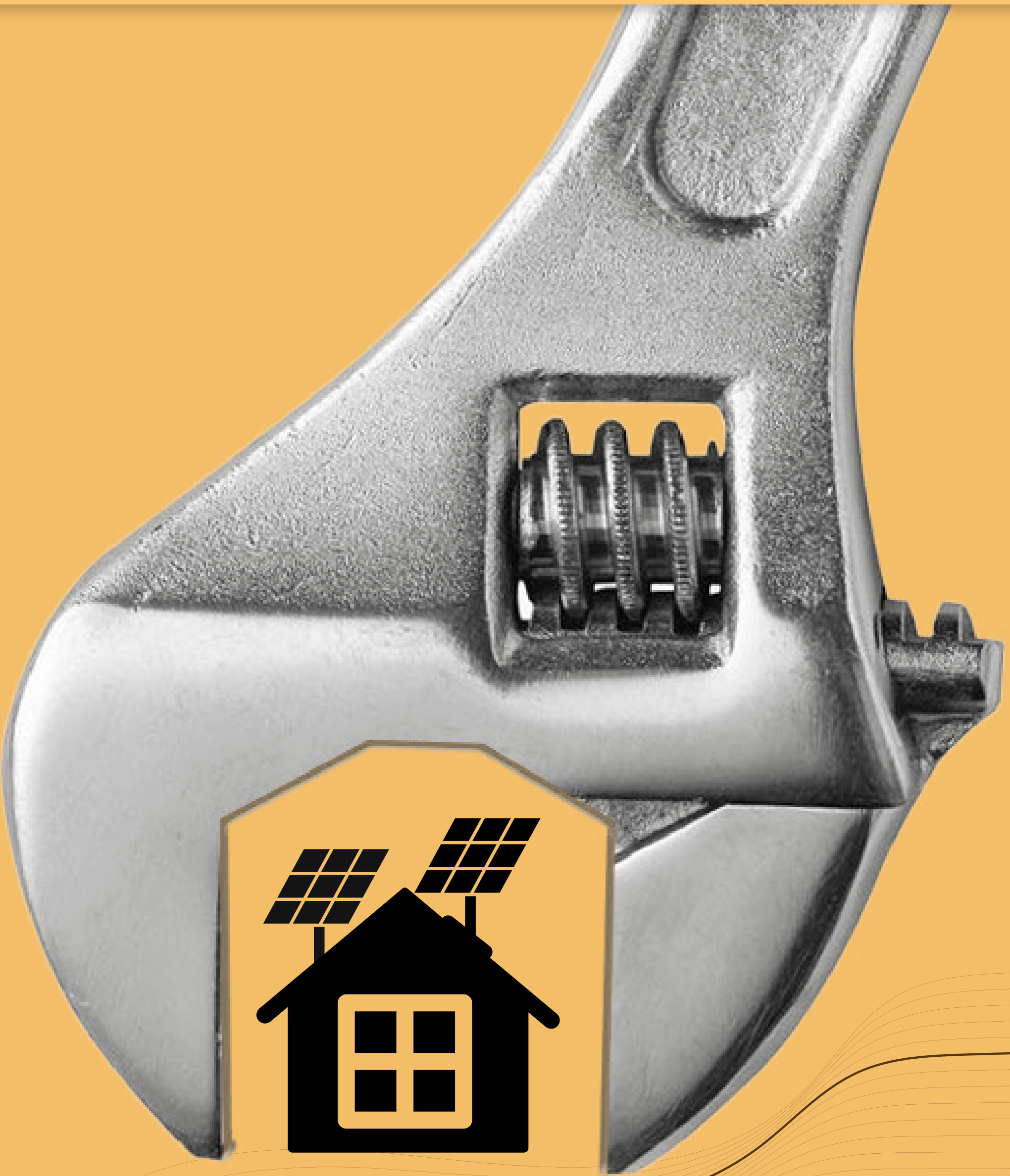
THE SOLAR PLAYBOOK

A techno-commercial guide for solar rooftop developers



CENTRE FOR ENERGY, ENVIRONMENT & PEOPLE

The Solar Playbook

A techno-commercial guide for solar rooftop developers

May 2026

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Grover, S., & Agarwal, S. (2026). Solar Playbook: A techno-commercial guide for rooftop solar developers. *Centre for Energy, Environment & People.*

About the organisation

Centre for Energy, Environment & People (CEEP) is a human-centric research and policy advocacy initiative working towards energy justice in Rajasthan. Our work prioritises workers, communities, and environment at the intersection of energy infrastructure and services.

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May 2026 (first edition)

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संदेश

हर्ष का विषय है कि 'सेंटर फॉर एनर्जी एनवायर्नमेंट एंड पीपुल' द्वारा रूफ टॉप सौर ऊर्जा संयंत्र स्थापित करने वाले डवलपर्स के लिए मार्गदर्शिका 'द सोलर प्ले बुक' का प्रकाशन किया जा रहा है।

माननीय प्रधानमंत्री श्री नरेन्द्र मोदी जी की दूरदर्शी पहल प्रधानमंत्री सूर्यघर योजना ने देश में सोलर क्रांति का सूत्रपात किया है। यह सौर ऊर्जा को बढ़ावा देने वाली विश्व की सबसे बड़ी महत्वाकांक्षी योजना बन चुकी है। देश में 32 लाख से अधिक परिवार इस योजना से जुड़कर अपने बिजली बिल पर खर्च की चिंता से मुक्त हो गए हैं और कार्बन उत्सर्जन कम करने की राष्ट्रीय प्रतिबद्धता में अपना महत्वपूर्ण योगदान दे रहे हैं।

माननीय मुख्यमंत्री श्री भजनलाल शर्मा के मार्गदर्शन में ऊर्जा विभाग सौर ऊर्जा को जन–जन तक पहुंचाने के लिए संकल्पित है। मुझे खुशी है कि राजस्थान में 2 लाख से अधिक परिवार इस योजना के माध्यम से ऊर्जा आत्मनिर्भर बन चुके हैं। जयपुर, जोधपुर एवं अजमेर विद्युत वितरण निगम ने एसओपी के माध्यम से रूफ टॉप सोलर इंस्टॉलेशन की प्रक्रिया को सुगम बनाया है। इसके साथ ही, आवेदन, मीटर टेस्टिंग तथा सोलर सिक्योरिटी के रूप में लगने वाले शुल्क से उपभोक्ताओं को राहत दी है।

स्टेक होल्डर्स के रूप में सोलर डवलपर्स इस योजना की सफलता में महत्वपूर्ण कड़ी हैं। निचले स्तर तक उपभोक्ताओं को रूफ टॉप सौर ऊर्जा संयंत्रों से जोड़ने में उनकी भूमिका अहम है। मुझे आशा है कि यह मार्गदर्शिका उनके लिए उपयोगी तथा रूफ टॉप इंस्टॉलेशन की गति को बढ़ाने में सहायक सिद्ध होगी। मैं इस प्रकाशन की सफलता के लिए अपनी शुभेच्छा प्रेषित करता हूं।

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प्रबंध निदेशक, जयपुर विद्युत वितरण निगम लिमिटेड

संदेश

मुझे यह जानकर प्रसन्नता है कि सेंटर फॉर एनर्जी एनवायर्नमेंट एंड पीपुल (CEEP) द्वारा रूफ टॉप सौर ऊर्जा संयंत्र डवलपरों के लिए तकनीकी तथा वाणिज्यिक मार्गदर्शिका 'द सोलर प्ले बुक' का प्रकाशन किया जा रहा है।

भारत इस समय नवीकरणीय ऊर्जा के क्षेत्र में अभूतपूर्व परिवर्तन का साक्षी बन रहा है। पीएम–कुसुम तथा पीएम सूर्यघर योजना के रूप में विकेन्द्रित सौर ऊर्जा की पहुंच 'हर खेत–हर घर और गांव–ढाणी' तक संभव हुई है। कार्बन उत्सर्जन को कम करने तथा विकास के लिए प्रदूषणरहित ऊर्जा की आवश्यकता को पूरा करने में सौर ऊर्जा की भूमिका निरन्तर बढ़ रही है। मुझे खुशी है कि राजस्थान इस दिशा में देश का अग्रणी राज्य है।

भारत सरकार एवं राजस्थान सरकार द्वारा देश–प्रदेश को ऊर्जा आत्मनिर्भर बनाने की इस पहल में हमारे सौर ऊर्जा डवलपर महत्वपूर्ण कड़ी हैं। योजना के लक्ष्यों की प्राप्ति में उनका समर्पित सहयोग हम सभी के लिए अमूल्य है।

मुझे विश्वास है कि यह मार्गदर्शिका हमारे सशक्त भागीदार ऊर्जा डवलपर्स, इंजीनियर्स और स्टेक होल्डर्स की तकनीकी एवं वाणिज्यिक जिज्ञासाओं का समाधान करने में 'क्विक रेफरेंस टूल' सिद्ध होगी। साथ ही राज्य को सौर ऊर्जा के क्षेत्र में निरन्तर अग्रणी और आत्मनिर्भर बनाने के हमारे प्रयासों को और गति प्रदान करेगी।

इस प्रकाशन की सफलता के लिए मेरी शुभकामनाएं।

(आरती डोगरा)

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PREFACE

Solar photovoltaic technologies have come a long way from powering prestigious space programmes and satellites, to being a technology available to masses. Globally, distributed energy technologies are disrupting how energy is generated, transmitted and traded. Thanks to a windfall from pricing, solar photovoltaic technologies are central to this disruption.

India has set its eyes on an aggressive target of deploying more than 500 GW of solar photovoltaic capacity. While government policies and innovative financial tools are playing a catalytic role in promoting the adoption of solar rooftops. Transition towards clean and sustainable energy sources will not be complete without the participation of masses, and solar photovoltaics systems holding the potential to accelerate this transition.

This techno-commercial guide has been designed primarily to assist solar project developers and integrators in enhancing their technical capabilities, strengthening quality control and assurance protocols, and improving project management practices for the installation of solar rooftop systems. In addition, the guide serves as a valuable resource for other stakeholders in making informed decision during sourcing of rooftop solar installation services at their respective facilities. It also provides recommended frameworks for identifying typical project risks and de-risking investments, thereby enabling swifter and more affordable financing for deserving projects.

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ACKNOWLEDGEMENT

We would like to express our sincere gratitude to all individuals and institutions whose guidance, support, and encouragement contributed to the development of this techno-commercial guide for rooftop solar developers.

We are grateful to Mr Heeralal Nagar, Minister of State (Independent Charge), Department of Energy, Government of Rajasthan, and Ms Arti Dogra, Secretary, Energy Department, Government of Rajasthan, for their guidance and continued support towards strengthening the rooftop solar ecosystem in Rajasthan.

We also acknowledge the support extended by Mr S K Rajput, Additional Chief Engineer (Quality Control & Safety), JVVNL and Ms Mahima Sarabhai, Superintending Engineer (PM Suryaghar), JVVNL, for their cooperation and technical assistance throughout the process.

We especially thank Mr Ajay Yadav, President, Renewable Energy Association of Rajasthan, for reviewing the guide and sharing valuable inputs. Special thanks to Mr Shantanu Roy, Group Head (RE) and Sector Coordinator (RE and Energy Conservation) at the Center for Study of Science, Technology and Policy (CSTEP), and Mr Saptak Ghosh, Sector Head (RE and Energy Conservation), at CSTEP for their contributions and continued engagement in advancing rooftop solar and renewable energy initiatives.

We further acknowledge Mr Abhishek Kumar, Founding Partner at Indicc Associates, whose early support and belief in the initiative played an important role in enabling this journey.

We extend our heartfelt gratitude to our colleagues at CEEP – Lavanya Bahuguna, Tarun Swami, and Simran Bajaj - for their support and efforts in making this report possible.

1. INTRODUCTION

While most consumers understand the basics of solar today, their capacity to judge the quality of components and services offered by a project developer is often very limited. In the absence of strong regulatory mechanisms and effective grievance channels, consumers' confidence in solar technology is often found to be lacking. Similar challenges are faced by financing institutions. Solar rooftops are expected to perform for more than 25 years, but the performance of the energy generation assets is dictated by a variety of technical and environmental factors. Understanding and addressing these risks is extremely critical for ensuring well-informed investment decisions.

This publication is designed primarily to support solar project developers in strengthening the quality of materials, services offered, and project execution practices in line with international standards. It also provides guidance on identifying and mitigating risks associated with a typical solar rooftop project, improving the long-term reliability of the installations. In addition, this guide serves as a resource for consumers and financing institutions, offering insights into the fundamentals of solar photovoltaic (PV) rooftop systems.

2. GRID-CONNECTED SOLAR PHOTOVOLTAIC ROOFTOP SYSTEMS

As the name suggests, a grid-connected solar PV system is directly connected to the main grid. The systems are designed to operate in synchronisation with the main grid, wherein the PV system acts as a micro power plant. While the grid-connected solar PV system allows a consumer to produce its own energy, the main grid acts as a pool to supply power in case of any shortfall, or evacuate power when excess is being generated.

In rare cases, solar PV systems are also designed to operate in synchronisation with an alternative power generator such as diesel generators. Such applications also mandate integration of additional hardware to protect the generator from reverse current and ensure that a minimum idling load is maintained.

Solar photovoltaic rooftop (SPVRT) systems allow electricity consumers to install solar PV modules on a roof and generate their own electricity (Figure 1). These systems connect with the grid through different metering mechanisms and enable them to earn benefits. Some of the key features of SPVRT systems are:

- works in sync with the electricity distribution grid,
- does not provide back-up in case of power cuts,
- partially substitutes power consumption through localised generation, reducing electricity bills, and
- operate for 25 years or more with proper maintenance and upkeep.

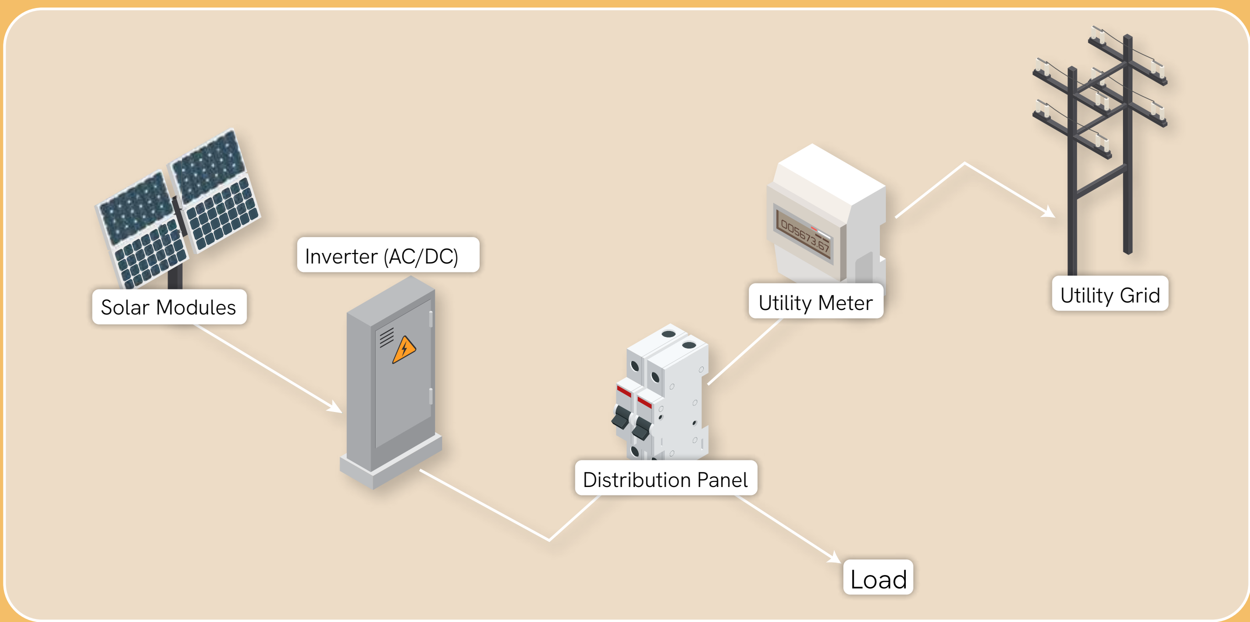


Figure 1: Line diagram of grid-connected SPVRT system

3. METERING AND ENERGY ACCOUNTING

Traditionally, electricity consumers have just been recipients of services. Distributed solar and other emerging technologies are driving a new category of electricity consumers who also produce electricity. Popularly called prosumers, these new categories of electricity consumers are redefining how electricity is produced and consumed, facilitating grid modernisation and integration of renewable energy.

