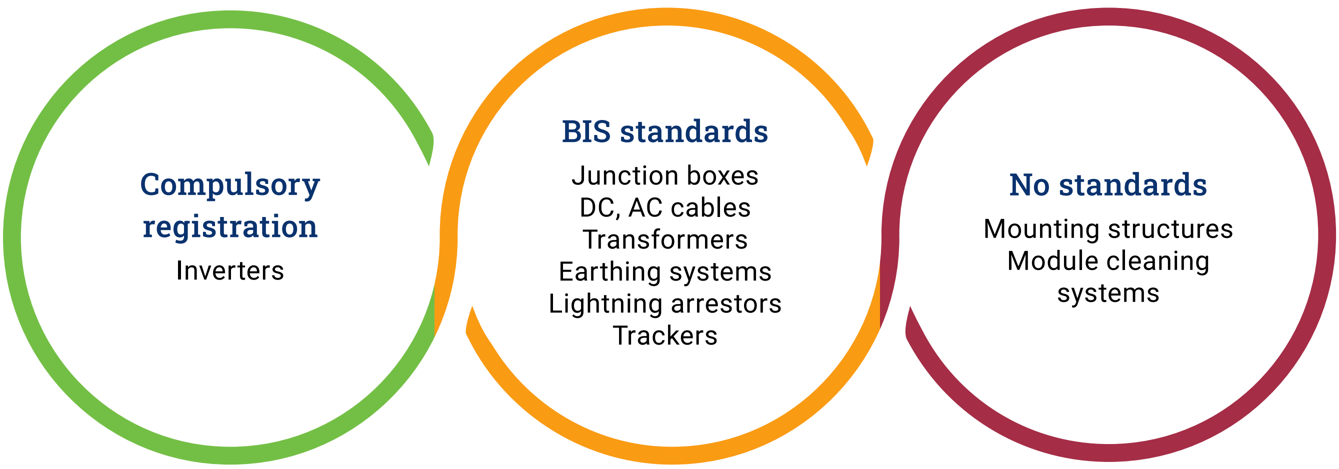
ALMM	Approved List of Models and Manufacturers
BIS	Bureau of Indian Standards
BOS	Balance of System
CEA	Central Electricity Authority
EPC	Engineering, procurement and construction
EHS	Environmental health and safety
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
IP	Ingress Protection
IS	Indian Standard
LCOE	Levellised Cost of Energy
MNRE	Ministry of New and Renewable Energy
O&M	Operation and Maintenance
PV	Photo Voltaic
RTV	Room Temperature Vulcanizing
SECI	Solar Energy Corporation of India

Executive summary

Solar power is one of India's biggest hopes in the fight against climate change. India has adopted ambitious target of building 280 GW solar capacity by 2030. The sector has accounted for nearly 50% share in total generation capacity addition in the last few years. Amid rapid growth prospects, accelerating technology changes and intense market competition, project developers and contractors face increasing commercial pressure to optimise capital cost.

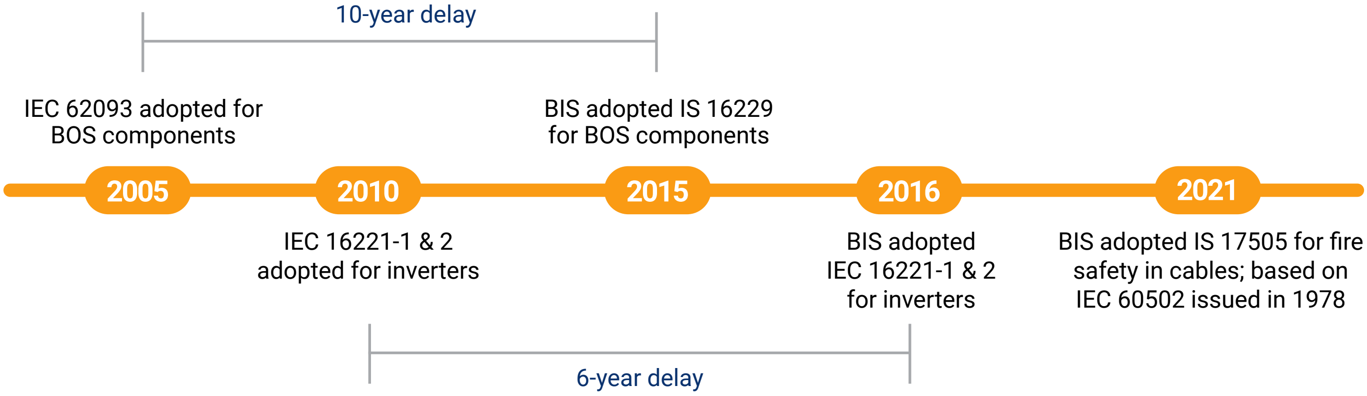
The government has introduced third-party certification for modules and inverters and issued an Approved List of Models and Manufacturers (ALMM) for approval of solar cells and modules. However, Balance of System (BOS) components lack standards for design, installation and O&M practices. There are no technical standards or guidelines for components like mounting structures and mechanised module cleaning systems and emerging technologies like floating solar.

Figure: Certification and standards for major BOS components



Developers increasingly adopt new and emerging technologies, like robotic module cleaning systems and trackers, to reduce levelised cost of energy. However, there is a significant lag (up to 10 years) in Bureau of Indian Standards (BIS) adopting technical standards for these equipment issued by international agencies like International Electrotechnical Commission (IEC).

Figure: Examples of delay in adoption of international standards by BIS



In absence of clear technical standards and certification regime, BOS components, including transformers, junction boxes, cables, mounting structures, module cleaning systems, earthing and lightning systems bear most of the brunt of cost cutting. It has been shown by several studies that faulty BOS equipment selection and installation, accounting for around 30% of solar project cost, has a disproportionate impact on power output.

Based on discussions with several industry experts, we have examined typical design and installation issues affecting individual BOS components and suggested solutions for the same. There is an obvious and urgent need for the government to widen the scope of technical standards and improve compliance. But we believe that there is also a considerable opportunity for the industry to engage with the government as well and adopt a set of voluntary best practices code to instil confidence in the sector.