The energy meters or electricity meters were originally designed for unidirectional flow of electricity, accounting for the consumption of electricity. To allow for prosumers to become part of the grid, bi-directional meters have been introduced. These meters not only account for energy consumed from the grid but also account for any energy fed into the main grid because of excess generation.

There are four popular metering mechanisms that are typically deployed with solar rooftop systems, unless they are designed for captive generation[1]. These four mechanisms are explained as follows.

[1] Power generation unit setup to meet a facility's own energy needs.

3.1 Net Metering

Net metering is a utility billing arrangement that enables prosumers to export surplus electricity generated during periods of excess production to the distribution grid and receive credits against their electricity consumption. Using a bi-directional meter, the system records both electricity imported from the grid and electricity exported to it, with consumers billed based on their net energy usage over a specified billing period.

Net units consumed = Total grid electricity units consumed - Total solar energy units fed into the grid

In case of net metering, benefits accrued are a function of avoided electricity consumption and applicable tariff rate as per the tariff schedule notified by the appropriate distribution company (DISCOM).

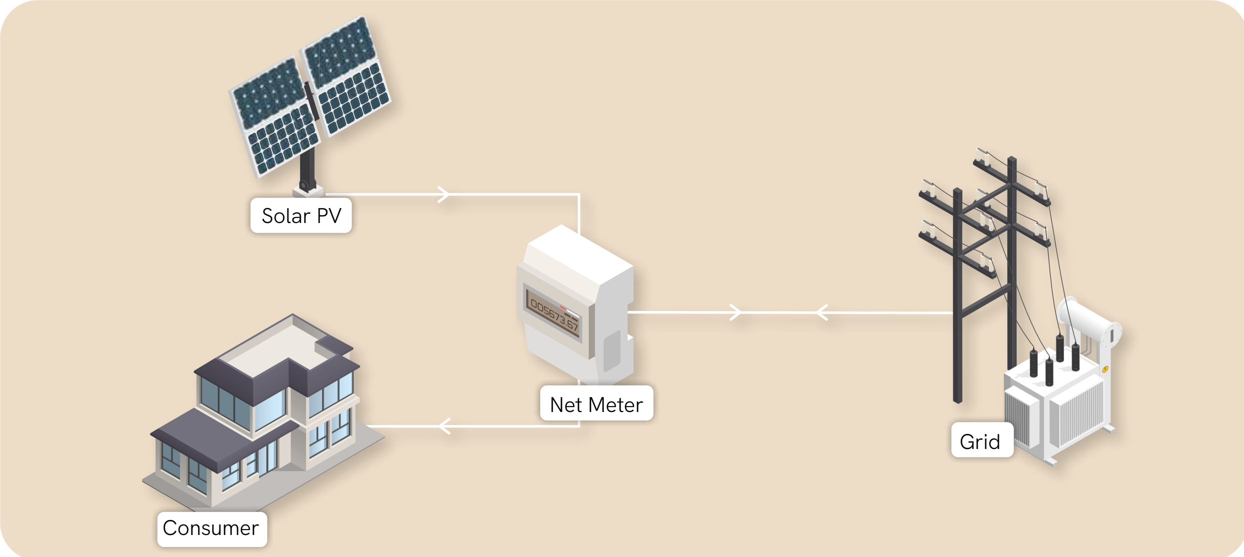


Figure 2: Line diagram of net metering arrangement

3.2 Gross Metering

Gross metering mechanism is deployed when energy generated by a solar rooftop system is directly fed into the grid. Such an arrangement is popular when policy dictates preferential rates for power fed into the grid, and hence, maximum benefit can be received by feeding the electricity directly into the grid.

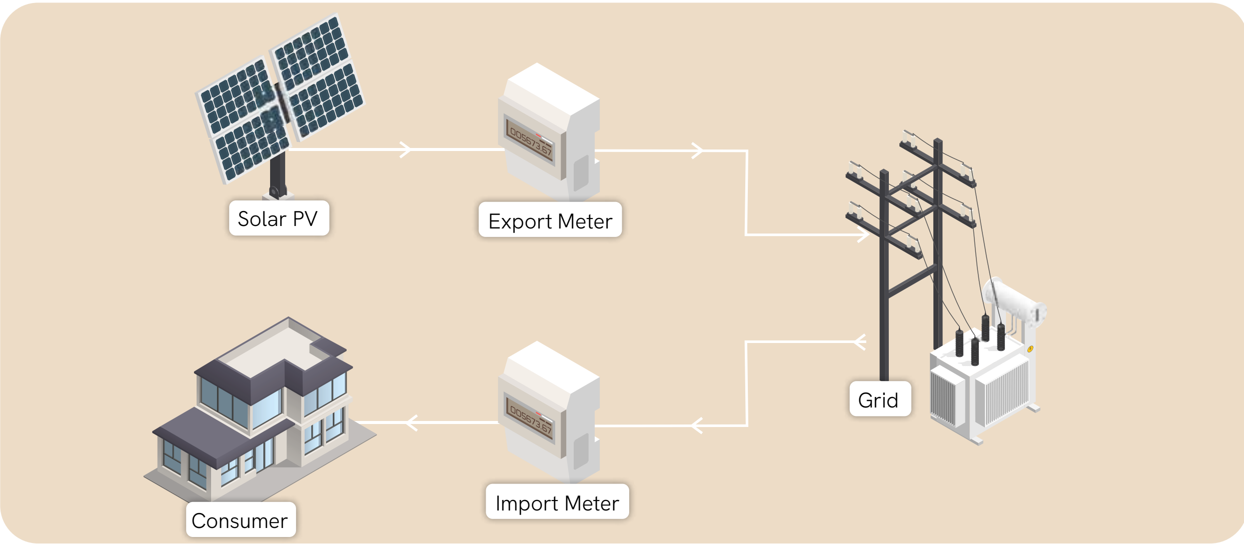


Figure 3: Line diagram of gross metering arrangement

The gross metering mechanism mandates the generation of two bills. The first bill accounts for electricity consumption by the consumer, and it is to be paid by the consumer. The second bill accounts for electricity fed into the grid, and the prosumer is compensated for it by the DISCOM.

3.3 Virtual Net Metering

Virtual net metering refers to an arrangement whereby all the energy generated or injected from a renewable energy system situated in a single location is exported to the grid from a renewable energy meter or gross meter, and the energy exported is adjusted in more than one electricity service connection(s) of participating consumers located within the same distribution licensee's area of supply. The participating consumers nominate a 'Lead Consumer' who are themselves a participating consumer, and they are nominated by other participating consumers under virtual net metering for making all correspondence on their behalf with the distribution company.

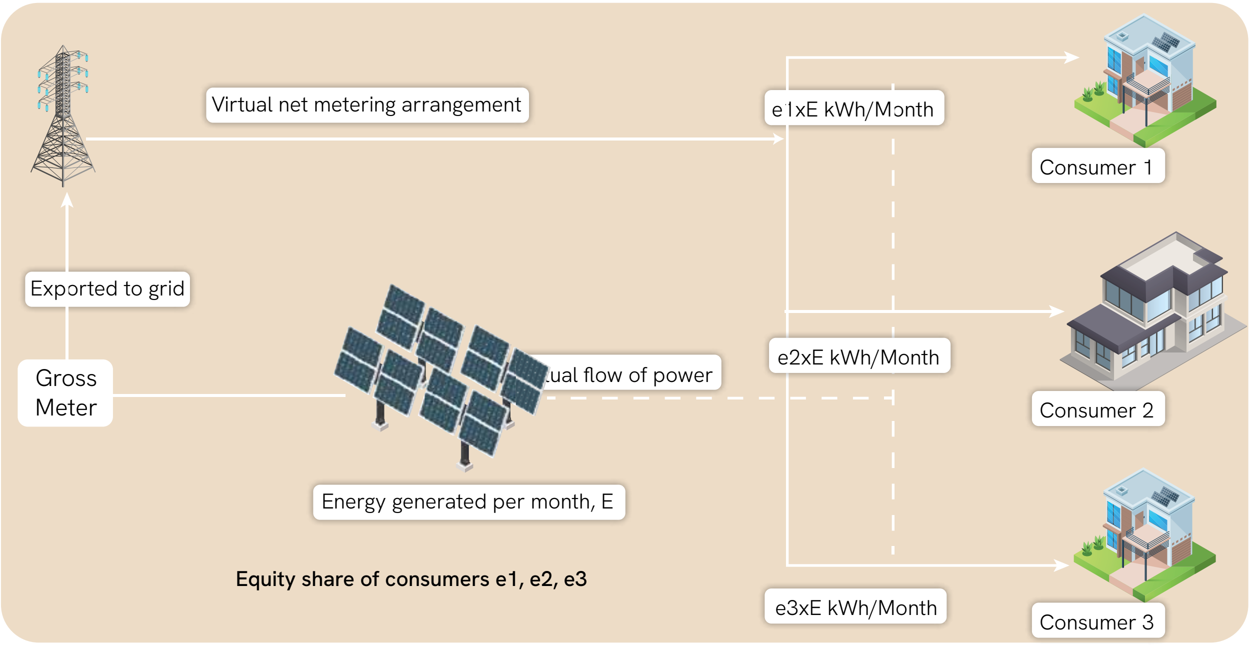
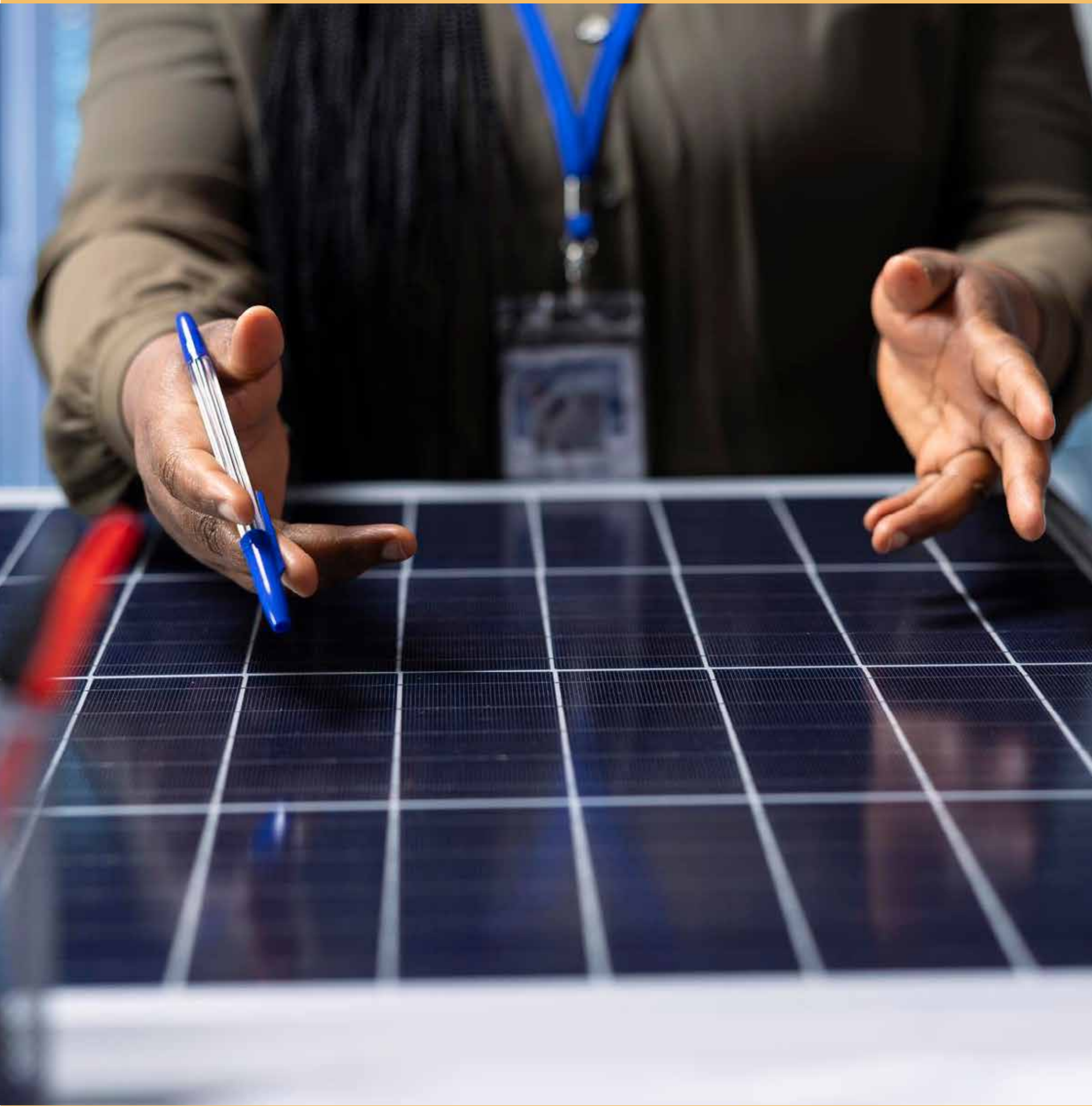


Figure 4: Line diagram of virtual net metering arrangement

3.4 Group Net Metering

Group net metering refers to an arrangement whereby surplus energy generated or injected from a renewable energy system situated in a single location is exported to the grid through a net meter, and the exported energy is adjusted in more than one electricity service connection(s) of the same consumer located within the same distribution licensee's area of supply.

4. PROJECT FINANCING



SPVRT systems are reliable, long-term generation assets with proven technology. Salient features of the rooftop technology open up multiple financing options, though the financing options are constrained by the size of the project and the financial or credit rating of the prosumer. A project can be financed by a project developer, a financial institution or a third-party investor. Key models for deploying solar rooftop systems are discussed as follows.

4.1 CAPEX Model

CAPEX or Capital Expenditure model basically refers to a project financed by the client using his own capital or through loans sourced from financial institutions. The project, hence deployed, is owned by the prosumer; hence, responsibility for operation and maintenance of the plant lies with the owner. The project is developed by an experienced Engineering, Procurement and Construction (EPC) contractor selected by the prosumer. The plant may be maintained using its own resources, or alternatively, it can be outsourced to an experienced contractor.

Institutional finance is available for up to seven years' term loan through public and private banks. The interest rates for the loans can vary from 11-13%. In India, solar photovoltaic (SPV) project owners can benefit from capital subsidies currently provided by the Ministry of New and Renewable Energy (MNRE), Solar Energy Corporation of India (SECI) or other state nodal agencies when deployed at a residential facility or a facility of a not-for-profit agency. However, subsidy is strictly subject to the validity of respective schemes, and the quantum of subsidy may also vary accordingly. Commercial institutions, businesses and industries can avail the benefit of accelerated depreciation on SPV systems.

4.2 OPEX Model

OPEX (Operational Expenditure) or BOOT (Build, Own, Operate and Transfer) model refers to a project financed by a third-party investor or a project developer. The project developer either executes the project themselves or sub-contracts installation and commissioning to an EPC contractor. They also sign a Power Purchase Agreement (PPA) with the facility owner to recover its investments. The term of the PPA is typically anywhere between 15 and 25 years and comes with a buy-back clause. The clause enables the transfer of ownership from the project developer to the owner of the facility.

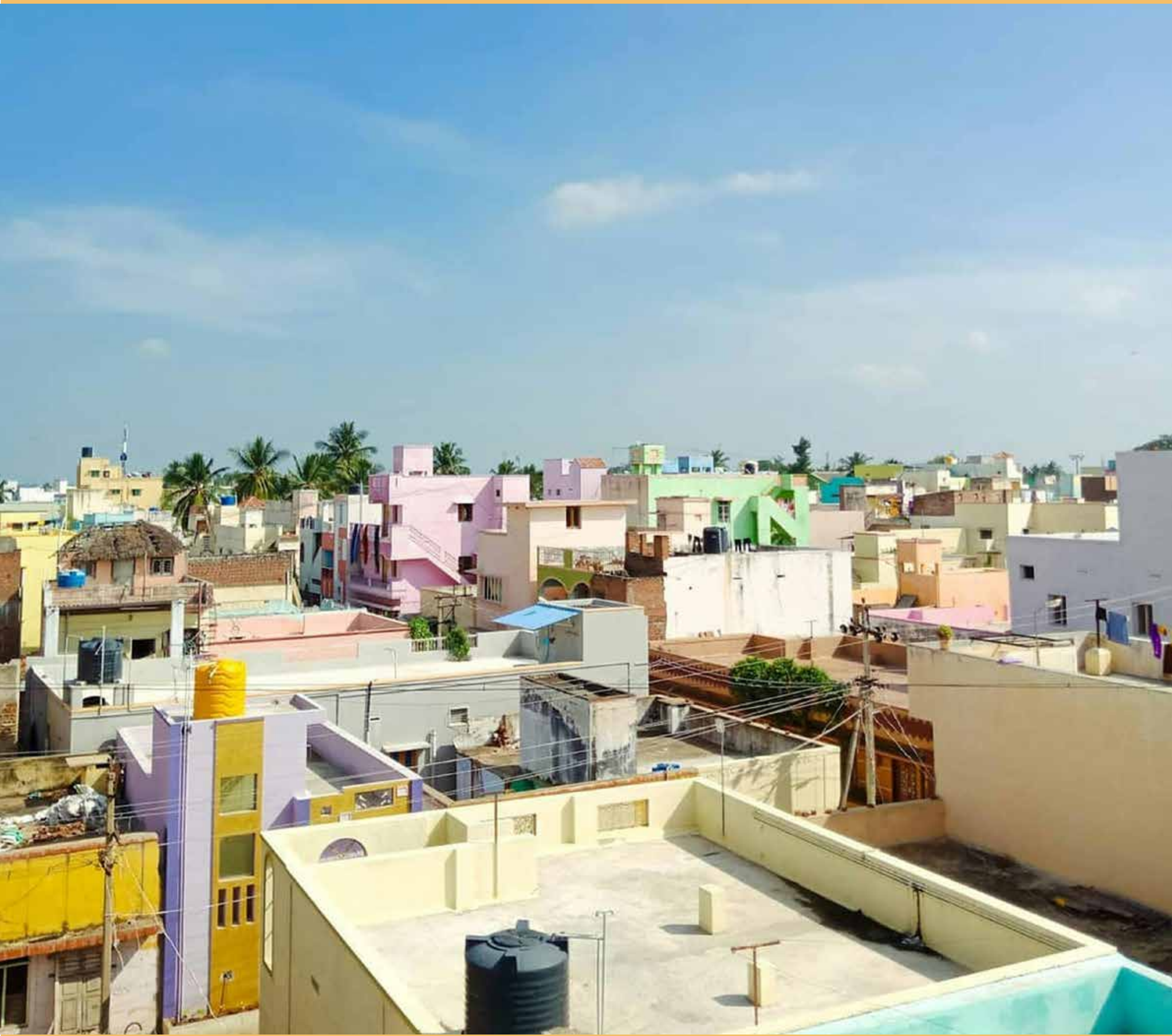
In the case of the BOOT model, the benefit of accelerated depreciation is availed by the project developer. The risk of performance of the system lies with the project developer, and hence operation and maintenance of the plant is either done by the project developer themselves or through a competent subcontractor deployed by them.

The prosumer benefits from cheaper electricity and does not have to invest in the system. Although the prosumer is typically unable to avail the benefits of capital subsidy or accelerated depreciation, there is no financial risk for them.

4.3 Leasing Model

Leasing is a unique model wherein a project developer installs a solar system on a rooftop. Electricity generated is sold to the utility company through gross metering. The owner of the rooftop is provided with compensation for every unit of electricity generated or paid a fixed compensation through a leasing contract. The project developer is compensated based on PPA or as per state policy.

5. SITE ASSESSMENT AND TECHNICAL FEASIBILITY STUDY



A site assessment is the first step to determine how a solar PV system will work at the proposed facility. The purpose of this assessment is to collect site-specific information about space availability, structural and electrical information, and user expectations to propose suitable technology solutions, optimal system capacity and simulate information related to the performance of the PV system to be installed.

While site assessment and feasibility studies are critical to provide optimal solutions for clients' needs, they are also extremely crucial for accurate engineering and smooth execution of the project. Hence, it is highly recommended that the exercise be carried out by competent personnel only. A typical comprehensive site assessment report is shared in Annexure A.

5.1 Roof Assessment

Mapping the layout of the roof, along with construction and equipment on the roof, is extremely critical for designing solar array layout and ensuring the performance of the plant throughout the year. Ideally, solar modules shall be facing true south for locations in the northern hemisphere, which includes India. In the case of fixed tilt structures, the ideal tilt angle is approximately equal to the latitude of the location. While variation in orientation or tilt angle impacts the performance of the system, the degree of impact is relatively low, and hence acceptable when it allows for better space utilisation or reduced installation costs. On the other hand, shadows can significantly impact the performance of a system and induce rapid degradation of modules. Partial and point shadows are often responsible for the formation of hot spots in modules and carry a risk of fire.

The design of solar mounting structures and methodology for anchoring is dictated by the type of roof and its structural construction. Different module designs are available based on whether the roof is flat or indented. The same are discussed in Engineering (Section 8.3). The weight of the solar array (including structure) varies between 10-20 kg per sq. m. Solar modules transfer wind load to the roof, which can be significantly greater compared to the dead load of the mounting structure and solar modules. Hence, it is advisable that clearance is sought from a competent structural engineer.

Different types of mounting structures are discussed in SPV Mounting Systems (Section 9.3). Suitable options should be discussed with clients, and a formal approval should be attained, especially for penetrating-type structures, to avoid issues during the project execution stage.

5.2 Electrical Assessment

Electrical assessment is critical for sizing, performance and safety of equipment. Typically, electric utility bills are sufficient for establishing consumption patterns and system design boundaries, especially when net metering is available. The route for cable shafts and the location of low tension (LT) panels are established to estimate the length and gauge of cable to be used. Further, the location for housing equipment such as Direct Current Distribution Box (DCDB), Inverter, Alternating Current Distribution Box (ACDB) and meters is established in consultation with the client. It is recommended that the cable route and location of equipment are mapped to ensure that the length of cable is kept to a minimum to minimise resistive losses.

5.3 Risk Assessment

The safety of the equipment and installation team deployed on the site for project execution is of paramount importance. It is critical that factors which may impact the performance of the plant or the safety of the equipment in the long run are duly accounted for in the design process. Some key points for on-site risk assessment are discussed in the table as follows.

S. No.	Risk Checklist
1	Access for off-loading and lifting material to the roof
2	Availability of dry, ventilated and safe space for storage of material
2	Access to the roof for installation team
3	Presence of any hazardous material on the roof
4	Overhead high-tension lines
5	Existing electrical equipment and cable routes on the roof
6	Air vents or chimneys present on the roof
7	Availability of water for use during installation of system, and for cleaning of solar modules
8	Any threat from pest or animals

Table 1: Risks associated with solar PV plant construction

Once the risks have been duly accounted for, they can be easily mitigated through proper planning and suitable actions.

5.4 Shadow Analysis

While shadow analysis is an obvious critical analysis for designing an SPV system, it is also easily overlooked. Incompetent and non-trained personnel tend to designate a shadow-free area without giving due consideration to the sun path throughout the year. Partial or complete shadow can have a significant impact on the performance of the system and accelerate the degradation of modules. Partial and point shadows are one of the major causes for the formation of hot spots and discolouration of cells. Hence, it is imperative that shadow analysis be performed by trained technical personnel using proper on-site tools such as Solar Path Finder or online tools such as PVsyst or Sketch-up.

If the project site is located above the Tropic of Cancer, shadow analysis shall be performed for the day of the Winter Solstice (December 22). For project sites located between the Tropic of Cancer and the Tropic of Capricorn, shadow analysis shall be performed for both the Summer (June 21) and Winter Solstice. It should be ensured that partial or complete shadows are avoided during peak-sunshine hours. It is recommended that a time window of four hours, before and after solar noon, be considered for the analysis.

A typical shadow analysis report is shared in Annexure B.

5.5 Capacity Estimation

Output of the shadow analysis shall dictate the maximum solar capacity that may be installed on a given roof. As a thumb rule, for every 8-10 sq. m. of available shadow-free space, 1 kWp of solar modules can be installed.

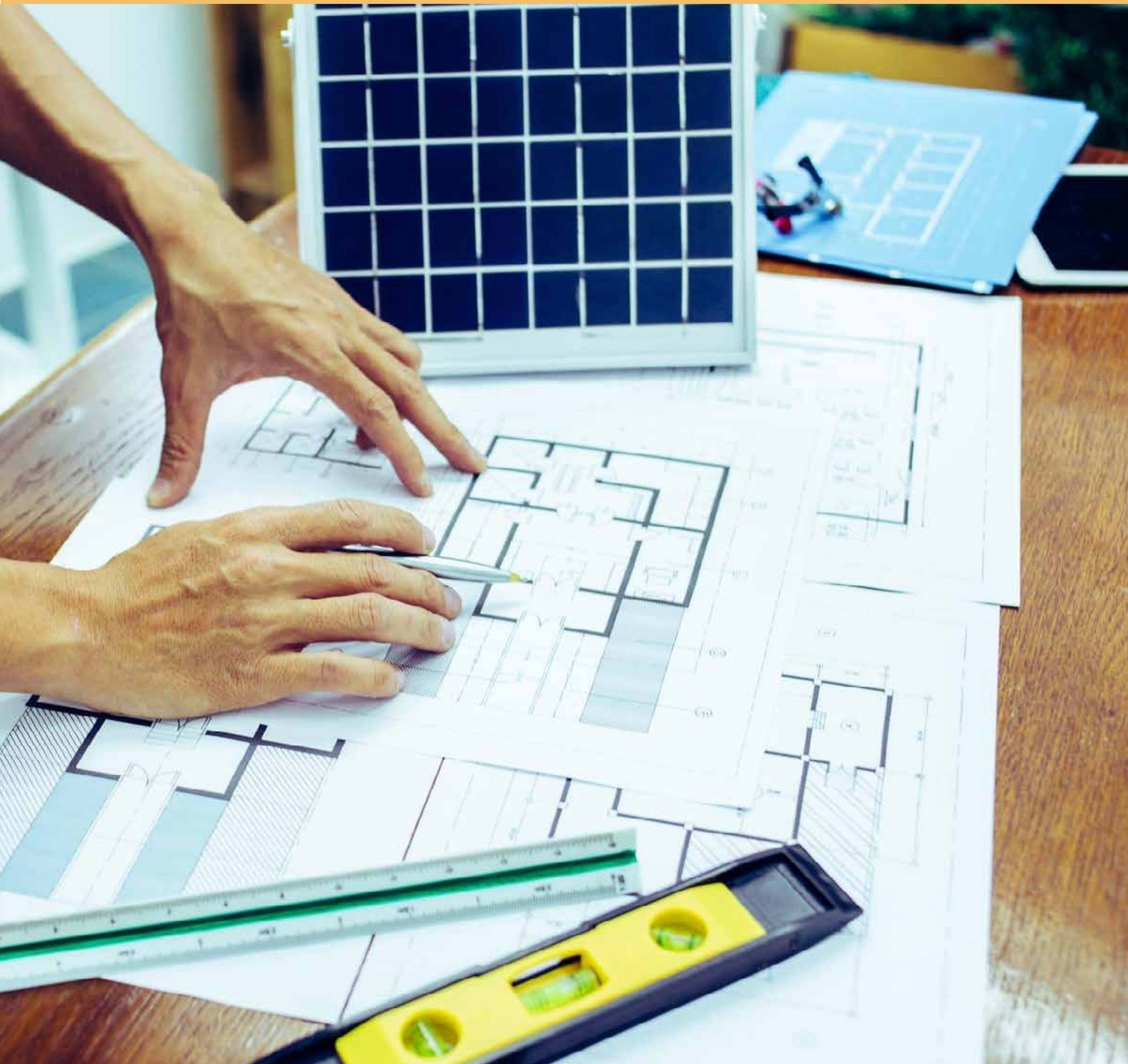
Other than the willingness of the client to invest, policy also limits the capacity of the system that may be installed. Prevalent policy in most states limits the maximum solar capacity to 100% of the sanctioned load or 100% of the capacity of the distribution transformer, whichever is less. In case a facility does not have a dedicated distribution transformer, the rated capacity of the distribution transformer for the locality is considered by DISCOM to provide a No Objection Certificate (NoC). In this case, DISCOMs consider total solar capacity installed on the LT side of the transformer. Hence, applications are typically approved on a first-come, first-served basis.

6. NO OBJECTION CERTIFICATE

In case net metering is required for the installation of a solar PV rooftop, a no objection certificate (NoC) needs to be obtained from the local electric utility for the installation of a net meter. List of documents required for net metering application and NoC from the electric utility is provided as follows. Concerned form and list of documents are available on the electric utility's website. The same are also listed as follows:

- Net Metering Application form
- Net Metering Agreement on Judicial Stamp of suitable value
- Copy of the latest electricity bill
- Single Line diagram for the SPV plant
- Bill of Material for the SPV plant
- An application fee may be required as per state policy for net metering

7. PROJECT PREPARATION



Solar systems are long-term assets, which are exposed to multiple technical, operational and environmental risks. Using high-quality components, installation as per best practices, and periodic maintenance are critical for their long-term performance. In case of OPEX-based projects, operational and performance risks are carried by Renewable Energy Service Company (RESCO), but still, savings and value generated for the client are directly linked to the performance of the system. In the case of a CAPEX-based project, the majority of the risks are in the scope of the client, and most risks are difficult to mitigate even through legal contracts. Hence, while selection of a good project developer or EPC contract is crucial, irrespective of the project's business model.

7.1 Vendor Selection

While the solar rooftop market space is extremely competitive, finding competent project developers and EPC contractors can prove to be very difficult. Absence of a recognisable brand makes the selection extremely difficult for prospective prosumers. It is advised that a techno-commercial review of the project developer/EPC contractor is carried out using at least the following guidelines.

Technical Review	Technical Competency	▪ Evaluate competency of engineering and project management team
		▪ Evaluate Company's project portfolio and experience
	Track Record	▪ Quality and timely of execution of projects in past
		▪ Generation performance of past projects, especially ones which are older than few years
		▪ Previous client feedback
	Service Record	▪ Dedicated resources for operations and maintenance
		▪ Previous client feedback
	Documentations	▪ Assessment reports, quality plan, execution plan, strength of legal contracts
Financial Review	Audited Balance Sheets	▪ Review medium and long term sustainability of the company
	Credit Rating	▪ If available, ratings of credible Credit Rating Agencies is a good reflection of a company's fiscal strength

Table 2: Guidelines for evaluating EPC contractor's techno-commercial competency

7.2 Contract Document

A project contract is a legal tool which lays out minimum deliverables and timelines, along with terms and conditions for financial transactions. A fair project contract shall safeguard the interests of both parties, i.e., the EPC company/Project Developer and the prospective prosumers, in a fair manner. While a project contract largely safeguards payment risk for the EPC Company, it plays a crucial role in safeguarding the client against technical and performance risks, along with possible delays in project execution. This section discusses the structure for a fair contract between the concerned parties, for both CAPEX and OPEX models. Guidelines for the selection of the Project Developer/EPC company and financial negotiations are also discussed.

Performance Obligations

The absolute output of a solar plant is not exactly indicative of its performance and efficiency, as the output varies due to weather conditions and solar insolation. Further, system performance is also a function of operations and maintenance (O&M) practices in the long-term. This section highlights key mechanisms deployed by industry to assure long-term performance.