Table: Key expectations from stakeholders

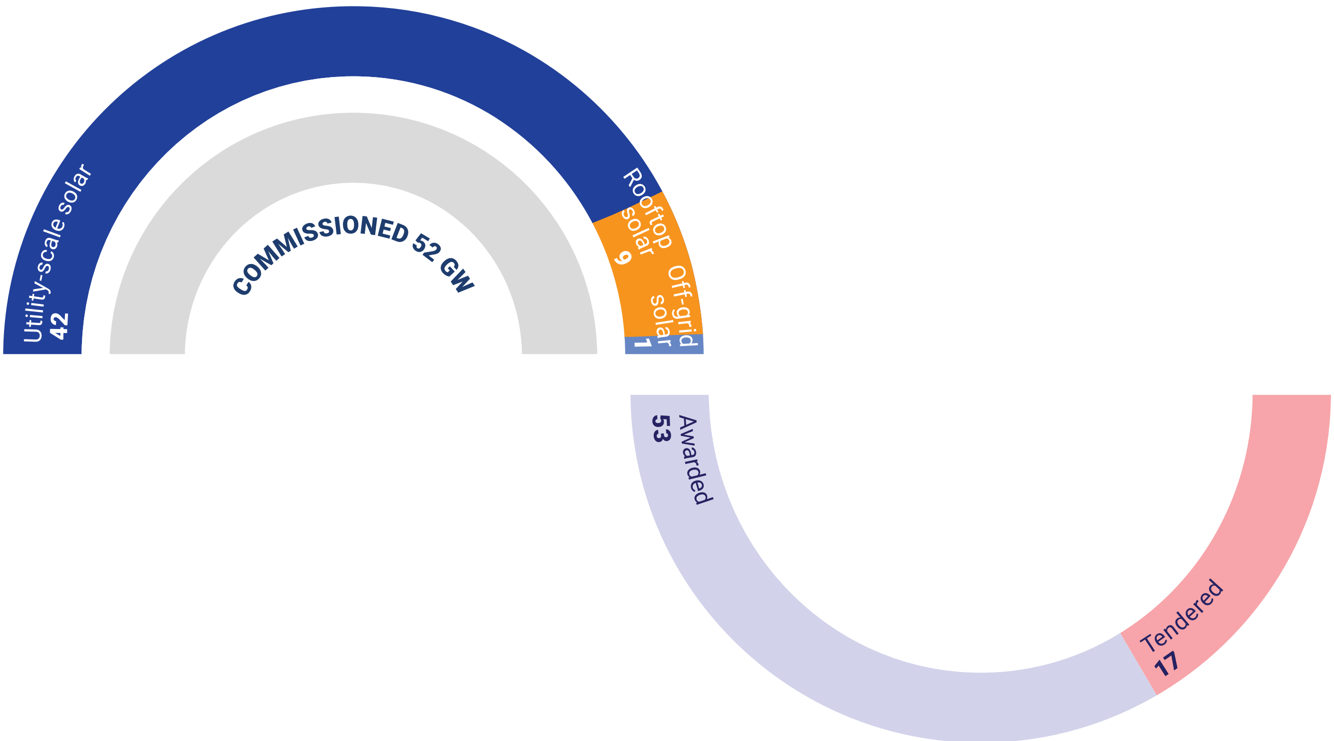
Standards agencies (BIS, CEA)	• Issue standards covering project design and selection of materials and components • Develop new standards or adapt existing standards to suit different ambient conditions including soil type, weather and wind speeds • Increase interaction with industry on project performance issues and latest technology trends for suitable amendment in standards • Fast track adoption of international standards
Industry associations	• Develop a platform for project developers, EPC contractors and equipment suppliers to share best practices and performance data • Identify and collate installation and O&M best practices for components with no standards – mounting structures, robotic cleaning, trackers • Develop repository of latest international standards for easy access by all stakeholders
Tendering agencies (SECI, state government)	• Specify detailed technical requirements in tender documents

1. Introduction

India has set a target to build 280 GW solar power capacity by 2030. By the end of 2021, 52 GW capacity had already been commissioned across utility scale and rooftop solar markets, another 53 GW was in different stages of implementation and 17 GW had been tendered awaiting results.

Figure 1: Solar power capacity as of December 2021, GW

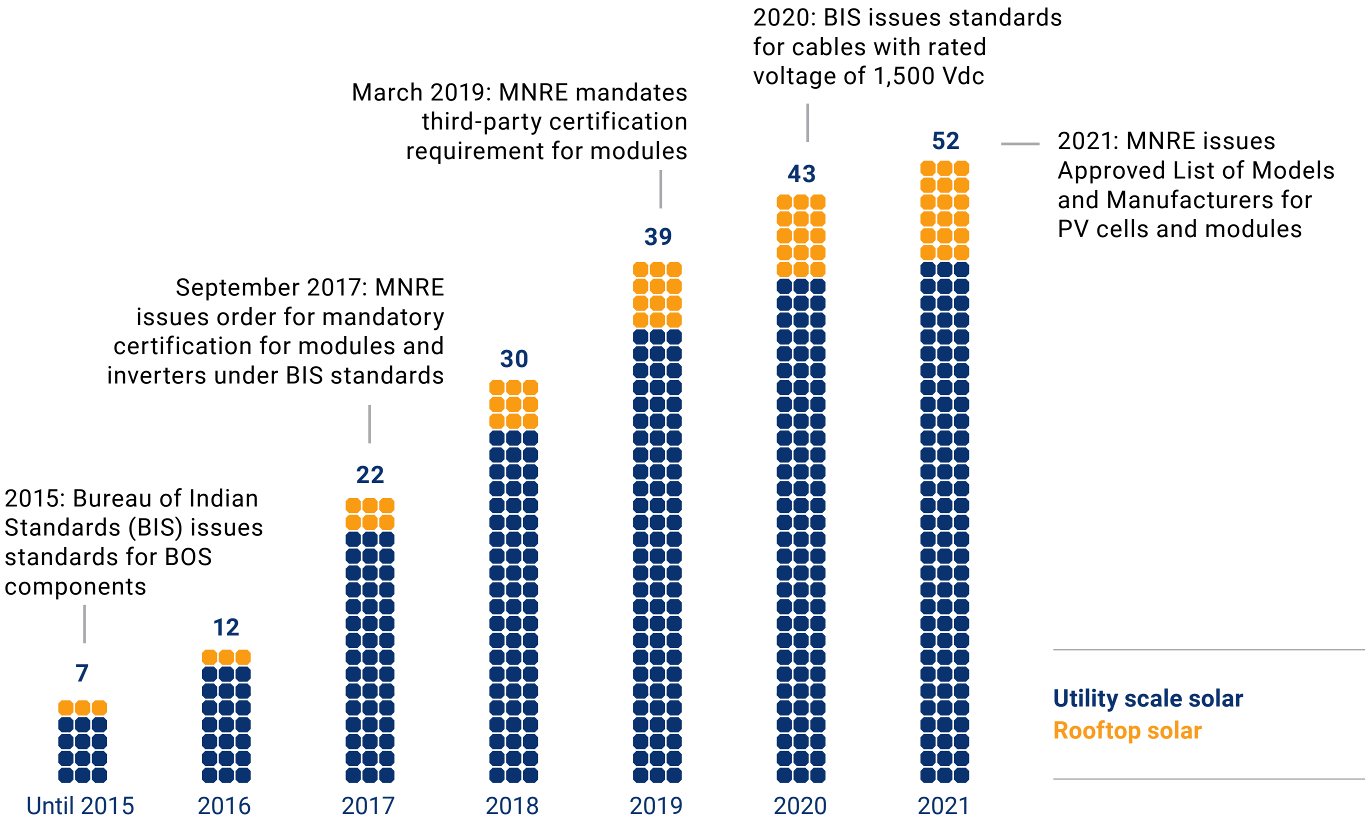
Total 122 GW



Source: BRIDGE TO INDIA research

As figure 2 shows, installed capacity has grown rapidly since 2016. High growth prospects in the sector have attracted many domestic and foreign companies making it extremely competitive. Average project tariff fell at 8.8% CAGR from INR 4.62/ kWh to INR 2.66/ kWh between 2016 and 2021 outpacing the 5.6% annual decline in EPC cost in the same period.

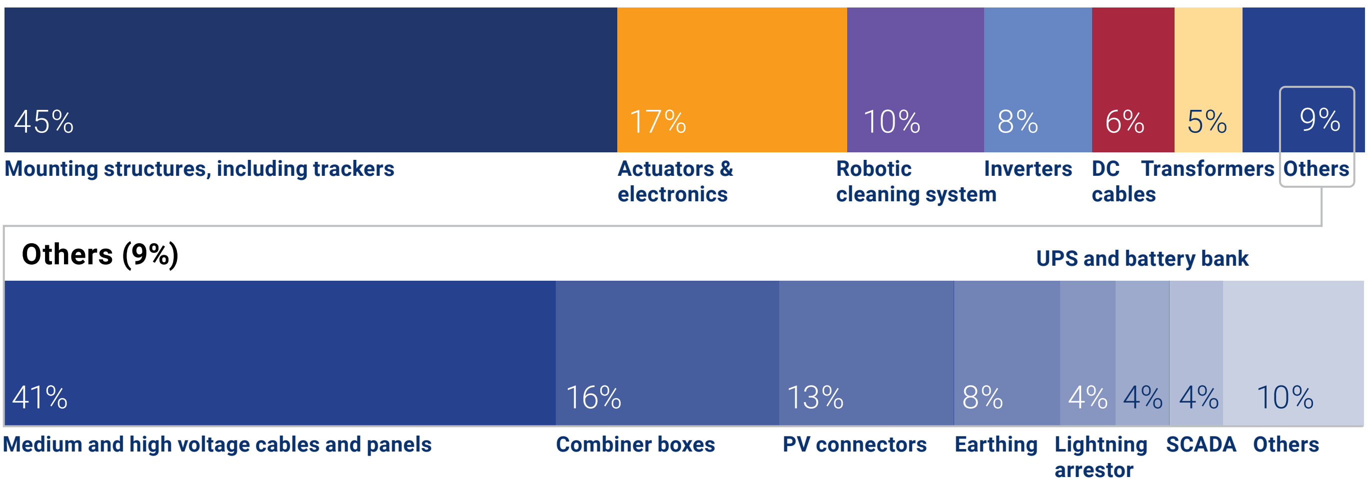
Figure 2: Total installed capacity, GW



Source: BRIDGE TO INDIA research

Figure 3 shows that cost of mounting structures and related electronic components, key target for cost optimisation is estimated INR 9.2 million per MWp - approximately 62% of total BOS cost.

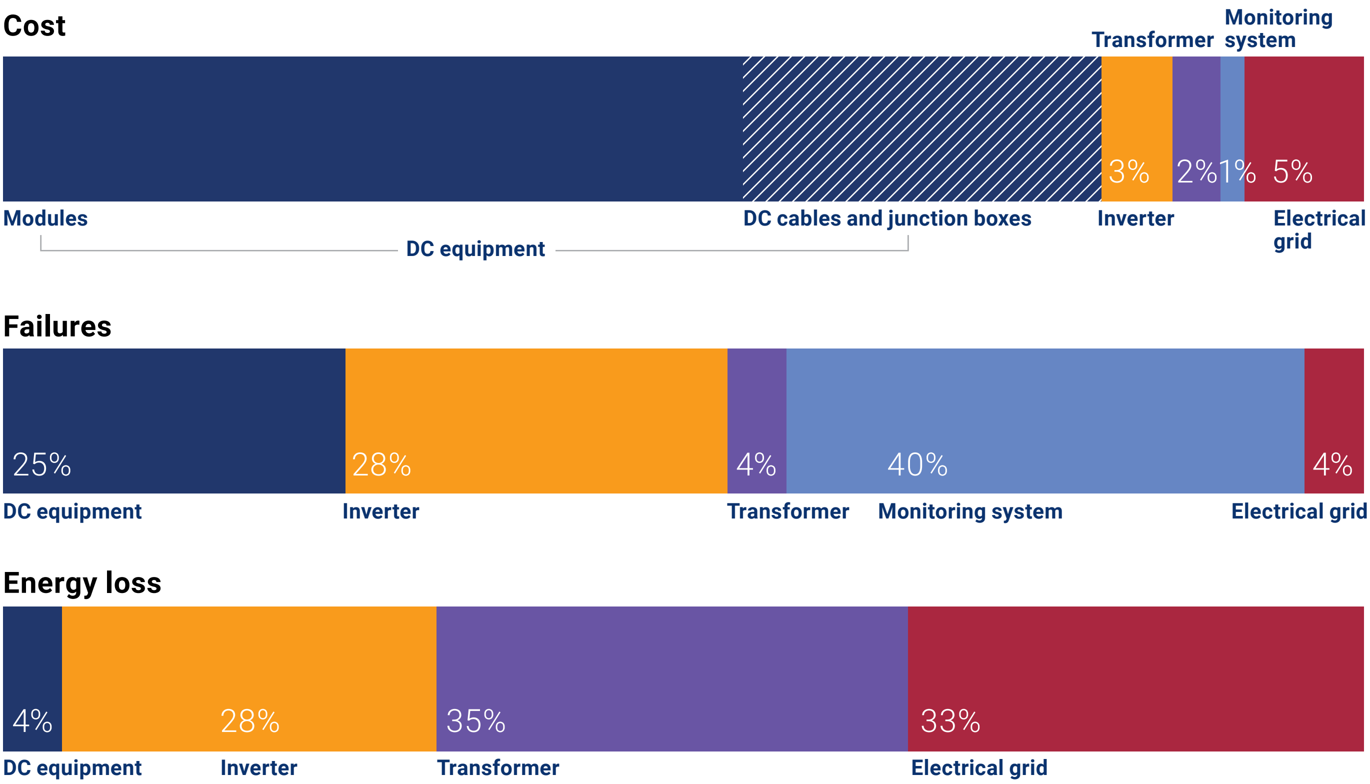
Figure 3: Cost of BOS components in a typical solar project



Source: BRIDGE TO INDIA research
Note: Cost is inclusive of import duties, GST and other taxes as applicable.

It has been proven in many international studies that BOS plays a critical role in optimal and safe operation of solar projects. There are no comprehensive studies on failure rates and energy losses in India but a study conducted in Spain and Italy shows that failure of BOS components accounts for the highest energy loss as shown in figure 4.

Figure 4: Equipment failure and resulting energy loss in typical solar projects



Source: 'Impact of Energy Losses Due to Failures on Photovoltaic Plant Energy Balance Performance', Lillo-Bravo, González-Martínez, Larrañeta, Guasumba-Codena, February 2018.

To address concerns on project quality and performance standards, the government has mandated third-party certification of modules and inverters as per standards issued by the Bureau of Indian Standards (BIS) and separately issued Approved List of Models and Manufacturers (ALMM) policy for approval of PV cells and modules used in projects. However, there are multiple gaps in defining and implementing technical standards beyond these products – no standards for many components including mounting structures and module cleaning systems, lack of specification in tenders, inadequate testing infrastructure and poor implementation. There are also no technical standards and safety regulations for emerging technologies like floating solar despite greater challenges associated with higher wind speeds, humidity and water salinity for new projects.

It is believed that intense cost pressure, inadequate certification and inspection regime is promoting use of sub-standard equipment and inefficient design leading to critical underperformance and safety risks.

This report presents an overview of various technical standards prevalent in the sector and typical implementation challenges leading to project performance issues. It highlights potential solutions with the objective of providing guidance to the industry on design and installation of key balance of system (BOS) components. The report has been prepared using technical literature and interviews with select project developers, EPC contractors and equipment manufacturers.

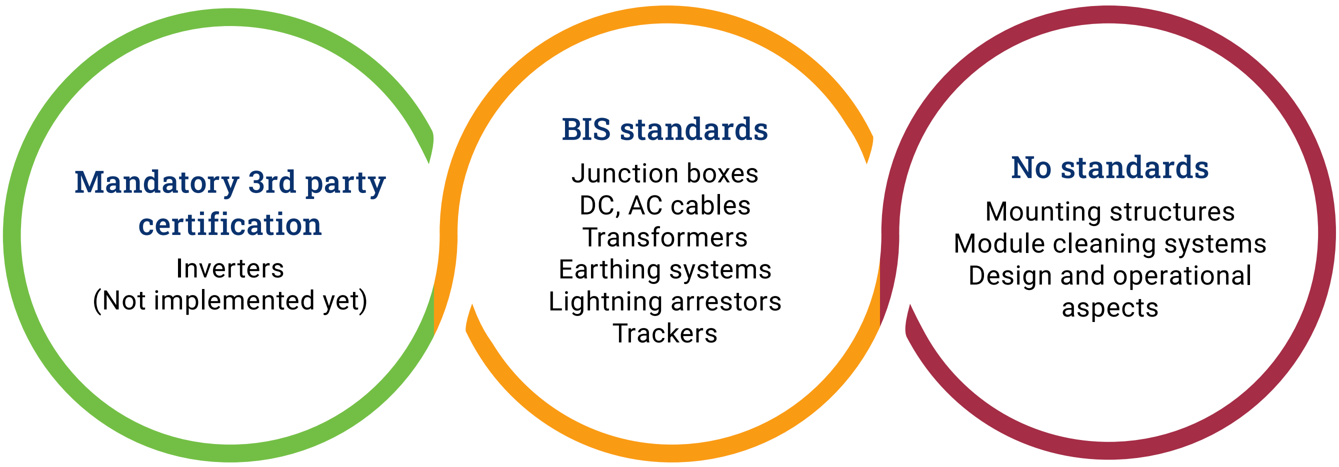
2. Current standards and specification regime

Modules and inverters, accounting for approximately 68% of EPC cost, are standard equipment covered by extensive international and Indian standards. The Ministry of New and Renewable Energy (MNRE) has also mandated third-party certification for both modules and inverters.