- Performance ratio and yield guarantee stipulate plant performance levels, such as a minimum amount of energy delivered based on the measured solar irradiation at a site, as per system design and modelled plant behaviour. These guarantees account for Force Majeure events and warranty defects.
- Production guarantees state annual plant production levels, independent of weather conditions. Insurance coverage can be used to mitigate weather risk.
- Performance incentives usually rewards/penalises plant performance that misses or exceeds projected production levels.

- Energy-based contracts link plant production (kWh/yr) with O&M service provider revenues to ensure the incentives are properly aligned to deliver high performance.

Operations and Maintenance

Depending on the size of a project, O&M obligations are either built in contract with the system provider or outsourced to a third-party O&M service provider. Many EPC players also outsource their O&M obligations to third-party service providers. A typical O&M contract shall include the following:

- scope and responsibilities of the O&M contractor,
- scope and responsibilities of prosumer,
- quality benchmarks (refer to Section 8.2), incentives, liabilities, and payment for services; and
- insurance requirements and responsibilities.

8. PROJECT EXECUTION PLANNING

Project execution is the art of planning, foresight and intuition to ensure that the project is delivered on time and complies with the quality standards. This section discusses some of the key deliverables which reflect the project execution capacity of an EPC contractor/project developer.

8.1 Execution Plan

Any good project starts with an execution plan. A good execution plan clearly maps each deliverable with timelines and resources, building in quality checks and outlining possible threats. It ensures that delivery schedules from multiple vendors are aligned, multiple teams work together seamlessly and efficiently, and material dispatch and safety are well managed.

A well-detailed project execution plan is a good template for the client to monitor project progress and keep track of deliverables. Although planning helps in safe, timely and efficient execution of projects, it should be noted that projects are often delayed because of unforeseen variables and situations which are not in the control of an EPC company.

A sample Project Execution Plan is listed in Annexure C for reference.

8.2 Quality Plan

The quality of a project is not defined by its components alone. Accurate engineering as per standards, handling of material and quality of construction are some of the key aspects that define the quality of a project. A 'quality plan' primarily lays out quality standards and guidelines for engineering, procurement and construction, including necessary checks and testing procedures to ensure compliance. Some key aspects of a quality plan are discussed in Table 3.

Project Head	Key Quality Guidelines
Material	▪ Compliance with Bill of Material (BoM) ▪ Pre-dispatch inspection ▪ On-site check ▪ Pre-commissioning check ▪ Well defined transit and material handling practices
Engineering	▪ Accurate site inspection ▪ Compliance with IEC and other relevant standards ▪ Approvals by authorised personnel ▪ Pre-construction approval by client (if required)
Project Execution	▪ Project team with clearly defined roles and responsibilities ▪ Compliance with engineering ▪ Compliance with constructions and assembly practices ▪ Approval and record of deviations, if any ▪ Pre-commissioning checklist ▪ Punch list for any issues raised during pre-commissioning check ▪ Clearing of punch list with proof of rectifications
Documentation	▪ Well defined document control practices ▪ Record of all revisions made in documents ▪ Numbering and logging of all documents ▪ Recording of on-site deviations during construction ▪ Issuance of as-built drawings
Safety	▪ Duly appointed safety officer ▪ Pre-project risk assessment ▪ Well-equipped and trained project team ▪ Emergency response procedures

Table 3: Key quality guidelines for project

8.3 Engineering

Engineering encompasses detailed analysis and design of the system. This section briefly outlines critical engineering activities and design calculations, along with deliverables or outputs of the engineering exercise.

Solar Resource Assessment

Energy from the sun travels through space (in vacuum) at the speed of light in the form of electromagnetic waves, in a stream of energy packets called photons. These photons release heat when absorbed by any surface. Solar irradiance, measured in units of W per sq. m., is defined as an instantaneous measurement of solar power over a specific area. For the estimation of the yield of solar systems, solar insolation or incident solar radiation is used, which is defined as cumulative energy measured over a specified area for a defined period. The unit of Insolation is the same as that of energy, i.e., kWh per sq. m.

Solar radiation received by a surface consists of direct, diffused and reflected radiation. While estimating total solar radiation at a surface, also known as Global Solar Radiation for the respective region/surface, the tilt angle of the plain or the surface is also accounted for. Some key definitions are as follows:

- Direct Radiation: The solar radiation that reaches the surface of the Earth without being diffused is called direct beam solar radiation (DNI). It is measured by a pyrheliometer.
- Diffused Radiation: As sunlight passes through the atmosphere, some portion of it is absorbed, scattered and reflected by water vapour, clouds, dust, pollutants, etc., and is called diffuse solar radiation (DHI). It is measured by a shaded pyranometer and thermopile detectors.
- Ground Reflected Radiation: The radiation which is reflected by the ground is called Ground Reflected Insolation (GRI) or Albedo. It is more prominent in reflective regions like snow or water.
- Global Solar Radiation: The vector sum of direct and diffuse solar radiation is called global solar radiation (GHI = DNI Cos Ø + DHI). GHI is given for Ø = latitude angle, for any other tilt angle, it is called GTI (Global Tilted Irradiance). It is measured by a pyranometer.

PV Array Layout

PV array layout is designed in such a manner that it minimises the impact of shadow on the array layout and maximises energy output. Shadow because of permanent structures such as water tanks, surrounding trees, buildings, and other civil constructs in the vicinity needs to be considered. Shadow because of solar modules is also considered to define the inter-row spacing. 3D modelling and simulation tools such as PVsyst, Sketch-up and others are very effective for shadow analysis, if the input data is accurate.

As a best practice, it should be ensured that the shadow cast by solar modules on subsequent rows is avoided for a period of 4 hours on either side of solar noon. This typically is equivalent to time between 8 am and 4 pm. Azimuth angle and altitude angle extended by the sun on the day of Winter Solstice (December 21) shall be considered for shadow analysis since the shadow lengths are longest on this day. Basic methodology for manually determining the row spacing is as follows:

$$\text{Row spacing} = \text{module height} \times \frac{\cos(\text{azimuth angle})}{\tan(\text{altitude angle})}$$

where,

Module height: Length of module when mounted in portrait position, and width of module when mounted in landscape position.

Azimuth angle: This horizontal coordinate defines the sun's relative direction along the local horizon.

Altitude angle: Refers to the angle of the sun relative to the Earth's horizon. It is measured in degrees. The altitude angle varies based on time of day, time of year and latitude on Earth.

Solar String and Array Design

Solar string inverters are either designed for DC input as a single array, multiple sub-arrays for respective maximum power point tracking (MPPT) inputs or individual string inputs that feed into the AC bus. In either case, DC input characteristics of operating voltage, voltage at maximum power and input current shall always be within the range prescribed for the inverters by the manufacturer.

For design, the necessary technical specifications of solar modules and grid-connected inverters are provided by the equipment manufacturer. While designing solar PV strings or arrays, it must be ensured that maximum and minimum voltage levels are within the mandated range for the inverter(s). For this purpose, it is important that the effect of temperature on the electrical characteristics of the solar PV module is considered. This can be estimated by the use of temperature coefficients for voltage and current.

i. Maximum Operating Voltage for String/Array

This is defined as the open circuit voltage at the minimum ambient temperature for the project site. In the early morning, at the instant when solar modules begin to function, cell temperature is equal to ambient temperature.

$$\text{Maximum Voltage for PV string/array} = M \times V_{OC} \times \{1 - [\gamma_{VOC} \times (T_{min} - T_{STC})]\}$$

ii. Maximum Voltage at Maximum Power

The maximum string voltage for maximum power is calculated at the minimum operating temperature. The formula is given as follows:

$$V_{maxPVstring} = M \times V_{MP} \times \{1 - [\gamma_{MP} \times (T_{min} - T_{STC})]\}$$

iii. Minimum Voltage at Maximum Power

The minimum voltage corresponding to the maximum power point is calculated at the maximum operating temperature. The formula for the same is as follows:

$$V_{min,MP} = M \times V_{MP} \times \{1 - [\gamma_{MP} \times (T_{max} - T_{STC})]\}$$

iv. Maximum Input Current

As the temperature increases, the short circuit current of PV modules increases, although the variation is very small. The maximum short circuit current can be computed corresponding to the maximum expected cell temperature

The maximum array current can be determined by the following equation.

$$I_{Max} = I_{SC} \times [1 - \gamma_I \times (T_{max} - T_{STC})]$$

In case of a string, Maximum String Current = PV Module Max current

In case of Solar Array, Maximum Array Current = S x PV Module Max current

where,

M = Number of modules in a series

S = Number of strings in an array

V_{oc} = Open circuit voltage of module at standard test conditions (STC)

V_{mp} = Open circuit voltage of module at STC

I_{SC} = Short circuit current of module at STC

I_{Max} = Maximum short circuit current for the module

γ_V = Voltage coefficient

γ_I = Current coefficient

T_{max} = Maximum expected cell temperature = Maximum ambient temperature + 20°C

T_{min} = Lowest expected cell temperature = Lowest expected ambient temperature

T_{STC} = Cell temperature at Standard Test conditions = 25°C (approximately)

Temperature coefficients for the solar PV modules can be obtained from its technical data sheets. A sample data sheet is provided in the Annexure D.

Circuit Protection Design

Design or sizing of various circuit protection systems is discussed as follows.

i. Isolators or Disconnect Switch

Circuit breakers that are used as PV array isolators are rated per pole. In case of non-isolated or transformer-less inverters, the minimum voltage rating per pole shall correspond to the maximum open circuit voltage for the solar array. This shall correspond to the voltage corresponding to the minimum expected cell temperature, as discussed in section 6.3.2. A safety factor of 1.15 is considered for the same. The total ISC of the array determines the current-capability requirements for the switch (safety margin of 125%) to address increased currents during solar noon. A temperature derating factor must also be considered to determine the rating of the DC disconnect switch under normal conditions.

ii. Main Circuit Breakers

Fault current protection is provided to each string to protect from the risk in case other strings feed current into a single string due to shading or an earth fault. This might cause a situation where the faulty current is higher than the safety current that can be tolerated by the faulty string. The rated trip current of the protection device for PV strings can be determined as follows:

$$1.5 \times I_{SCMOD} \leq I_{trip} \leq 2.4 \times I_{SCMOD}$$

I_{SCMOD} = Module short circuit current

I_{trip} = Rated trip current of the fault current protection device

Fuse or circuit breakers can also be used for over-current protection. Circuit breakers must satisfy the criteria as follows:

- Must be rated for maximum DC array voltage, corrected for minimum ambient temperature.
- Bi-directional/non-polarised, which can break the current flowing in both directions.
- Must be within the current range as specified above.

iii. Surge Protection Device (SPD)

SPDs are provided on the DC and AC sides. They are selected based on the maximum operating voltage and maximum discharge potential required. While the former is based on the electrical circuit characteristics, the latter is based on the application or requirement of surge capacity, which is defined by the type of SPD.

Location of SPD	Scenario	Rated Voltage	SPD Type
DCDB	Without LA	Max. String Voltage	Type II, DC
	LA Installed	Max. String Voltage	Type I + II, DC
ACDB	Without LA	230V of 1P, 440V for 3P	Type II, AC
	LA Installed	230V of 1P, 440V for 3P	Type I + II, AC

Table 4: SPD location and operating characteristics

Cable Sizing

Cables can add a high cost to the system, but under-sizing cables can significantly impact the efficiency and performance ratio of a system. Cable sizing is done based on two key criteria:

i. Current carrying capacity of the conductors

ii. Voltage drop across the cables is less than 5%

Current carrying capacity is the maximum amount of current that can be carried by the conductor without sustaining any damage. String, array and AC cables shall carry different volumes of current, and hence, they need to be sized accordingly. A safety factor of 1.25 is considered while estimating the current carrying capacity required.

For PV string cables, the current-carrying capacity is defined as:

$$\mathrm{CCC} \geq (\mathrm{Imp})_{\mathrm{Tmax}} \times 1.25$$

where,

CCC: Current carrying capacity of the conductor

$(\mathrm{Imp})_{\mathrm{Tmax:}}$ Current at maximum power, corresponding to maximum cell operating temperature

For sub-array cables, the following equation should be used for determining the current-carrying capacity of the system:

$$\mathrm{CCC} \geq \mathrm{I}_{\mathrm{max,array}} \times 1.25$$

where,

$I_{max,array}$ is the sum of all short circuit currents all PV strings.

It is recommended that the voltage drop across DC and AC cables should not be more than 5%. As a practice, voltage drop across DC cables is kept at less than 4%, and less than 1% for AC cables. Basic formulae for computing voltage drop in DC and AC cables are provided as follows. Length of cables shall be accurately provided based on the on-site assessment and cable layout.

$$V_{dropDC} = \frac{2XLD_{Ccable}XI_{DC}X\rho}{A_{DCcable}}$$

$$V_{dropAC} = \frac{2XL_{ACcable}XI_{AC}X\rho Xcos\emptyset}{A_{ACcable}}$$

where,

$L_{DC\ cable}$ = Route length of DC cable (m)

$L_{AC\ cable}$ = Route length of AC cable (m)

I_{dc} = DC current carried by the cable

I_{ac} = AC current carried by the cable

ρ = Resistivity of the conductor

cos ϕ = Power Factor

$A_{DC\ cable}$ = Cross sectional area of AC cable

$A_{AC\ cable}$ = Cross sectional area of AC cable

Lightening Arrestor

A lightning arrestor's (LA) area of protection is usually characterised by a protection radius which is dependent on the type and height of the arrestor. It shall be ensured that all critical equipment, including the PV array, is within the radius of protection extended by LA. A plane of reference is defined corresponding to the tallest equipment to be protected.

The height of the lightning arrestor can be determined as follows:

$$H = h_{LA,referenceplane} + h_{referenceplane}$$

$$h_{LA,referenceplane} = r_{protrad} \times \tan^{-1}\theta$$

$$r_{protrad} \geq \text{Minimum radius of protection required to protect the equipment}$$

where,

H = Height of the arrestor from ground/roof

$h_{LA,\ reference\ plane}$ = Height of LA from Plane of Reference

$h_{reference\ plane}$ = Height of the reference plane

$r_{prot\ rad}$ = Radius of protection

Structural Design and Analysis

The mounting structure for the solar module needs to be designed as per the governing standards, especially to withstand wind loads at the location. It should be ensured that structural analysis is done using accurate structure design, material properties and wind speed.

Some important checks for structural analysis are listed as follows:

i. Height of the building where the plant is being installed. Data is available for basic wind speed at 10 m above the mean ground level and should be extrapolated using a correction factor to determine the design wind speed at the height at which the plant is located.

ii. Wind speed data usually uses the peak gust velocity averaged over a short time interval (usually three seconds) for the location. These are estimated for a 50-year return period.

iii. Any obstruction to the wind in the vicinity of the plant should be noted, as these can be taken into consideration in the form of a correction factor, so the analysis can simulate the impacts of such obstructions.

iv. Angle of tilt of the plant - a higher tilt angle will block more wind, leading to a higher design wind load. Hence, the client must ensure that the tilt angle used in the wind analysis is as per the structure drawings.

v. Elevation: In some cases, the structure is elevated to accommodate shadow impact or increase the installed capacity. In such cases, wind load impact on the structure increases because of an increase in torsional stress.

Based on these inputs, the structural analysis report provides stress ratios for all members and joints in a structure. In case any members or joint failure is reported, the structure needs to be redesigned. Further, it should also be ensured that the maximum deflection of members should be less than "(span of the member in m)/150". This is to ensure that there is no undue stress on the solar modules, which can lead to the formation of micro-cracks.

It is recommended that the structural analysis shall be verified by an independent and competent structural engineer.

Performance Ratio & Plant Yield

Plant yield is defined as the total energy generated by the PV plant annually to meet the consumer's energy demand. The PV array size, solar insolation and the system efficiency determine the overall energy yield of the plant.