2.1 BIS standards

As there is relatively little leeway in cost optimisation of modules and inverters, most cost pressure falls on BOS – transformers, cables, junction boxes, electrical panels, monitoring and protection equipment, among others. BIS issued technical standards for several components including transformers, mounting structures and cables in 2015. Another set of standards was issued in 2020 for cables rated at 1,500 V. However, both these sets of standards are not specified in tenders issued by Solar Energy Corporation of India (SECI) or other government agencies. Moreover, there are no specified standards for key BOS items like mounting structures and module cleaning systems.

Figure 5: Certification and standards for major BOS components



The Central Electricity Authority (CEA) has also laid down various generic power sector regulations covering grid connectivity, plant construction and metering standards. However, there is no specific regulation for solar power projects. CEA issued draft regulations for safety and technical standards in March 2021 specifying requirements for earthing and lightning protections systems.

2.2 Tender specifications

Ground mounted projects

Most tenders issued by government agencies prescribe technical standards for select components like inverters and cables.

Table 1: Commonly prescribed standards for BOS components in SECI utility scale tenders

COMPONENT	STANDARDS	ASPECT
Inverters	IEC 61683	Efficiency measurement
	IEC 62109	Electrical safety
	IEC 61000	Electromagnetic compatibility
	IEC 62116 or IEEE 1547:2003 or UL 1741	Anti-islanding
	IEC 60068	Environmental testing
	Tariff bid	Tariff bid
DC cables	EN 50618 or TUV 2pfg 1169/08/07	Life expectancy testing

Rooftop solar systems

There is a wide range of technical specifications and standards specified in rooftop solar tenders. Some tenders specify standards for cables, inverters, junction boxes and surge and lightning arrestors. A small proportion of tenders also include additional requirements related to ingress protection and use of specific material in cables (copper or aluminium core).

SECI rooftop solar tenders specify detailed technical requirements for mounting structures, junction boxes, inverters, cables, monitoring system, earthing and lighting protection systems besides permitted materials for mounting structures (galvanised mild steel or aluminium) and DC cables (copper).

Table 2: Commonly prescribed standards for BOS components in SECI rooftop solar tenders

COMPONENT	STANDARDS	ASPECT
Inverters	IEC 61683	Efficiency measurement
	IEC 62109	Electrical safety
	IEC 61000	Electromagnetic compatibility
	IEC 62116 or IEEE 1547:2003 or UL 1741	Anti-islanding
	IEC 60068	Environmental testing
DC cables	EN 50618 or TUV 2pfg 1169/08/07	Life expectancy testing
	IEC 60227/ IS 694	Cable insulation
	IEC 60502/ IS 1554	Dimensions and test requirements
Mounting structures	IS 2062:1992	Steel type
	IS 4759	Galvanisation
Junction boxes	IP 65	Ingress protection
AC distribution panel board	IEC 60947 and IC 60947	Testing
	IP 54 (indoor) or IP 65 (outdoor)	Ingress protection
Lightning protection	NFC 17-102:2011	Equipment layout and installation
Earthing protection	IS:3043-1987	Code of practice

3. Policy and regulatory gaps

There are many gaps in definition and implementation of technical standards for solar projects. Such gaps create room for compromise in equipment selection and project construction leading to risk of poor operational performance and higher O&M cost.

3.1 Lack of standards for key components

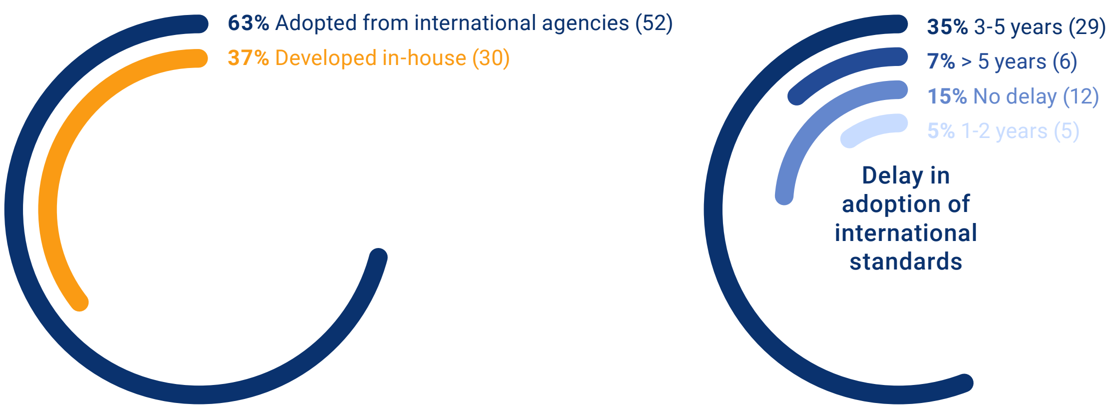
As discussed earlier, there are no Indian standards specified for critical components like mounting structures and robotic cleaning systems. For mounting structures, developers follow BIS standard IS 875-3:2015 which prescribes wind loading for buildings. The ambiguity is believed to lead to use of cheaper, less durable mounting structures in the industry.

Despite issuance of multiple floating solar project tenders and many such projects under construction, there are no specific guidelines, standards and safety regulations for floating solar projects. Components like floating platforms, anchors and mooring cables are susceptible to significant degradation, corrosion and biofouling risk requiring specific standards for design and installation.

3.2 Delay in adoption of international standards

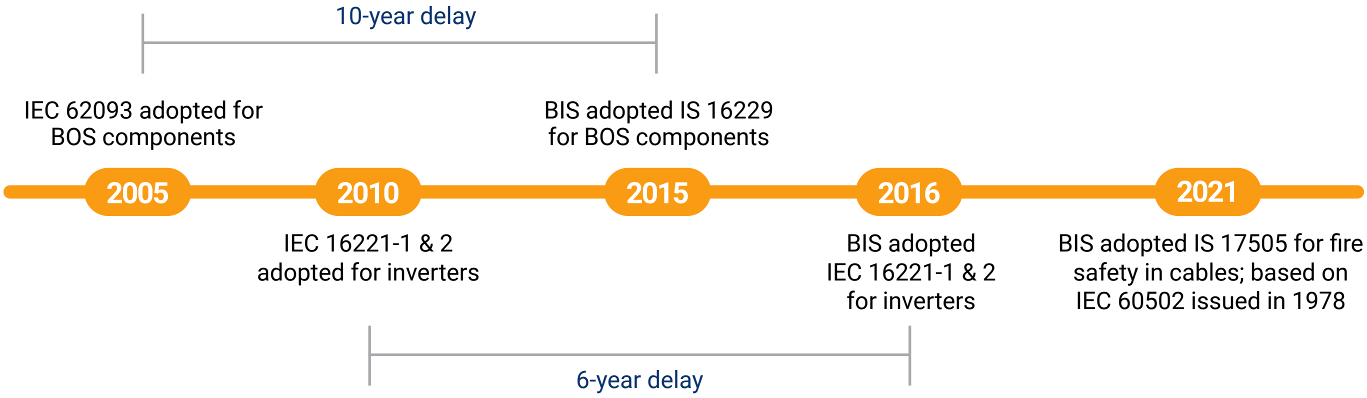
BIS often adopts international standards, particularly those issued by IEC. Out of the total 82 standards issued by BIS for solar power systems (for complete list, refer to annexure I), 52 have been adopted from international agencies. Often, the standards are adopted with long delays of up to ten years leading to use of outdated standards in the industry.

Figure 6: Use of international standards



Source: BIS, BRIDGE TO INDIA research

Figure 7: Examples of delay in adoption of international standards by BIS

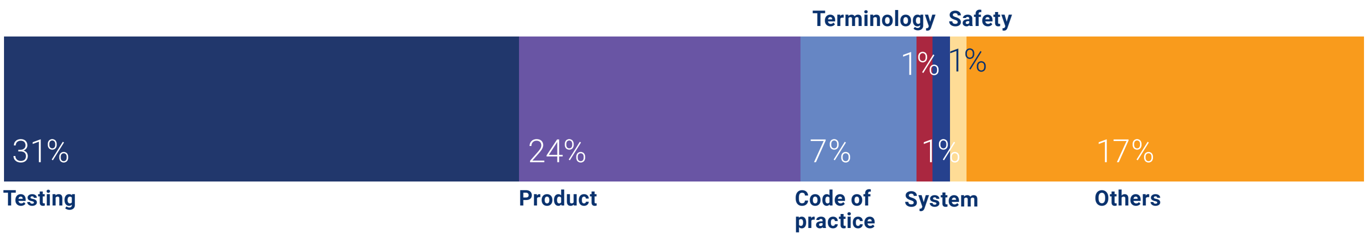


Source: IEC, BIS, BRIDGE TO INDIA research

3.3 Lack of detailed guidelines for component selection and installation

Most international standards focus on component manufacturing and specification rather than design and operational aspects. BIS and IEC standards specify generic performance parameters; for example, less than 1-2 ohms resistance for earthing systems. Project developers are typically free to choose materials to achieve these values often leading to sub-optimal installation quality. Inspections for utility-scale solar projects are typically limited to safety measures for different equipment and rarely address standards related to design and operation of equipment.

Figure 8: Applicability of BIS standards for solar PV systems



Source: BIS, BRIDGE TO INDIA research

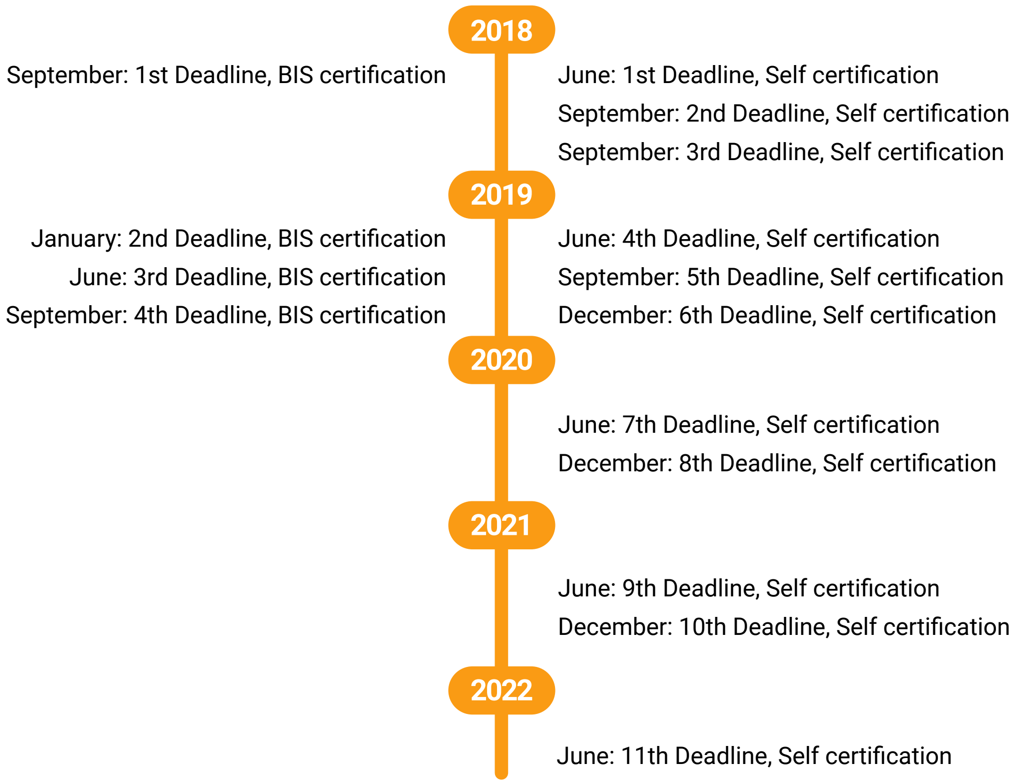
Several states have issued technical guidelines for installation of rooftop solar power systems. But in most cases, these guidelines offer limited or generic specifications for individual components. For example, technical requirements issued by renewable energy development agencies of Uttar Pradesh and Maharashtra do not specify materials to be used for earthing conductors or lightning rods. Further, these guidelines are mandatory only for government-owned/ tendered projects leaving majority of rooftop solar installations at risk of sub-optimal equipment selection.

Most states exempt rooftop solar power systems below a specified threshold size from safety inspection. As an example, Haryana recently increased threshold for third-party safety inspection from 20 kW to 500 kW.

3.4 Implementation delays

Implementation of MNRE's September 2017 order for mandatory certification of inverters has been delayed multiple times and is still incomplete. Deadline to obtain BIS certification has been extended three times, while deadline for self-certification has been extended nine times due to lack of sufficient testing labs. MNRE has therefore been forced to allow manufacturers to self-certify their products.

Figure 9: Timeline of MNRE's certification order related to inverters



Source: BRIDGE TO INDIA research

Similarly, mandatory certification of modules has been delayed multiple times and was implemented in April 2019.

4. Performance challenges in BOS

Most challenges faced during installation and operational phase result from sub-optimal choice of material and design and installation practices. Consequences include accelerated degradation of equipment and sub-components, loss of power generation and higher maintenance cost. Various challenges related to design and selection of different components, their impact on power output, revenue and lifecycle cost and potential solutions are discussed below.

4.1 Inverters

The most common challenges faced with respect to inverter performance are insufficient earthing, ground faults and inefficient cooling. Ground faults, or unintentional flow of current to ground accounting for a third of failures, are caused by loss of cable insulation and drop in insulation resistance of PV array. Switching operation leads to heat generation and increase in ambient temperature leading to drop in inverter efficiency from around 98.5% at 25°C to less than 95% at 45°C. Inefficient switching operation accounts for a third of power loss.

Such inverter performance issues can be addressed by installing ground fault protection devices with high sensitivity to detect unintended power flow and using more efficient insulate-gate bipolar transistors (IGBTs), like those based on silicon carbide (SiC) or gallium nitride (GaN) instead of silicon. Such inverters are up to 3% cheaper, 40% lighter and result in 15% lower O&M cost. However, contractors and project developers are still hesitant to adopt these inverters due to their shorter performance track record.

For utility scale projects, inverter technology selection plays a critical role in project and O&M cost. String inverters typically have a lower average operational life (5-15 years) compared to central inverters (10-25 years). Failure of string inverters results in considerably small generation loss compared to failure of central inverters. Developers maintain spare string inverters on-site. Due to their size and complexity, central inverters are generally repaired on-site. On-site repair of central inverters has become easier as manufacturers have shifted to a modular design over the years.