Performance Ratio,

$$\mathrm{PR} = (1-\alpha) \times (1-\mathrm{T}_{\mathrm{loss}}) \times (1-\mathrm{S}_{\mathrm{soilingloss}}) \times (1-\mathrm{V}_{\mathrm{drop}}) \times \eta_{\mathrm{inverter}}$$

$$\text{Plant Yield} = \mathrm{P}_{\mathrm{sun}} \times \mathrm{P}_{\mathrm{rated}} \times \mathrm{PR} \times 365$$

where,

P_{sun} or Peak Sun is numerically equal to average solar irradiation per day (kWh/m2/day)

P_{rated} is rated power of solar module (kW)

α is manufacturer's tolerance

T_{loss} is efficiency loss due to variation in temperature from STC

$S_{soiling\ loss}$ is loss in efficiency because of solar module soiling

V_{drop} is impedance loss in power cables

$\eta_{inverter}$ is the inverter efficiency

Table 5 provides a summary of key deliverables of design and engineering.

Deliverables	Checklist
Shadow Analysis Report	▪ Analysis is done such that the array is shadow-free from 9:00 am to 3:00pm (or 3 hours on either side of solar noon)
Design Calculations	▪ String sizing and invert matching
	▪ Cable sizing
	▪ Sizing of protection equipment
Array and Equipment Layout	▪ Proper row spacing to avoid shadow of modules during peak sunshine hours
	▪ Sufficient access to equipment and all solar modules for cleaning and maintenance
Foundation Design and Layout	▪ Size and composition of foundation blocks
	▪ Excavation plan for civil work
	▪ Composition of concrete mix is M20 grade
	▪ Anchoring mechanism is clearly defined
	▪ Adhesion and water-proofing application is clearly defined
Earthing Calculations	▪ Correct soil resistance is used for calculation
	▪ Step and touch potential (for larger plants)
Structure Drawings and Structural Analysis	▪ Detailed BoM of structure with specifications and material used for all members
	▪ Material and size of nuts, bolts and other accessories
	▪ Galvanisation thickness (if applicable)
	▪ STAAD report (as discussed in Section 8.3.)
	▪ Correct wind speed data for the location as per zone
Single Line Diagram	▪ Equipment size, gauge of cable and protections are clearly depicted
Performance Ratio and Generation Estimation	▪ All relevant losses are included and accounted for in the estimation
Bill of Material	▪ List of all material and equipment as per contract

Table 5: Deliverables of design and engineering

8.4 Safety Plan

Safety is the responsibility of both the employer and the employee, along with any other personnel present at the site. The employer is responsible for ensuring that the employees are well-trained and properly equipped. The employees are responsible for following the safety practices that protect them and their fellow workers. Good safety practices and their adherence are reflective of the contractor's commitment to the safety of its employees and its professional competence, while ensuring incident-free project execution.

Safety policies and practices should be proactive in nature. This involves assessing risks, hazards and unsafe behaviours to predict possible accidents. Safety practices and prevention procedures are designed accordingly. Some key aspects of a good safety plan are discussed in the table as follows:

Safety Team	▪ Safety lead
	▪ Trained personnel for risk assessment
Risk Assessment	▪ Slippage and fall risks
	▪ Electrical risks because of existing equipment, overhead lines and live cables
	▪ Existing gas and water pipelines
	▪ Risks because of extreme environments or workspaces
	▪ Fire hazards
	▪ Evacuation plan

Equipment and Tools	▪ Ensure power tools are handled by trained personnel only
	▪ Best practices for handling tools and equipment shall be clearly defined, including use of relevant safety gear
	▪ Ensure integrity of tools such as power tools, welding torch etc. before use
Construction	▪ Log and record of people working on job site
	▪ Job schedules and reporting managers
	▪ Best practices for lifting and handling equipment
	▪ Use of PPE along with safety harness, helmets, goggles etc
	▪ Ensuring no metal surface is live before starting work
	▪ Ensuring equipment are turned live by authorised personnel only, after proper communication to the team.
	▪ Ensuring supervision for hazardous works or working in extreme spaces such as elevations or closed spaces
	▪ Risk mitigation for working in extreme environmental conditions
	▪ Ensuring cleanliness of work area to avoid trips and entanglement
Emergency Response	▪ Well defined chain of command
	▪ First aid kits and support procedures
	▪ Nearest clinic and hospital
	▪ List of emergency numbers
	▪ Firefighting equipment
	▪ Evacuation plan
	▪ Reporting procedure

Table 6: Safety guidelines for different aspects of project design and construction

8.5 Project Monitoring

Once a project is in the execution phase, multiple teams shall be working together to deliver the desired outcome. Monitoring the progress of a project is a critical activity for any project developer, but it can be equally important for the client if they wish to track progress and enforce quality by performing periodic checks. Table 8 briefly discusses various stages of the project, along with parameters for monitoring outcomes and progress. Tentative timelines are also shared, although they shall vary significantly with size, complexity and location of the project. This shall be applicable to projects of capacity up to 100 kWp.

Project Phase	Outcomes/Progress Tracking	Timeline (days)
Feasibility Study	▪ Site assessment report ▪ Shadow analysis and capacity estimate ▪ Techno-Commercial proposal	7 - 15
Engineering	▪ Engineering Drawings ▪ Bill of Material	10-20
Project Preparation	▪ Project Plan ▪ Quality Plan ▪ Safety Plan	3-7
Dispatch of Material	▪ Dispatch Schedule ▪ Transit plan and details ▪ Receipt of material	20-45

Project Phase	Outcomes/Progress Tracking	Timeline (days)
Construction	▪ Team deployment details ▪ Daily progress report (to include civil, mechanical and electrical works) ▪ Deviation records ▪ Safety incidences	10-30
Commissioning & Handover	▪ Commissioning check ▪ Punch list record ▪ Clearing of Punch list ▪ Commissioning report ▪ As built drawings ▪ Labelling, signage and on-site records ▪ Certificates and warranty documents	2-7

Table 7: Deliverables and timelines for project phases

Some key tools for project monitoring are described as follows:

i. Daily progress reports (DPR) are designed to provide information on on-site project progress during the construction phase, along with details of resources deployed on-site. Typically, project tasks are broken down into Civil, Mechanical and Electrical works. The DPR also provides a comparison between planned milestones and realised milestones, providing insights into delays and inefficiencies arising during project executions. A sample of a DPR is provided in Annexure E.

ii. Deviation Records are used to log any deviations from design and engineering instructions, or from the BoM. Such deviations are to be reported by the on-site technical lead, and they shall be approved by authorised personnel (for example, project manager or engineer) and the client.

iii. The Commissioning Checklist enlists all the important tests, reviews, and checks that must be conducted before a system is energised. A sample commissioning checklist is shared in Annexure F.

8.6 Net Metering

Once the solar plant is ready for commissioning, a suitable net meter, depending on the type of connection (1P, 3P, HT), is submitted to the local DISCOM office for testing and approval. Once the meter is approved after testing, DISCOM officials shall install the meter after inspecting the solar rooftop plant.

8.7 Commissioning and Handover

Commissioning and handover are typically the final phase of the project, especially in CAPEX projects. Client shall ensure that the project is delivered as per commitments and all critical documents are handed over before releasing final payments as per the contract. A standard checklist for project handover is provided in Annexure G.

9. QUALITY GUIDE FOR KEY SYSTEM COMPONENTS

This section discusses the main components used in a solar PV system, along with parameters to establish the quality of respective components. Since factory or lab testing is not always feasible, especially for small-scale projects, an attempt has been made to provide a practical approach for gauging the quality of various components.

9.1 Solar Modules

Solar modules are the primary energy-generating component of a solar power plant. They are built as a packaged and connected assembly of solar cells that directly convert solar radiation to DC electricity, which may be further converted to AC electricity with the help of inverters. Solar panels are rated by the amount of power they produce at standard test conditions (STC).

Solar cells of different technologies and material compositions are available in the market. Technologies such as passivated emitter and rear cell (PERC), Heterojunction with Intrinsic Thin-Layer (HIT), and bifacial are also gaining market share because of their better performance and higher efficiency. Mono and polycrystalline solar modules are most used, and for the purpose of this module, the information covers only the aforementioned solar modules.

Bill of Material for Solar Modules

It is very difficult to predict the quality of a solar module through visual and mechanical inspection. The performance of a module can depend on a variety of reasons, which include the components of materials used in its assembly, assembly process, handling of the solar module during manufacturing, freight and installation. This section discusses key components used in the construction of a solar module. Once installed, evaluating the performance of solar modules can be quite difficult. Hence, it is best to ensure that solar modules are made from quality components, sourced from reliable manufacturers.

i. Solar cells are the heart of a solar module as they largely define the electrical and performance characteristics of a solar module. Various cell technologies are available today, with polycrystalline and monocrystalline cells being the most common ones. PERC and HIT have also been gaining popularity because of their high efficiency and better long-term performance. Once manufactured, cells are graded based (A, B, C, I grade) on their quality. Cells must always be A grade, with no reverse current, scratches, or spots.

ii. Backsheets are designed to electrically isolate, protect and shield the PV cells from weather, moisture and external conditions. They are prone to various defects such as yellowing, cracking, burning holes and delamination. It is critical that backsheets are designed for a life cycle of at least 25 years. Good quality backsheets have tough film with high surface tension, durable adhesion, good weatherability, high melting temperature (about 200 °C), UV resistance, and do not react to any major solvent.

iii. Encapsulant is used to provide adhesion between solar cells, the top surface and the rear surface of the solar modules. Its desired properties are stability at high temperature and high UV exposure. It should also be optically transparent and have low thermal resistance. Ethylene vinyl acetate (EVA) is an encapsulant commonly used in the PV panel manufacturing process.

iv. Top surface of solar panels is covered with a layer of low-iron tempered front glass. Some key characteristics of glass sheets are impact resistance, low thermal resistivity, self-cleaning, and allow high transmission of light in the visible wavelength range. It also protects PV modules from ingress of water, vapours and dust particles.

v. Aluminium frames hold together various layers of a solar PV module using a good silicon sealant. The frame should provide protection from dust, winds, water and humidity. It should also be extremely resistant to corrosion and other degradation effects.

Other than the key components mentioned above, solar modules use silver-plated copper ribbons for the interconnection of cells. Different busbar designs are used to impact the quantity of material used and the internal resistance of solar modules. Currently, the 5BB (5-Busbar) design is popular because of less usage of material and better cell efficiency. Manufacturers also include different combinations of bypass and blocking diodes, which dictate the performance of modules under low light or shading conditions. They also protect the modules from reverse currents by providing an alternative low-resistance path and hence enhancing the life of solar modules.

Parameters to Assess a Solar Module

A few key parameters to assess a solar module are discussed as follows. A sample data sheet for a typical solar module outlining these parameters is also shared in Annexure D.

i. I-V curve

The current-voltage curve of a PV module, commonly known as the I-V curve, is used to describe its energy conversion capability at the existing irradiance levels and temperature. Theoretically, the I-V curve will provide the combinations of current and voltage at which the PV module could be operated, given that the irradiance and cell temperature are held constant.

The span of the I-V curve ranges from short circuit current (Isc) at 0 volts to 0 current at open circuit voltage (Voc). The 'knee' of a normal I-V curve is the maximum power point (Imp, Vmp), at which the module generates maximum electrical power.

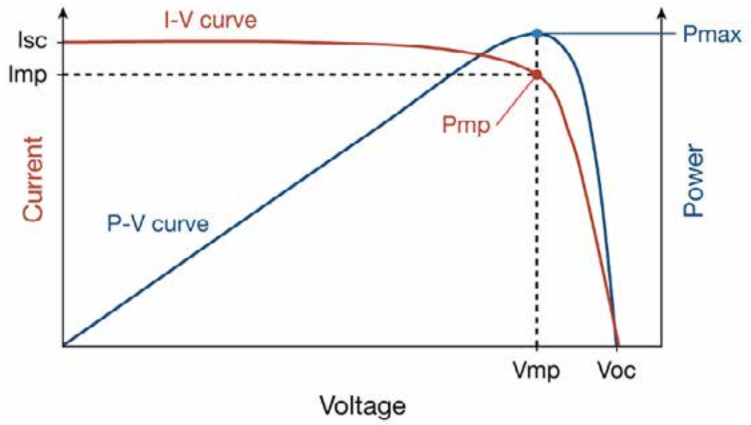


Figure 5: Sample I-V curve for solar PV module

In an operating PV system, the MPPT algorithm continuously calibrates output current and voltage corresponding to maximum power yield. A sample I-V curve is shared as follows.

ii. Efficiency

A solar module's efficiency is determined by its ability to convert energy in the form of sunlight into electricity. Typically, solar module efficiencies lie between 14-24%. The efficiency of a solar module is a factor of efficiency and grade of cells used, packing of cells and internal resistance of solar modules. Internal resistance of solar modules again is dependent on the quality of material used in fabricating the module, and the quality of the product processed. For different modules with the same rated capacity at STC, the module with higher efficiency will be smaller in size.

iii. Fill factor

It represents the squareness of the I-V curve, and is the ratio of two areas defined by the I-V curve, as follows:

$$\text{Fill Factor} = \frac{(V_{mp} \times I_{mp})}{(V_{oc} \times I_{sc})}$$

where,

V_{mp} = Open circuit voltage

I_{mp} = Current at maximum power

V_{oc} = Open circuit voltage

I_{sc} = Short circuit current

Although it's practically impossible, an ideal PV module would produce a perfectly rectangular I-V curve in which the maximum power point coincides with (Isc, Voc) and the fill factor would be one. Typically, I-V curves of two individual PV modules have the same values of Isc and Voc, but the module with the higher fill factor would produce more power. The actual magnitude of the fill factor depends strongly on the module technology and design and can range from 0.5 to 0.82.

Derating Coefficients (Box)

The PV derating factor is a scaling factor that is applied to the PV module power output to accommodate for the reduced output due to external factors such as temperature. Derating coefficients can be applied to a PV module's performance to determine how temperature would impact voltage, current and power output values. While voltage and power output reduce with increasing temperature, current increases as temperature increases. Modules with lower values of temperature coefficient tend to be more efficient over a range of operating temperatures.

Degradation in Solar PV Module

Multiple factors can induce degradation of solar modules, resulting in a decrease in efficiency and output of solar modules over the years. Some of the important factors are discussed as follows:

i. Time-based degradation: The efficiency of solar panels decreases over time automatically, but such degradation is typically accounted for in their performance warranties. Typical causes for time-based degradation of solar panels include thermal cycling, damp heat, humidity freeze and UV exposure. Typically, solar modules carry a performance warranty of 25 years. Most manufacturers provide this warranty in the form of a stepped efficiency degradation as a minimum guaranteed output power of 90% for up to 10 years, and then 80% for 25 years. Some top manufacturers provide linear performance efficiencies in the form of maximum annual degradation. This ensures better performance of the modules. Annual degradation of solar modules is typically expected to be less than 0.8% on a year-to-year basis.

ii. Potential induced degradation (PID): It is an undesirable property of some solar modules that reduces panel efficiency and power output over time. PID is usually caused when modules have a negative potential with respect to ground. Although it's a reversible effect, it can reduce the yield of a solar system by 30%. Factors such as humidity, grounding system, components of PV modules and choice of inverter used can contribute to PID. The risk of PID can be mitigated by appropriate grounding as recommended by the module and inverter manufacturer.

iii. Cell defects: Cells are exposed to various possible defects during manufacturing, handling and operations. These defects are discussed separately as follows:

- Micro-cracks are hairline fractures in PV cells caused by thermal or mechanical stress during fabrication, handling or operations. These cracks are not visible to the naked eye, but they can critically impact the performance of solar modules over time.
- Discolouration is typically caused by exposure of EVA to UV rays. Additives are added to EVA to improve its UV resistance. Hence, poor quality EVA are exposed to risks of discolouration. Moreover, if EVA is stored under improper conditions or when stored for too long before manufacturing, the additive in the EVA partly disappears, increasing the risk of discolouration when exposed to UV rays. Bleaching of the browning cell may cause bubble formation in the EVA sheet and backsheet, resulting in corrosion of cells.