Table 3: Typical challenges related to inverters and potential solutions

Challenge	Impact	Solution
DESIGN		
Material mismatch between cable and terminal lugs	Arcing, fire	Use copper main DC cables or bimetallic lugs at terminal points
Mismatch between string voltage and MPPT voltage range	Generation loss	Connect module strings as per inverter specifications
Higher operating temperature due to inefficient cooling	Lower efficiency and reduced generation	Install inverters with more efficient IGBTs
Mismatch between DC and AC output due to higher yield for modules	Clipping losses of 2-4% with DC-AC overloading of up to 1.5 times	Optimise DC-AC overloading to minimise inverter cost and clipping losses
INSTALLATION		
Inadequate earthing of cables and inverter	Accelerated degradation of cables and inverters	Provide earthing for all major cable sheaths; sufficient redundancy in earthing system
Insufficient ventilation or access for repairs	Increase in operating temperature leading to reduced efficiency and fire	Follow inverter manufacturer specifications regarding installation practices
Installation on inflammable structures like wooden platforms	Higher fire risk	Use fire resistant materials for installation base
OPERATIONS		
Ground fault, unintentional flow of current to ground due to loss of cable insulation	Power output loss and higher fire risk	Install highly sensitive ground fault protection devices
Switching losses due to high temperature	Power output loss due to reduced efficiency (98.5% at 25°C to less than 95% at 45°C)	Install more efficient inverters with insulated-gate bipolar transistors (IGBTs)

Recommendations

BIS:
Amend standards to cover new and emerging inverter technologies.

Tendering agencies:
Mandate use of copper or bimetallic lugs at terminal points and sufficient redundancy in earthing systems.

Industry associations:
Develop guidelines for selection of inverters addressing key commercial, installation and operational aspects.

4.2 Transformers

Undersizing of transformers has emerged as a major challenge in the recent years due to increasing use of large sized modules resulting in high power output on clear days. Sudden increases in radiation lead to increase in power generation exceeding prescribed operational parameters like temperature and input power. Undersizing of transformers causes degradation of various sub-components, shorter life spans and frequent disconnection of solar project from grid. Oversized transformers can supply maximum solar power during high irradiation but require higher capital cost.

Transformer failures account for around 35% of total power loss in solar projects. Moreover, repair and replacement of transformers can take many weeks resulting in high revenue loss.

Table 4: Typical performance issues related to transformers and potential solutions

Challenge	Impact	Solution
DESIGN		
Undersized transformers/ overloading	Accelerated degradation of components leading to loss of power and revenue	Estimate overloading duration and install transformers with sufficient loading margin (minimum 10%)

Challenge	Impact	Solution
OPERATIONS		
Prolonged overloading leading to increase in operating temperature and contamination of insulation oil	Accelerated failure of sub-components	Integrate real-time data with SCADA for remote monitoring
Overheating and presence of moisture	Accelerated failure of sub-components	Undertake regular preventive maintenance activities and physical inspections

Recommendations

BIS:
Amend standards to require manufacturers to provide details related to monitoring and protection systems of transformers

Tendering agencies:
Mandate developers to assume minimum 10% overloading in transformer design

Industry associations:
Share best practices for sizing of transformers with new developers

4.3 DC and AC cables

Mismatch between materials used in cables and terminal lugs at inverters and junction boxes, long cable routes and incorrect thickness are some of the major challenges in design and use of DC cables. For AC cables, use of aluminium core has become more prevalent in the industry due to lower capital cost (50% cheaper than copper cables) and lighter weight (30%). However, aluminium cables have lower current carrying capacity and are more prone to thermal expansion and arcing at terminal joints in comparison to copper cables.

Table 5: Typical challenges related to design and installation of cables

String DC cables

Challenge	Impact	Solution
DESIGN		
Greater voltage drop due to longer DC cables routes	High system losses	Optimise cable routing and length
INSTALLATION		
Suspension of cables in air for long stretches	• Ground faults and loss of power • Safety hazard for staff	Lay cables in conduits or trays
Incorrect crimping of cable ends	Short circuit or sparks	Use crimping tool and guidelines issued by BIS or international agencies for cable joints

Main DC cables

Challenge	Impact	Solution
DESIGN		
Mismatch between DC cable material and terminal lugs at junction box and inverter	• Thermal expansion and hotspot generation • Higher arcing and fire risk • Accelerated degradation of junction boxes and inverters	• Use cables with copper conductors or bimetallic lugs at terminal point • Undertake regular visual and thermal inspection of termination joints
Lower current carrying capacity for aluminium cables (50-70% larger cables required for same current carrying capacity as copper cables)	• Larger junction boxes required • Higher capital and O&M cost	Use cables with copper conductors
Lower short-circuit current limit for aluminium cables in comparison to copper cables	• Lower reliability • Frequent cable replacement • Higher O&M cost	Use cables with copper conductors
Greater voltage drop due to use of thinner cables	High system losses and accelerated degradation of cables	Use optimal cable thickness as per BIS/ IEC standards

Challenge	Impact	Solution
Greater voltage drop due to longer DC cables routes	High system losses	Optimise cable routing and length
Use of unarmoured or poorly armoured cables	• Water ingress • Loss of insulation resistance leading to power loss	Seal conduit openings with sealant
INSTALLATION		
Suspension of cables in air for long stretches	• Ground faults and loss of power • Safety hazard for staff	Lay cables in conduits or trays
Poor or inaccurate labelling of cables	• Difficult for O&M staff to identify and isolate cable faults • Safety hazard risk • Power loss for extended period	Adopt a standard labelling practice for cables
Submergence of cables due to waterlogging	Damaged cable sheath and loss of insulation	• Lay cables in sealed conduits with sufficient ground clearance • Ensure proper drainage of rainwater
Use of different types of cable connectors across components	• Loose connections • Higher short circuit, arcing and fire risks	Use similar connectors throughout the power plant
Incorrect crimping of cable ends	Short circuit or sparks	Use crimping tool and guidelines issued by BIS or international agencies for cable joints

AC cables

Challenge	Impact	Solution
DESIGN		
Use of unarmoured or poorly armoured cables	• Water ingress • Loss of insulation resistance leading to power loss	Seal conduit openings with sealant

Challenge	Impact	Solution
INSTALLATION		
Submergence of cables due to waterlogging	Damaged cable sheath and loss of insulation	• Lay cables in sealed conduits with sufficient ground clearance • Ensure proper drainage of rainwater
OPERATION		
Ground faults	• Overheating • Deterioration of cable insulation • Reduced current flow • Fire	• Undertake regular visual and thermal inspection of cables • Install ground fault protection devices with high sensitivity for low ampere current flow

Recommendations

Tendering agencies:
Mandate sealing cable conduits with sealant and rainwater drainage

Industry associations:
i. Share installation best practices regarding design and installation of cables
ii. Create training protocols for technicians responsible for installing and labelling cables
iii. Issue guidelines for routing of cables to minimise electrical loss
iv. Issue best practices for installing cables with repeat to soil type

4.4 Junction boxes

As per figure 9, junction boxes account for only 1% of BOS cost but 65% of losses in DC power output. Overheating, creation of hotspots and improper sealing can result in short circuit, fire and power loss. To address these challenges, junction boxes must be adequately ventilated and conform to Ingress Protection (IP) standard IP 65 or better.

Figure 10: DC equipment failure and energy loss

Source: 'Impact of Energy Losses Due to Failures on Photovoltaic Plant Energy Balance Performance', Lillo-Bravo, González-Martínez, Larrañeta, Guasumba-Codena, February 2018

Table 6: Typical challenges related to junction boxes and potential solutions

Challenge	Impact	Solution
DESIGN		
Material mismatch between cables and termination lugs	• Overheating and hotspots creating arcing and fire risk • Accelerated degradation of surge protection devices • Power loss	• Use copper or bimetallic lugs at terminal point • Undertake regular visual and thermal inspection of termination joints
Incorrect choice of junction box enclosures	• Water ingress • High likelihood of fire	Use IP65-compliant enclosures
INSTALLATION		
• Loose terminal connections • Improper sealing of junction box	• Water ingress leading to short circuit and power loss • Cable damage by rodents	Fill junction boxes with sealants like room-temperature-vulcanizing (RTV) silicone
Tightly packed junction boxes	Surge protection devices likely to operate at very high temperatures leading to fire risk	Provide sufficient space between junction boxes

Challenge	Impact	Solution
OPERATIONS		
Loose or rusted termination points	• Arcing, fire • Power loss	Undertake regular visual and thermal inspection of cables
Accumulation of dust due to improper sealing of junction box	• Likelihood of corrosion • Reduced functionality of fuse holders and breakers	• Fill junction boxes with sealants like room-temperature-vulcanizing (RTV) silicone • Undertake regular inspection

Recommendations

BIS:

Issue standards mandating use of copper or bimetallic lugs for string DC cables

Industry associations:

i. Create training protocols for technicians for properly filling junction boxes with sealants
ii. Share monitoring best practices for regular inspection and preventive maintenance of termination joints
iii. share monitoring best practices for regular inspection and preventive maintenance of termination joints

4.5 Mounting structures

Mounting structure is a major target for cost optimisation by developers as it accounts for up to 45% of BOS cost. There are no specific design and installation standards available for mounting structure. Instead, developers refer to a standard for wind load management in buildings. Recommendations mentioned in these standards related to thickness of structure and wind load are usually ignored to reduce cost. As per table 7, triangular wind loading and hot dipped galvanised steel (with thicker zinc coating) offer most durable mounting structures.

Figure 7: Features of wind loading and material options

Design criteria	Triangular wind loading	Rectangular wind loading
	+ can sustain high wind speeds	+ cheaper by 20-25% – lower wind bearing capacity
Material	**Hot dipped galvanised steel**	**Galvanised steel**
	+ more durable and resistant to corrosion – more expensive	+ Less expensive – more susceptible to corrosion and damage in high-speed winds

Most private developers generally opt for cheaper and less durable design and material. Complete failure of mounting structure in strong winds can lead to significant generation loss. However, even slight buckling of structure can disturb orientation of modules leading to undetected and prolonged generation loss.

Table 8: Typical challenges related to mounting structures and potential solutions

Challenge	Impact	Solution
DESIGN		
Installation of mounting structures based on rectangular loading	• Marginally lower capital cost • Higher susceptibility to damage in high speed winds	• Validate design as per worst possible site conditions for wind speed • Use triangular wind loading to limit damage in high wind speed conditions
Use of inferior quality steel (like galvanised steel)	Higher susceptibility to corrosion and damage in high speed winds	Use hot dipped galvanised steel for higher durability and resistance to corrosion
Use of poor-quality galvanised steel (galvanisation thickness less than 80 microns)	Increased possibility of rust-ing and degradation	Use structures with minimum 80 microns thickness of uniform galvanisation
Non-modular mounting structure	Difficult to repair and replace mounting structure leading to longer downtime and generation loss	Use modular design with easy replacement

Challenge	Impact	Solution
INSTALLATION		
Inadequate tightening of braces to support modules	• Unintended rotation of modules during high speeds • Radiation and power output loss	• Adequately tighten braces for modules • Regular visual inspection of modules
No room for thermal expansion of modules leading to: • distortion of modules • water ingress in modules	• Reduction in insulation resistance of modules • Surge in DC power output • Repeated inverter tripping • Power output loss	Undertake regular inspection
Weak foundation and anchorage	Foundation loses adherence to roof surface leading to reduced structural strength of mounting structure	Build wide foundation to ensure strong anchorage with surface
OPERATIONS		
Poor quality water used for module cleaning	• Corrosion of module structure and loss of structural strength • Increased susceptibility of damage to lighter members	Implement dry cleaning solutions for modules, or use soft water for module cleaning

Recommendations

BIS:
Develop specific standards for mounting structures with requirements related to material, thickness and minimum wind load bearing capacity

Industry associations:
Issue guidelines for design validation at extreme conditions of wind speeds and corrosivity

4.6 Trackers

An increasing number of developers now consider using trackers to achieve higher generation and reduce levellised cost of electricity (LCOE). Corrosion of actuators and restricted movement of drivelines connecting multiple rows are common challenges associated with tracker performance.

Table 9: Typical challenges related to trackers and potential solutions

Challenge	Impact	Solution
DESIGN		
Use of actuator material prone to corrosion	• Tracking error • Accelerated degradation of actuators • High replacement cost	Use stainless steel actuators
INSTALLATION		
Drivelines joined together using screws leading to low rigidity and tracking error	• High inter- and intra-row shading • Reduced power output • Accelerated degradation of modules	Weld drivelines together to ensure high rigidity
Lack of drains below drivelines leading to mud accumulation and restricted movement	• Tracking error • Reduced power output	Construct V-shaped drains underneath drivelines to ensure drainage of rainwater and prevention of mud accumulation
OPERATIONS		
Poor quality water used for module cleaning	Corrosion of drivelines leading to tracking error	Implement dry cleaning solutions for modules, or use soft water for module cleaning

Recommendations

BIS:

i. Update existing standards – BIS standard IS 16663:2018 is based on IEC 62727:2012 which was withdrawn in December 2020
ii. Specify requirements for material of sub-components depending on ambient environmental conditions
iii. Specify requirements for minimum ground clearance for drivelines

4.7 Module cleaning systems

Currently, there are no standards for design or selection of cleaning devices. Thus, developer's choice between manual and robotic cleaning is largely driven by project cost considerations, water availability and availability of labour. Potential damage to modules during manual cleaning and use of hard water leading to deposition of water and minerals are leading challenges faced by developers.

Table 10: Typical challenges related to module cleaning and potential solutions

Challenge	Impact	Solution
OPERATION		
Manual cleaning of modules	High likelihood of physical damage to modules	• Implement mechanism systems for cleaning • Standard operating procedure for module cleaning
Use of hard water for module cleaning	Lower power output due to deposition of minerals on modules	• Implement robotic dry cleaning • Use demineralised water for cleaning
Non-homogeneous distribution of dirt on modules	• Scaling and hotspots on modules • Accelerated potential induced degradation	• Use soft water for module cleaning

Recommendations

Industry associations

Develop training guidelines and module cleaning protocols for manual cleaning, including recommendations on frequency of dry and wet cleaning based on site conditions

4.8 Earthing and lightning arrestors

Earthing and lightning arrestors account for less than 1% of BOS cost and are often overlooked as components with little impact on project performance. Inadequate coverage of project area, low redundancy and low conductivity of air terminals and earthing conductors are some common challenges faced with these components.

Table 11: Typical challenges related to earthing and lightning arrestors and potential solutions

Challenge	Impact	Solution
DESIGN		
Use of galvanised iron strips as earthing conductors	• Higher maintenance due to short life span (around 8 years) • Higher installation cost and effort	Use copper/ copper clad steel conductors with longer life (up to 40 years)
Use of aluminium lightning arrestors	• Lower conductivity leading to damage to equipment • Higher O&M cost due to higher susceptibility to corrosion	Use copper/ copper clad steel lightning arrestors
Selection of earthing conductors with insufficient current carrying capacity and/ or reduction in current carrying capacity due to rusting of ground conductors	Short circuit leading to disruption in operation or complete failure of equipment	Consider sufficient margin for current carrying capacity depending on corrosivity of project site
Lack of sufficient number of lightning arrestors to cover entire solar array	Limited protection available to system	Install adequate number of lightning arrestors covering entire solar array
INSTALLATION		
Common earthing for critical components like junction box and inverters	Short circuit and damage to critical equipment	Install adequate number of lightning arrestors covering entire solar array
Lack of sufficient number of lightning arrestors to cover entire solar array	Limited protection availa-ble to system	• Build independent earthing pits for critical equipment designed to their respective short-circuit current capacity • Install minimum two earthing conductors for each equipment to ensure redundancy
Lightning arrestors not installed at adequate height and/ or in sufficient numbers	Protection not available for entire system	Strictly follow guidelines and standards regarding height of lightning arrestors to ensure full coverage of solar field

Challenge	Impact	Solution
Earthing conductor touching building surfaces	Damage to equipment and building as excess current may not flow through earthing conductor	Strictly follow standards and guidelines for installation of lightning arrestors and earthing systems
No testing after installation	Failure of earthing system due to high conductor resistance	Test earthing system to ensure soil resistance is less than 1-2 ohm

Recommendations

Industry associations:

i. Develop guidelines for selection of earthing conductor material, size and number

ii. Develop installation guidelines for lightning arrestors to ensure coverage of entire solar arrays and critical components

5. Conclusion

With increasing competition and race to reduce levellised cost of electricity (LCOE), project developers and contractors are under tremendous pressure to cut project cost. Bulk of cost optimisation effort is directed towards project design, equipment and installation aspects lacking clear specification of standards, for example, civil works, project or personnel safety, mounting structures, trackers and weather monitoring systems.