Further, discolouration of bus bars and ribbons can be caused by oxidation. This is typically caused by water vapour entering a module, which may be a result of poor-quality sealant or backsheet. Poor soldering technology may also cause burning, which is seen as a yellowish colour on ribbons.

- Delamination occurs when the bond between the backsheet and the glass separates. This results in air and moisture creeping into the module, causing corrosion and failure of cells. This phenomenon may also occur if the EVA sheet is improperly encapsulated or not allowed to cure properly. The layer of EVA may dissolve over time and result in a milky colour, exposing the cells to air and moisture.
- Hot spots are caused by localised excessive heat production in cells because of cell defects or partial shading. This causes damage to encapsulation material and cells, and in extreme cases, it may also cause a fire. They also seriously impact the performance of a solar module.

9.2 Solar Grid-Connected Inverters

Inverter is the primary component of a solar PV system which is used to convert the DC electricity generated from the PV modules to useable AC power. Nowadays, multiple configurations of solar inverters are available in the market and can be used in plants based on the power requirements/plant capacity.

Types of Grid-Connected Inverters

i. String inverters are the most commonly available solar inverters in the market, where each string of the solar panels is connected to one input of the inverter. In case of large system capacities, there can be multiple string inverters, each with multiple string inputs. While these are the most used type of inverters, they suffer from a few issues. In case even one panel in the string is operating at a lower voltage, either due to the shading effect or different orientation, the voltage of the entire string is reduced to that level, resulting in low power generation.

ii. Micro inverters are becoming popular for residential and commercial installations. Micro inverters are typically module-level components where one micro inverter is installed on each panel. Micro inverters convert DC to AC power right at the panel and hence, do not require a string inverter. Also, because of the panel-level conversion, if one or more panels are shaded or are performing on a lower level than the others, the performance of the remaining panels won't be compromised. Micro inverters monitor the performance of each individual panel, whereas string inverters monitor the performance of each string. Thus, micro inverters are a good option for installations with shading issues or for panels installed on multiple planes facing various directions. While overall systems using such inverters are more efficient, these often cost more than typical string inverters.

iii. Central inverters are similar to string inverters but offer a much larger capacity and can support the connection of multiple strings. In this case, the strings are combined in a DC combiner box, which is then connected to the inverter. These require fewer component connections; however, they can be used only in high-power generation installations.

Gauging a good quality inverter can be extremely tricky, especially since inverters are also prone to failures and faults in a solar PV system. Some standard parameters, such as IP protection, efficiency, number of available MPPT and wide operating range, are good indicators of the quality of the system. But most importantly, feedback from former customers can provide the best input on the quality of the inverter and service support provided by the manufacturer. In the present market, very few companies are committed to providing timely and hassle-free service support to their customers.

Annexure H provides a comparative analysis of a 50kW string inverter offered by multiple manufacturers. Other than electrical efficiencies, the cost of inverters varies depending on in-built protections, monitoring and other features. It also shows the technical datasheet for a typical on-grid inverter.

9.3 SPV Mounting Systems

SPV mounting systems are used to fix solar modules on surfaces such as roofs, building elevations, or ground. In the case of solar rooftops, the design of structures is dictated by the type of roof. Systems are usually designed as fixed tilt, although systems with seasonal tilts are also feasible. Tracking structures are typically not feasible for rooftop systems because of their small scale and the complexity of operations.

This section discusses different types of structures commonly deployed on rooftops, along with their critical assessment. Types of structures based on the different types of roofs such as industrial sheds, slant roof, or a flat roof structure, different categories of structure are discussed as follows:

i. Mounting Structure for Pitched Roofs

Pitched roofs are mostly found on industrial sheds, farmhouses or residential roofs in hilly regions. The most common mounting configurations are railed, rail-less and shared-rail structures. These structures are riveted to the tin shed. Waterproofing is done using ethylene propylene diene monomer (EPDM) rubber and waterproofing sealant.

Railed mounting system uses rails attached to the roof to support the modules. The rails are typically secured to the roof by a bolt or screw with appropriate material around the hole for a watertight seal.

Rail-less mounting system uses a bolt/screw to connect the module to a hardware attached to the roof without any rails. As there are no rails, the overall cost of the system is lower than that of a railed structure. It also allows for flexibility in the installation of panels, as the panels are not limited to the direction of rails and can be positioned in any manner.

Figure 6: Types of mounting structures

A shared rail system allows two adjacent rows of panels to be clamped to a commonly shared rail. This reduces the punctures on the roof and allows for quick installation. In some cases, instead of a continuous rail, small segments of rail are used, which provides the flexibility of installation.

ii. Flat Roof Mounting Structure

Flat roof mounting structures are the most common in India, and they are highly customisable. Based on the client's needs and space availability, the flat roof structures can be designed to maximise the generation and optimise space utilisation. In the case of rooftops, mounting structures are either designed for fixed tilt or seasonal tilt.

In the case of fixed tilt modules, an optimal tilt angle is used to ensure maximum possible generation. This tilt angle is approximately equal to the latitude of the project site. Seasonal till structures are typically designed for three positions: optimal fixed tilt angle, and angles of +/- 15 degrees from the fixed tilt angle.

Penetrating-type solar structures are fixed by either anchoring to the reinforced cement concrete (RCC) slab or to RCC foundations constructed on top of the RCC slab. The latter is more time-consuming, but the same is preferred when either the slab thickness is low or its integrity can't be compromised. This is often the case in old buildings. Three types of anchoring mechanisms are commonly used.

a. Mechanical anchoring is done using anchoring bolts. It is essential that these bolts achieve 2-3 inches of penetration in the RCC slab to gain sufficient traction. RCC or plain cement concrete (PCC) foundations are constructed on top to add dead load and provide waterproofing.

b. Chemical anchoring is done using steel studs or bolts, which are bonded into masonry and concrete substrate using a resin-based adhesive system. This is suitable for high-load applications, especially in cases where the strength of concrete is unknown. Chemical anchoring naturally provides waterproofing, and hence, the construction of foundation blocks on top is not necessary.


Figure 7: Ballast type mounting structure

c. Ballast-type structures provide non-penetrating anchoring for the installation of mounting structures. Concrete ballasts provide the necessary dead load to ensure that the structure can sustain wind loads.

iii. Carport Mounting Structure

A carport mounting structure is a special application variant of an elevated flat roof mounting structure designed to support solar photovoltaic panels above parking areas. It is installed at a considerable height, providing a covered parking space while generating electricity through a rooftop solar system. There are multiple design variants for carport mounting to suit different customer requirements, site

conditions, and vehicle capacities.

Figure 8: Carport mounting structure

Selection of Structural Material

Mounting structures are typically made of galvanised iron or anodised aluminium. Though recently the market has seen many more new variants, most of which are alloys (like PosMAC, which is a POSCO Magnesium Aluminium Alloy Coating product). Since the mounting structure is continuously exposed to the environment, it is important to ensure that it is protected from corrosion and environmental degradation for the plant's design life, which is at least 25 years. Corrosion protection can be achieved in several ways, especially by choosing the correct material for fabricating the structure.

Civil work, which mostly includes foundation and anchoring, forms an integral part of the PV plant and ensures strength, integrity and longevity of the plant. Foundations can be built, either with RCC or PCC, depending on the strength required. Additional adhesives may be mixed to enhance the mechanical, waterproofing and anti-corrosion properties of the foundation blocks. Some of the key elements to ensure the quality of civil work are discussed as follows:

i. Reinforcement: Twisted steel bars (rebar) are used as reinforcement in RCC foundations, which increase the strength of the concrete pedestals. These bars should be of the correct size as mentioned in the design document and should be corrosion resistant. The size of the RCC bars is usually determined based on the strength required, wind loading on the plant and elevation of the plant.

ii. Concrete: Different grades of concrete are used based on the strength requirement. Concrete grades are specified in terms of the proportion of cement, fine aggregate (sand) and coarse aggregate. The client must ensure that the contractor is using an industry-grade mix of cement to ensure the strength of the structure and civil work. Besides the concrete mix, it is also important to ensure that the mix is poured properly into the mould and allowed to set in such a manner that no air gaps or bubbles exist in the mix, as air gaps tend to weaken the strength of the foundation. Concrete grade of M20 or M25 is typically recommended for solar rooftop projects.

iii. Curing time: The recommended curing time for small and large foundations is 1-2 days and 5-7 days, respectively. If adequate curing time is not allowed, it may result in cracks and chips in the foundation over time, leading to poor structural strength. In cases where wet curing[2] is not feasible, intermittent curing of at least three times a day shows acceptable compressive strength of concrete and saves water and electricity.

iv. Fasteners: It is important that properly sized fasteners as per BIS specifications are used for anchoring so that they can sustain the wind loads. Stainless steel fasteners are recommended, or else exposure to environmental elements may lead to corrosion and degradation over time, compromising the structural integrity of the mounting structures. The bolts should be tightened as per the recommended torque, and if required, the connection design should be verified by a structural engineer.

9.4 Cables or Wires

Cables or wires connect different components of the solar PV system, enabling the flow of electrons and delivery of energy to its destination. In a grid-connected solar PV system, the cables need to be designed for both AC and DC applications. The environmental and electrical parameters for the respective applications can be very different and hence require a conscious design and selection of materials. A well-designed cabling system is engineered to optimise efficiency, while ensuring that it withstands thermal, electrical and mechanical stress throughout the life of the system.

[2] The process of maintaining moisture on new concrete for 7-10 days to ensure proper hydration.

Application-specific cables are paramount to ensuring the economic viability of solar power systems. Wire types vary in conductor material, insulation and built. Aluminium, copper and steel are commonly used materials in cable manufacturing. Cables can be solid or stranded, unsheathed or armoured, single-core or multi-core. In addition, cables may have characteristics like resistance to fire, UV protection and moisture resistance, etc.

DC Cable

DC cables in a solar PV system are exposed to various environmental elements such as heat, UV rays, moisture, dust particles, and even pests. Individual modules are connected using cables to form the PV array, to connect the string to the generator junction box, and a main DC cable which connects the generator junction box to the inverter. These cables are continuously exposed to environmental elements, and hence, the following characteristics are highly desired:

- UV-resistant, as they are subjected to direct solar radiation
- Usable within a large temperature range (-40°C to 90°C)
- Insulated, and integrally or non-integrally jacketed
- Rated voltage of 1100 volts
- Withstand thermal and mechanical loads
- Insulation and jacket materials must be extremely resistant to abrasion
- Sheathing should be saltwater-resistant

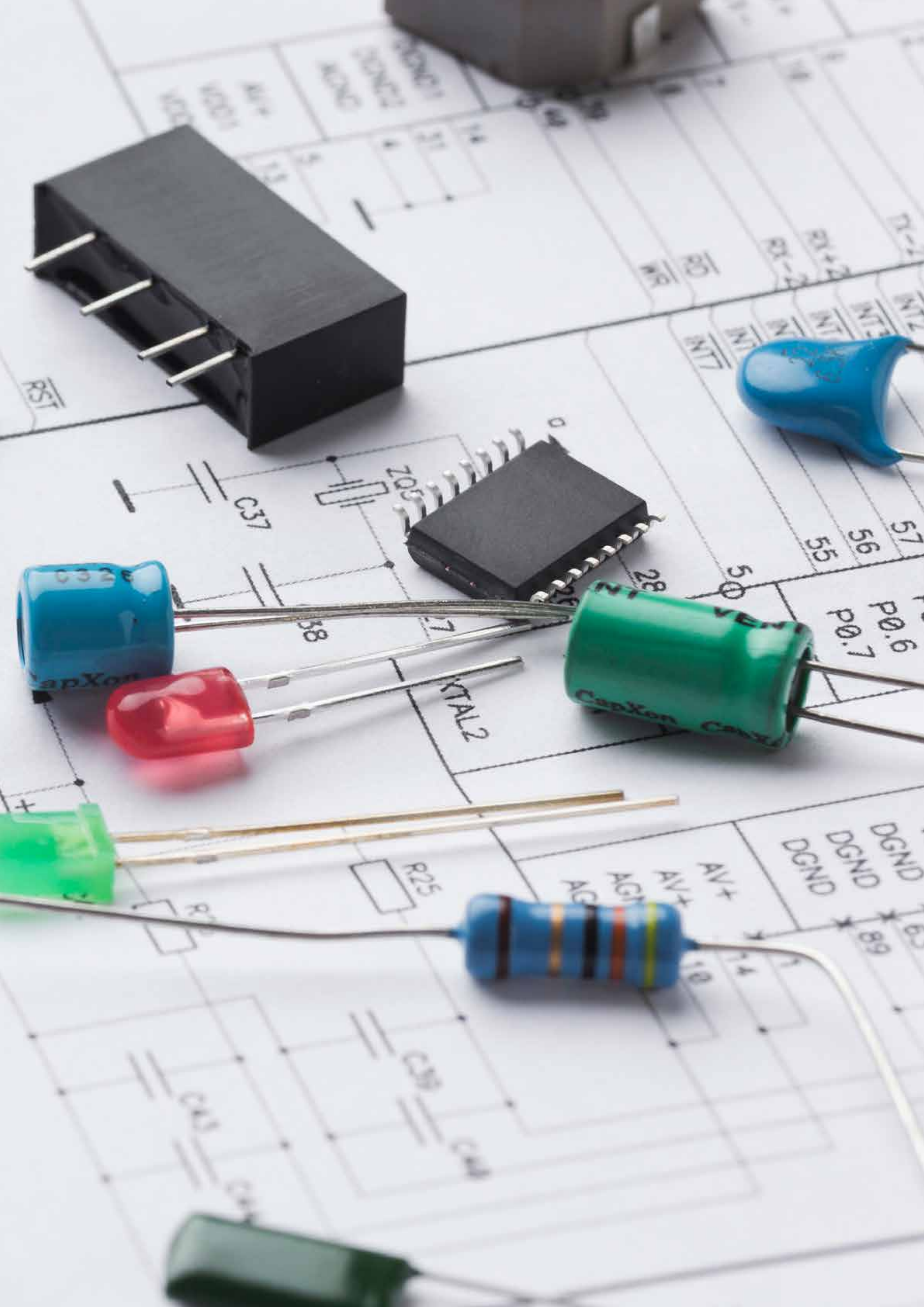
AC Cable

AC cables are used from the inverter output to the utility meter box. These cables are available in different external sheathing and sizes based on the location of laying and the voltage and current they are supplying. Some basic features to be considered while selecting cables are listed as follows:

- Ability to withstand mechanical stress such as compression, tension, bending and shear loads.
- Abrasion-resistance, therefore, most sheaths are made of plastics cross-linked using an electron.
- Resistance to acids and alkalies.
- Withstand high dielectric strength (depending on the type of application).
- Flame-retardant and halogen-free, this prevents the release of any harmful gases in case of fire.
- Short-circuit proof even at high temperatures.
- Sometimes cables have an optional reinforcement (e.g., metal mesh) to protect against marten, rodents, and termites.
- In the case of agricultural applications, an additional resistance to ammonia, digester gases, oxalic acid, caustic soda and other chemical media is desired.

9.5 Protection Systems

Solar PV systems are typically designed as long-term assets for 25 years or more. The plants are exposed to many unknowns that impact long-term system reliability and necessitate maintenance exercises. Protection devices ensure that the systems function efficiently and reliably for their design life. These products are particularly useful in keeping the systems safe from any current or voltage


RST
C37
XTAL2
P0.6
P0.7
55
56
57
DGND
DGND
DGND
AV+
AV+
R25
CapXon

surges, lightning damage and grid harmonics. Including protection devices prevents system downtime and keeps the system running.

Miniature Circuit Breakers

Miniature circuit breakers (MCB) are current-based protection devices, widely used in electrical systems to protect the system in case of faults and overcurrent. An important characteristic of MCBs is to prevent accidental overloading of the cable in a no-fault situation. The speed of MCB tripping varies with the degree of overload and is usually achieved by the use of a thermal device. Another characteristic is magnetic fault protection, which is intended to operate when the fault reaches a predetermined level, tripping the MCB within one-tenth of a second. The third characteristic is short circuit protection, which protects equipment against heavy faults (in 1000s of amps) caused by short circuit faults.

The capability of MCB to operate under these conditions gives its short circuit rating in kA. In general, for residential consumer units, a 6 kA fault level is adequate, whereas for industrial boards, 10 kA fault capabilities or above may be required. MCBs are rated in amps, which is the amount of current it passes continuously and is normally called the rated or nominal current.

MCB functions by interrupting the electrical current through a circuit when a fault is detected, typically when the current flows through it and passes the maximum acceptable limit. They are designed to guard against overcurrent and overheating. The breaker detects when too much current is flowing through the circuit, then disconnects the circuit from the main power source to protect the wiring from overheating. MCB is widely used for low-power domestic and industrial applications and protects against short circuit, overload and switching. These are obtainable in different pole versions like single, double, triple pole and four poles with neutral poles if necessary. The normal current rating ranges from 0.5-63A with a symmetrical short circuit breaking capacity of 3-10 kA, at a voltage level of 230V (single phase) or 440V (three phase). Since MCBs function to disconnect equipment during high current flow/ fault conditions, it does so by disconnecting the internal contacts and separating them. As the contacts pull apart from each other, an arc forms as the current jumps across the air gap. This arc is extinguished to ensure that the circuit breaks. The AC and DC breakers extinguish this arc differently and hence are not interchangeable.

i. DC MCB: These are installed in fuse boxes to protect individual loads that work with direct current. These are specifically used in solar PV plants to protect the main circuits of inverters, solar PV arrays or battery banks, as this equipment and circuit use DC current. The DC MCB uses a magnet to attract the arc, pulling it from the air gap and extinguishing it. Only DC MCBs should be used for DC applications.

ii. AC MCB: A distribution board provides a protective fuse or circuit breaker for each circuit in a common enclosure. In contrast to a DC breaker, an AC breaker is not equipped with a magnet and cannot extinguish a DC arc. It breaks the connection at 0V, thus protecting the wiring from higher current.

Most dual-rated breakers have different DC voltage ratings and different AC voltage ratings for the same amps.

Further, based on application and surge current implications, MCBs are classified into three common categories:

- Type B MCB, which is commonly used in domestic and light-load applications. The MCB has the capacity to manage surge currents that is three and five times the full load current.
- Type C MCB, used for commercial and industrial applications wherein a higher value of in-rush current is expected. The MCB can accommodate surge currents between 5 and 10 times the full

load current. The connected load in such cases is typically inductive in nature.

- Type D MCB, used for commercial and industrial applications wherein the in-rush current of a connected load is extremely high. Type D MCB can manage surge currents between 10 and 20 times the full load current. Examples of applications include transformers or X-ray machines, large winding motors, etc.

All three types of MCBs provide tripping protection within one-tenth of a second.

Surge Protection Device

Surge protection devices (SPD) are used in electrical systems to provide a low-resistance discharge path to ground the system components, which might be damaged due to exposure to high-voltage transients. These transients can typically be caused by either direct or indirect lightning, utility surges from the AC side, line-to-ground faults, or any electromagnetically induced transients through interconnected power cabling. SPDs function well when used in conjunction with external lightning protection devices and help provide complete protection to the PV plant. They must be adequately designed, sized and installed as per the plant requirements. SPD acts like a clamp and is connected in parallel, across the live wires, with another wire going to the ground. The protection level of the equipment is proportional to the value of the admissible surge current of the SPD. Hence, if the surge exceeds the rated value of the SPD, it shall fail to protect the equipment.

Under normal operating conditions, they do not perform any function, but if the voltage goes above a certain level, they start to conduct, thus providing the voltage a lower resistance path to the ground, hence protecting the equipment from a voltage surge. SPDs are particularly critical in lighting-prone areas or areas exposed to AC transient surges. They are installed both on the DC side (inside the combiner boxes) and on the AC side near the LT panel.

Surges are usually created in industrial areas because of fault currents, harmonics, surge loads, etc. In such cases, equipment needs to be protected, and AC SPDs are used. In case an external lightning arrestor is used, type I AC SPDs are used as these ground direct lightning surges. In case of the absence of a lightning arrester, type II AC SPDs are typically used.

There are three main types of SPDs available in the market: Type I, II and III. Their key characteristics and functions are defined as follows:

i. Type I SPDs are used for protecting electrical installations against direct lightning strikes since they have the highest value for admissible surge current resistance. They are deployed where lightning currents are conducted via an external lightning protection system and electrical cables. This is usually used when the system to be protected is directly connected to an external lightning protection system or if the distance between DC cables and external lightning protection is too small. While AC SPD type I is relatively cheaper, Type I DC SPD that can carry lightning current are extremely costly.

ii. Type II SPDs are deployed in low-voltage systems and protect against the spread of overvoltage in solar installations primarily arising from indirect lightning. These SPDs have a lower value for admissible surge current resistance.

iii. Type III SPDs are typically known as 'point of utilisation SPDs' and protect equipment against nominal surges. They have the lowest value for admissible surge current resistance. Typically, they are not deployed in solar systems because such surges are not expected on the DC side, whereas on the AC side, inverters can handle these surges independently.

Depending on the point of connection and protection required, single-pole, bi-pole and three-pole SPDs are used. Single-pole SPDs are used for single-phase systems, two-pole SPDs for a split-phase system, and three-pole SPDs for a three-phase system. In a solar PV system, SPDs are typically integrated into DCDB and ACDB, although certain inverter manufacturers provide inverters with in-built SPDs.

Importance of Installing SPDs

SPDs perform many important functions with regard to providing protection to the PV plant, as discussed here:

i. The strategic placement of SPDs mitigates transient voltage surges by grounding them.

ii. Multiple inverters can be protected with one SPD on the AC side since they are connected to the same grid voltage, also making the process more cost-effective.

iii. In case the contractor is using string fuses, SPD must be installed at the point of interconnection of the combined strings after the fuses.

iv. If external lightning protection equipment is used, a type I + II SPD should be used.

v. Type II SPDs should be rated at a continuous operating voltage of at least 125% of the PV string Voc. As the string inverters used for rooftop PV systems do not allow more than 800 VDC, surge arrestors rated for 1,000 VDC are commonly used.

vi. The surge arrestors should be connected to both positive and negative outgoing terminals of the string junction box (if the inverter already does not have an equivalent in-built DC surge arrestor).

vii. SPDs typically last for a certain number of strikes after which they are rendered useless and function as short circuits. It is usually recommended to periodically monitor the SPD during maintenance checks to determine if it needs replacement.

Earthing System

Earthing systems form an essential part of the PV protection system. These are used to provide a low resistance path to any current/voltage surge in the system induced due to the following reasons:

i. Lightning

ii. Switching surges

iii. Static

iv. Contact with a high-voltage system

v. Line to ground fault

An earthing system comprises a network of conductors (strips, wires, cables, etc.) and earthing electrodes that connect all equipment to the grounding pits. The network configuration and the specifications (size, material, etc.) of conductors and electrodes are determined with the help of an earthing calculation/study. A good earthing system will be able to ground any surges during fault conditions.

Typically, a solar PV plant consists of separate grounding systems for the DC side, AC side and lightning arrestor. A single DC side earthing may be used in conjunction with a lightning arrestor, in combination with a type-I SPD. Equipment is typically connected to a grounding copper rod using a GI strip, aluminium cables or copper cables. The copper rods are inserted in a pit dug into the ground to ensure any voltage surge is provided a low resistance path to the ground, thus preventing any damage to the plant. All grouping strips and pits are clearly marked by different coloured tags to demarcate the equipment they are grounding.

Best Practices for Earthing

Some of the best industry-wide practices for grounding are as follows:

i. It is required to ground all PV systems. A properly grounded system helps protect the user from unintentional shocks and possible deaths. It also prevents post-installation fires in the system.

ii. For PV modules, all frames should be connected by a single continuous earthing cable. It is incorrect to use jumper cables to connect consecutive modules.

iii. Earthing conductor should be sized appropriately to carry the fault current in case of a fault. Typically, it should be rated for 1.56 times the maximum short circuit current of the PV array. This includes a 25% safety margin and 25% to protect from any factor resulting in increased current.

iv. The minimum cross-sectional area or the earthing conductor for PV equipment should not be less than 6 mm^2 for copper, 10 mm^2 for aluminium or 70 mm^2 for hot-dipped galvanised iron strip.

v. For lightning arrestor grounding, wider cross-sections are used as compared to those for grounding the PV array. The grounding conductor should not be less than 16 mm^2 for copper or 70 mm^2 for hot-dipped galvanised iron.

vi. It should also be ensured that the resistance between any point of the PV system and earth should not be greater than 5 Ω.

vii. The grounding system should be installed before the system is energised.

Ground Fault Protection

In an SPV system, an earth fault can occur when the grounding wire or equipment body comes in contact with a live wire, resulting in high current flowing to the ground via the earthing conductor. This may be caused by loose connections, moisture or water ingress, overloading and insulation failure. Ground fault may result in loss of energy and system shutdown. It also presents safety concerns, especially shock hazards and the risk of fire. Intermittent ground faults can also occur due to flooding after rain. Another cause could be expansion or contraction of metal during hot or cold ambient conditions, respectively. Intermittent faults can be extremely difficult to identify and troubleshoot. In some cases, the ground fault can disappear as soon as the Solar PV system is shut down. This can happen when a ground fault is caused by arcing, resulting in carbon buildup.

Following best practices for cable laying and using cables with appropriate insulation and protection can help in completely avoiding ground faults. A residual current circuit breaker (RCCB) must be installed for ground fault detection and protection of the system.

Lightning Protection System

In case any of the equipment is directly struck, the electric discharge may result in an explosion, burn, or total destruction. Indirect lightning can also cause transient voltage and current surges, which may travel for many kilometres and hence pose a potential threat to the safety of equipment. A lightning arrestor (LA) provides the least resistance path for lightning to the ground and can provide the necessary protection to equipment and personnel.

Lightning protection system for a PV plant usually includes a lightning arrester/rod, a lightning conductor and a dedicated earthing pit. Typically, the following lightning arrestors are used:

i. Single rod lightning conductors (Franklin rods): These consist of one or more tips, depending on the size of the structure and the down conductors. Down conductors provide the link between the lightning conductor itself and the earthing electrode. Since down conductors are subjected to intense currents, they must be of an adequate cross-section (min. 50 mm2 copper), firmly fixed, following the shortest possible route and should not have any rises or sharp angles. The down conductors can also be fitted with lightning strike counters. Typically, Franklin rods are connected either directly to the earthing electrode of the installation (foundation) or, depending on the type of protection and national work practices, to a special earthing electrode (lightning conductor earthing electrode) that itself is connected to the earth of the installation.

ii. Lightning conductors with spark over device: These are a modified version of the single rod and are equipped with a spark over device, which creates an electric field at the tip of the rod, thus helping to catch the lightning and improve their effectiveness. Several lightning conductors can be installed on the same structure. They must be interconnected, as well as their earthing electrodes.

iii. Lightning conductors with a meshed cage: The meshed cage consists of a network of conductors which are arranged around the outside of the building so that its whole volume is circumscribed. Catcher rods (0.3 to 0.5 m high) are added to this network at regular intervals on projecting points (rooftops, guttering, etc.), and all the conductors are interconnected to the earthing system (foundation) by down conductors.

iv. Lightning conductors with earthing wires: This system is used above certain buildings, outdoor storage areas, electric lines (overhead earth wire), etc. The electrogeometric model of the sphere applies to these. The electrogeometric model is an imaginary sphere model method which defines the spherical volume that is theoretically protected by a lightning conductor based on the intensity of the discharge current of the first arc. The higher this current, the higher the probability of capture and the wider the protected area.

Lightning arrestors' area of protection is usually characterised by a protection radius which is dependent on the type and height of the arrestor. All the equipment which lies within this area of protection will be protected from direct strike. Theoretically speaking, the LA extends a cone of protection from its tip. To ensure that all equipment is protected with a desired level of protection, it shall be ensured that the equipment lies within the area of protection. This requires considering the location of equipment and its height to ensure that the plan of protection covers the equipment at its point of maximum height. The LA height is calculated to provide the necessary protection, and multiple LAs are strategically deployed to ensure that the LA height is within manageable limits. While installing an LA for a solar PV system, care should be taken to avoid the shadow of the LA on PV modules.

Typically, three lightning protection levels are defined depending on the degree of criticality of protection required. These are discussed as follows:

a. Lightning protection level I covers the worst-case scenario of a direct lightning strike and pertains to external lightning protection facilities. It covers a pulse of 200 kA, half of which is conducted to the ground, and the other half is conducted to the section of the facility that is conductive itself. In case a four-wire system is available, a current of 25 kA is distributed to each wire. For a five-wire system, it corresponds to 20 kA. This lightning protection class covers multiple areas, including petrochemical facilities (ex-zones) and explosive material depots.

b. Lightning protection level II covers a pulse of 150 kA, half of which is conducted to the earth and the other half is conducted to that section of the facility that is conductive. This pertains to external lightning protection facilities. In the case of a four-wire system, 19 kA is distributed to each wire, whereas for a five-wire system, this would correspond to 15 kA. This lightning protection class covers multiple areas, such as parts of hospitals, shipping warehouses with fire alarm systems and telecommunication towers.

c. Lightning protection level III/IV covers a pulse of 100 kA by external lightning protection facilities. If a four-wire system is available, a current of 12.5 kA is distributed to each wire. For a five-wire system, it is about 10 kA. About 80% of all applications are covered by lightning protection Type III, which includes houses, homes, administrative buildings and industrial facilities.

The table in Annexure I discusses the different buildings and zones and the lightning protection level category they fall under.

9.6 Data Logging and Monitoring

Data logging solutions for solar rooftop plants have become a standard industry practice. Basic data logging solutions provide generation data for solar plants, along with electrical parameters on the DC and AC sides. More advanced monitoring solutions may include monitoring of sub-arrays in case of multiple MPPT, string monitoring and module monitoring. Implementing these typically depends on the functionality and architecture of the inverters, as implementing external third-party solutions can be very expensive. This is especially true for rooftop solar plants.

Other than tracking the yield of SPV plants, data logging or remote monitoring solutions can also monitor the performance of SPV plants and their components. Depending on the architecture of the data monitoring solution, technical and underperformance issues at the module and string levels can also be identified. To enable tracking the performance ratio of the system, it is pertinent to install a weather monitoring solution.

Weather monitoring solutions (WMS) provide data for solar irradiation, ambient temperature, module temperature, humidity and wind speed. To calculate the performance ratio, real-time weather data is critical. Weather data may also be sourced from nearby locations if a WMS is installed in the vicinity. A WMS will typically consist of the following hardware:

i. Pyranometer for measuring solar flux (kWh/m^2)

ii. Anemometer and wind vane for measuring speed

iii. Hygrometer for measuring wind speed

iv. Thermometers or temperature sensors

Without the weather data, enforcing performance warranties is not feasible.

9.7 Balance of System

Various other components are used for the assembly and installation of a solar PV system. The complete list of Balance of System (BOS) is provided in Annexure J.

Further, Annexure K provides a list of critical International Electrotechnical Commission (IEC) certificates for quality compliance for various components.

10. PLANT PERFORMANCE AND YIELD

For comparing two solar PV plants with the same technical specifications and environmental conditions, one of the key indicators is Performance Ratio, along with annual solar generation. Although the capacity utilisation factor (CUF) is also used, it is more suitable for comparing the performance of fossil-fuel-powered plants, which operate 24x7, rather than solar PV plants.

Performance Ratio

Performance ratio is a comparison of the actual plant output with the theoretical plant output estimated based on actual solar irradiation, panel temperature, availability of grid, size of the aperture area, nominal power output, and temperature correction values. Latest softwares are capable of accurate simulation performance of a solar PV plant based on weather data for the site, if all design inputs and variables are accurately accounted for.

$$PR = \frac{\text{Actual reading of plant output in kWh p.a}}{\text{Estimated nominal plant output in kWh p.a}}$$

Typically, the performance ratio of SPV plants in India varies from 72-78%, depending on various factors discussed above, as follows.