Selection of sub-optimal components and poor design can lead to high opportunity cost and loss of confidence in the sector. For every one percent loss in generation, financial loss for a 1 MW project with tariff of INR 2.50/ kWh is conservatively estimated at INR 0.5 million (USD 6,290) over 25 years.

Figure 11: Estimated annual financial loss due to reduced generation from solar projects

Source: BRIDGE TO INDIA research

Recent efforts by government agencies to mandate compulsory certification of modules and inverters are in the right direction. But as our study shows, much more work needs to be done to widen the scope of standards to other components and working practices, develop new standards on a timely basis and improve implementation. The industry should also work closely with the government and leverage experience gained through development and operation of over 48 GW of solar assets to develop an effective technical standards regime in the country.

Table 12: Key expectations from stakeholders

Standards agencies (BIS, CEA)	• Issue standards covering project design and selection of materials and components • Develop new standards or adapt existing standards to suit different ambient conditions including soil type, weather and wind speeds • Increase interaction with industry on project performance issues and latest technology trends for suitable amendment in standards • Fast track adoption of international standards
Industry associations	• Develop a platform for project developers, EPC contractors and equipment suppliers to share best practices and performance data • Identify and collate installation and O&M best practices for components with no standards – mounting structures, robotic cleaning, trackers • Develop repository of latest international standards for easy access by all stakeholders • Develop training courses for project design and O&M staff
Tendering agencies (SECI, state governments)	• Specify detailed technical requirements in tender documents

Annexure I: BIS standards for solar PV systems

INVERTERS

IS 16169: 2019 **IEC 62116: 2014**	Utility - Interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures (First Revision)
IS 16221: Part 1: 2016	Safety Of Power Converters for Use in Photovoltaic Power Systems Part 1 General Requirements
IS 16221: Part 2: 2015 **IEC 62109-2: 2011**	Safety Of Power Converters for Use in Photovoltaic Power Systems: Part 2 Particular Requirements for Inverters
IS/IEC 61683: 1999 **IEC 61683: 1999**	Photovoltaic Systems - Power Conditioners - Procedure for Measuring Efficiency
IS 16782: 2018 **IEC 62910: 2015**	Utility - Interconnected Photovoltaic Inverters Test Procedure for Low Voltage Ride - Through Measurements
IS 16798: 2018 **IEC 62894: 2014**	Photovoltaic Inverters - Data Sheet and Name Plate
IS/IEC 62920: 2017 **IEC 62920: 2017**	Photovoltaic Power Generating Systems EMC Requirements and Test Methods for Power Conversion Equipment

TRACKERS

IS 16663: 2018	Photovoltaic Systems - Specifications for Solar Trackers
IS/IEC 62817: 2017 **IEC 62817: 2017**	Photovoltaic Systems - Design Qualification of Solar Trackers

BALANCE OF SYSTEM

IS 16229: 2015 **IEC 62093: 2005**	Balance of System Components for Photovoltaic Systems - Design Qualification Natural Environments

CABLES AND CONNECTORS

IS 16781: 2018 **IEC 62852: 2014**	Connectors for DC Application in Photovoltaic Systems Safety Requirements and Tests

JUNCTION BOXES

IS 16781: 2018 **IEC 62852: 2014**	Connectors for DC Application in Photovoltaic Systems Safety Requirements and Tests

BATTERY STORAGE

IS 16797: 2019 **IEC 62509: 2010**	Battery Charge Controllers for Photovoltaic Systems - Performance and Functioning

O&M

IS/IEC 61724-1: 2017 **IEC 61724-1: 2017**	Photovoltaic System Performance Part 1 Monitoring (First Revision)
IS/IEC/TS 61724-2: 2016 **IEC/TS 61724-2: 2016**	Photovoltaic System Performance Part 2 Capacity Evaluation Method
IS/IEC/TS 61724-3: 2016 **IEC TS 61724-3: 2016**	Photovoltaic System Performance Part 3 Energy Evaluation Method
IS/IEC 63049: 2017	Terrestrial Photovoltaic (PV) Systems Guidelines for Effective Quality Assurance in PV Systems Installation Operation and Maintenance

GRID CONNECTION

IS/IEC 61727: 2004 **IEC 61727: 2004**	Photovoltaic PV Systems: Characteristics of the Utility Interface

PLANT DESIGN AND INSTALLATION

IS/IEC/TS 62738: 2018	Ground-Mounted Photovoltaic Power Plants Design Guidelines and Recommendations
IS 16230: 2017 **IEC 62124: 2004**	Photovoltaic (PV) Stand-Alone Systems - Design Verification
IS 16960: Part 1: 2018 **IEC 62446-1: 2016**	Photovoltaic (PV) Systems - Requirements for Testing, Documentation and Maintenance: Part 1 Grid Connected Systems - Documentation, Commissioning Tests and Inspection

EARTHING AND LIGHTNING ARRESTERS

IS 3043: 1987	Code of Practice for Earthing
IS 9921 (Part 1): 1981	Alternating Current Disconnectors (Isolators) and Earthing Switches for Voltages Above 1,000 V - Part I: General and Definitions
IS 9921 (Part 2): 1982	Alternating current disconnectors (isolators) and earthing switches for voltages above 1,000 V: Part 2 Rating
IS 9921 (Part 3): 1982	Alternating Current Disconnectors (Isolators) and Earthing Switches for Voltages Above 1,000 V - Part III: Design and Construction
IS 9921 (Part 4): 1985	Alternating Current Disconnectors (isolators) and Earthing Switches for Voltages Above 1,000 V - Part 4: Type Tests and Routine Tests
IS 9921 (Part 5): 1985	Alternating Current Disconnectors (Isolators) and Earthing Switches for Voltages Above 1,000 v - Part 5: Information to be Given with Tenders, Enquiries and Orders
IS 12776: 2002	Galvanized strand for earthing - Specification (First Revision)
IS/IEC 62271-102: 2018	High-Voltage Switchgear and Controlgear Part 102 Alternating Current Disconnectors and Earthing Switches
IS/IEC 62271-102: 2003	High - Voltage switchgear and Controlgear: Part 102 Alternating Current Disconnectors and Earthing Switches
IS 2309: 1989	Code Of Practice for the Protection of Buildings and Allied Structures Against Lightning
IS 3070 (Part 3): 1993	Lightning Arresters for Alternating Current Systems - Specification: Part 3 Metal Oxide Lightning Arresters Without Gaps
IS 62305-1): 2010	Protection Against Lightning: Part 1 General Principles
IS/IEC 62305-2: 2010	Protection Against Lightning: Part 2 Risk Management
IS/IEC 62305-3: 2010	Photovoltaic (PV) Stand-Alone Systems - Design Verification
IEC 62305-3	Protection Against Lightning: Part 3 Physical Damage to Structures and Life Hazard
IS/IEC 62305-4: 2010	Protection Against Lightning: Part 4 Electrical and Electronic Systems Within Structures