The yield of a solar PV plant depends on various factors, including operational environment, component properties, system design and availability of the main grid. While some of these factors can have a significant impact on the performance of a system, there are other non-critical factors which may be used as a trade-off to optimise system cost and capacity. The same are discussed as follows.

i. Tilt and Orientation

Ideally, when the orientation of solar modules is fixed, they should be installed facing the true south direction in the northern hemisphere and vice versa for the southern hemisphere. The optimal fixed tilt angle for solar modules is approximately equal to the latitude of the location. But it shall be noted that depending on the site parameters, solar modules may be installed at an orientation of '+' or '-' 90 degrees from true south, i.e., in east-facing or west-facing direction. Its total impact on annual generation is less than 10%. Similarly, there is hardly any significant impact of deviation of tilt angle by 15 degrees from optimal on either side.

As a practice, solar installers often deviate from optimal tilt angle and orientation to ensure better solar array packing on the rooftop or to optimise the cost of the system.

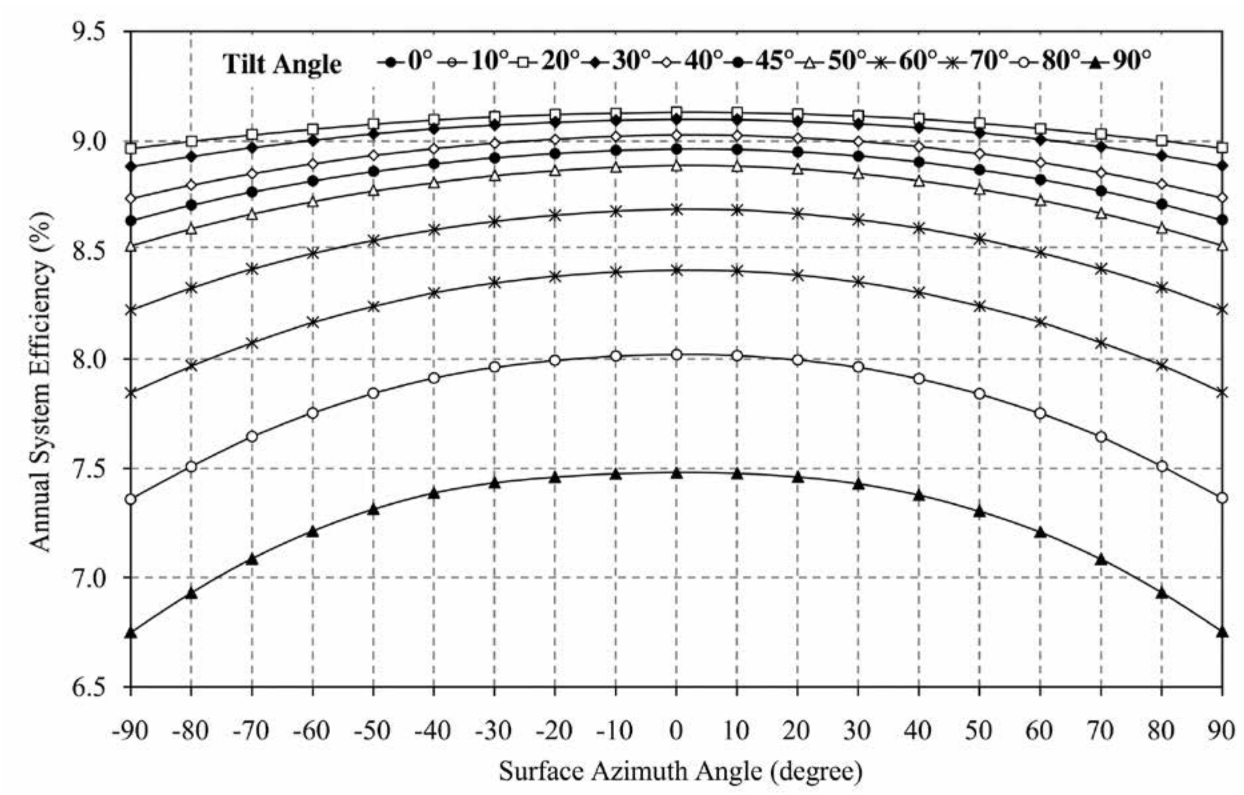


Figure 9: Variation of annual system efficiency as functions of surface azimuth and tilt angle

ii. Shadow Loss

This is a loss of irradiance caused by the shadow effect from trees, obstructions and surrounding modules. While designing PV plant systems, annual shadow loss shall be kept as follows 2% of the energy generation. Shadow loss is usually computed for a time span of three and a half hours on either side of the solar noon.

iii. Soiling Loss

Soiling losses occur due to the presence of dirt, bird droppings or other matter on the modules. Soiling loss can be minimised by regular cleaning of solar modules. The frequency of cleaning required may vary from site to site depending on particulate matter in the air, pollution levels and other emissions in the surrounding area. Solar PV systems installed in industrial areas typically require frequent cleaning because of high emissions and dust in the immediate environment.

For typical plants in India, soil loss is assumed to be around 5%. It can increase significantly if solar modules are not cleaned on a periodic basis.

iv. Environmental Conditions

Solar Modules are typically rated at standard test conditions, but such conditions are rarely encountered at a solar PV site. Temperature is a significant factor which impacts the performance of solar modules. As the temperature increases, efficiency and the power output decrease, and vice versa. This typically accounts for a performance ratio loss of approximately 9-10%.

v. Light-Induced Degradation (LID)

This represents the loss incurred due to a change in the electrical characteristics of crystalline silicon solar cells upon exposure to light. LID occurs within the first few hours of the panels being exposed to light, but since this effect changes the power output of a module relative to its STC rating, it is typically modelled as a fixed loss factor. The impact of LID is lower on high-quality modules.

vi. Module Mismatch

This is an attribute of the mismatch of the electrical characteristics of solar modules connected in a string. In solar modules with a positive capacity tolerance of 3%, this may be assumed as zero. Otherwise, module mismatch may account for up to 3% reduction in the performance ratio of a solar PV system.

vii. Ohmic Loss

Ohmic losses are basically due to the impedance of the cables used for connecting the system, as well as the points of connection. Ideally, ohmic loss should be kept less than 2% of total generation by using correctly sized cables and by ensuring that all connections are properly made.

viii. Inverter Efficiency

All conversion devices have an inherent efficiency factor. Most MPPT inverters have conversion efficiency in the range of 96-98%, as per European standards.

ix. Other Losses

These are miscellaneous losses that can affect the annual energy production of the system, such as the loss of generation with time. This could be due to a loss in component efficiency over time.

x. System Availability

This represents the loss in available energy due to the system being taken offline for maintenance or due to a grid outage. Any loss in generation because of power curtailment is not in the scope of the project developer.

A sample SPV system report is shared in Annexure L.

11. OPERATIONS AND MAINTENANCE

Even though solar plants do not have any mechanical or moving components, their various components are exposed to environmental factors which can induce thermal and mechanical stress. Corrosion is another phenomenon which may affect the structure, nuts, bolts, washers, connectors and joints. Since solar PV systems are expected to perform for a minimum of 25 years, regular operation and maintenance (O&M) as per industry best practices is critical to ensure their longevity.

11.1 O&M Approach

Traditionally, maintenance is divided into two categories, as described here:

- Scheduled maintenance is usually planned in advance and aimed at fault prevention, while ensuring that the plant is operated at its optimum level.
- Unscheduled maintenance is typically carried out in response to failures on a need basis. A more effective and scientific categorisation of maintenance activity is discussed as follows. This approach helps in reducing system downtime, avoiding failure of critical components, and enables the plant to perform at its ideal capacity.
- Preventive maintenance includes routine inspection and servicing of equipment at intervals determined by the equipment type, environmental conditions, and warranty terms provided in the O&M services agreement. The approach reduces the occurrence of failures and is able to capture faults at an early stage, thus resulting in lower PV system downtime. However, this maintenance schedule has a higher upfront cost and needs to be designed optimally to avoid any unnecessary labour activity. Preventive maintenance usually includes scheduled activities like PV module cleaning, managing water drainage, vegetation growth prevention, and retro-commissioning (which includes identifying and solving problems that have developed during the PV system's life).
- Corrective or reactive maintenance is used to address equipment repair and breakdowns after their occurrence. This incurs lower upfront costs but increases the risk of component failure, implying higher downtime costs. Though some amount of corrective maintenance will occur over a system's lifetime, it can be reduced by preventive and condition-based maintenance.
- Condition-based maintenance technique uses real-time data to anticipate failures and prioritise maintenance activities and resources. This is, however, accompanied by a higher upfront cost since it requires more communication, monitoring software and hardware. Sometimes, the maintenance process also experiences challenges caused by monitoring equipment malfunction or erratic data collection. This usually includes active monitoring, such as remote and on-site equipment replacement and warranty enforcement.

Some key maintenance activities for a solar PV plant are described in Table 8 as follows.

Component	O&M Activity	Periodicity
Solar Module	Cleaning of solar modules	Daily/Weekly/Bi-weekly
	Visual inspection of solar modules ▪ Inspection for any damage to module backsheet ▪ Visual inspection for discolouration, hot spots, micro-cracks in the module ▪ Inspection of module frame for damage or ingress of humidity ▪ Inspection of junction box on each panel for status of by-pass diodes	Quarterly or six monthly
String Inspection	▪ Electrical inspection of PV strings for output voltage and current	Quarterly or six monthly
	▪ Visual inspection of inter-connectors and DC cable for damage	

Component	O&M Activity	Periodicity
Mounting Structure	▪ Visual inspection for corrosion and physical damage ▪ Tightening of nuts and bolts ▪ Inspection for evidence of erosion from water run-off for mechanical integrity ▪ Visual inspection of the foundations for critical damage, or separation from roof ▪ Inspection of roof for water seepage	Quarterly or six monthly[3]
DCDB	▪ Check if SPDs need to be replaced ▪ Inspection of MCB/fuses ▪ Inspection of enclosure for ingress of humidity, pests and water ▪ Check electrical connections ▪ Inspection of enclosure for degradation ▪ Visual inspection of enclosure seal	Quarterly or six monthly
AC and DC Cable	▪ Visual inspection of conduit and cable tray for damage ▪ Inspection of conduits for ingress of water ▪ Inspect for any loose connection/terminations ▪ Visual inspection of cable for damage or degradation	Quarterly or six monthly
Inverter	▪ Inspection of cable connections ▪ Inspection of input and output voltage/current range. Record and validate all voltages and production values from the human- machine interface (HMI) display ▪ Check continuity of system ground and equipment grounding ▪ Look for signs of water, rodent, or dust intrusion into the inverter ▪ Functional inspection of the fan and cooling system, if applicable ▪ Check fuses and SPD, if applicable ▪ Look for discoloration from excessive heat buildup ▪ Check mechanical connection of the inverter to the wall or ground ▪ Check AC and DC disconnect (if applicable)	Quarterly or six monthly
ACDB	▪ Check if SPDs need to be replaced ▪ Inspection of MCB/Fuses ▪ Inspection of enclosure for ingress of humidity, pests and water ▪ Check electrical connections ▪ Inspection of enclosure for degradation Visual inspection of enclosure seal	Quarterly or six monthly
LA	▪ Visual inspection of foundation for integrity ▪ Confirm earthing strip continuity ▪ Inspection for corrosion on LA and earthing strip ▪ Ensure there is no short circuit between LA and balance of system	Quarterly or six monthly

[3] As warranted by environmental conditions.

Component	O&M Activity	Periodicity
Earthing System	▪ Check continuity for earthing system ▪ Inspect earthing cable (GI strips, if applicable) for corrosion or damage ▪ Check for corrosion on earthing rods ▪ Inspection of earthing pits for accumulation of water	Quarterly or six monthly
Data Logger	▪ Record voltage readings of power supplies ▪ Validate sensor reading by comparing with calibrated equipment	Quarterly or six monthly
Safety	▪ Check for the fire extinguisher's expiry date ▪ Check for any extinguisher nozzle damage ▪ Check the fire bucket sand, if applicable	Quarterly or six monthly
Miscellaneous	▪ Trimming of trees and vegetation in the surrounding to prevent shadow ▪ Inspection of roof for any unaccounted shadow objects	Quarterly or six monthly

Table 8: Components and O&M activity

11.2 Solar PV Module Cleaning Procedure

The following procedure should be followed for cleaning solar PV modules. These guidelines minimise the impact on plant power generation, reduce safety hazards, and minimise the risk of module damage.

- Walk the site to confirm that there are no broken modules (shattered glass). Cracked or broken modules represent a shock hazard due to leakage of currents, and the risk of shock increases when modules are wet. Before cleaning, thoroughly inspect the modules for cracks, damage, and loose connections. The voltage and current present in an array during daylight hours are sufficient to cause a lethal electrical shock.
- Never spray broken modules with water.
- Determine whether the module cover glass is too hot, as it will get damaged coming into contact with cool water. Depending on the local climate and time of year, it may be best to limit washing activities to the morning or evening hours. This minimises the impact on production and risk of electrical shock hazard is minimised. Do not use water that is more than 20°C warmer or colder than the module surface temperature.
- Include spraying the modules with low-pressure water that is closely matched in temperature to the temperature of the module, or using a dry brushing technique.
- Clean modules only when in open circuit or when the inverter is not operational.
- Do not use abrasive cleaners or de-greasers on the module.
- If needed, a mild, non-abrasive, non-caustic detergent with a final fresh water and detergent solution mix between $6.5 < pH < 8.5$ at 25°C may be used.
- Water must be free of floating oil or other immiscible liquids, floating debris, excessive turbidity, and objectionable odours.
- When using water, RO water provides the best results. When RO water is not available, tap water with low mineral content (total hardness <75 mg/L) or deionised water may be used.
- Do not use cleaning solutions containing hydrochloric acid, D-limonene, ammonia, or sodium hydroxide.

- Do not spray pressurised water directly at sealed interfaces of the module (junction box, edge seal, and connectors). Water pressure must not exceed 35 bar (500 psi) at the nozzle.
- Do not brush or clean the backside of the module to avoid accidental stress to the lead wires or junction box.
- If excessive soiling is present, a non-conductive nylon or similar material brush, sponge, or other mild agitating method may be used with caution.
- Ensure brushes or agitating tools are not abrasive to glass, EPDM, silicone, aluminium, or steel.
- Ensure any brushes or agitating tools are constructed with non-conductive materials to minimise the risk of electric shock.

12. CONCLUDING REMARKS

This guide is intended to enhance the industry's capacity to contribute effectively to India's energy transition ambition. It is pertinent that India achieves high-quality installations and services in the solar energy sector to deliver dividends to all stakeholders, particularly prosumers. However, it acknowledges that achieving high-quality benchmarks is subject to consumer awareness, market dynamics, and regulatory environment.

The authors do not claim this guide as the gold standard for the solar industry; practitioners should refer to the original standards when in doubt.

Annexure A: Sample Site Assessment Form

Equipment check list for site survey					
Pencil/Pen ☐	Scale ☐	Angle finder ☐	Compass ☐	Measuring tape ☐	Camera ☐

A. Client Details			
Date & Time of Site Survey -			
1	Name		
2	Address		
3	Contact Person Details	Name:	
		Mobile:	
		Email:	
4	Contact details of electrician / maintenance manager		
5	Site Address (if Different from Above)		
6	Nearest Landmark		
7	Latitude and Longitude		

B. Drawing Document Collection From Client (Please tick that are available)		
Rooftop Layout ☐	Plot Plan ☐	Electrical Layout ☐

C. Roof Details and Checklist			
1	Number of Roofs		
2	Access to the Roof(s)	Mention on the layout	☐
3	Height of Parapet Wall	Mention on the layout	☐ ☐
4	Orientation of the Roof	Mention on the layout	☐
5	Roof Pitch (Angle from the horizontal)	Mention on the layout	
6	Roof Specification / Type (Gable, Hip, Gambrel, Flat, Mansard, Corrugated Shed)	Mention on the layout	☐
		Is water proofing done on roof? ☐ Yes ☐ No	
7	Roof / Slab Thickness (mm)		
8	Type of Building structure	☐ Framed Structure	☐ Load Bearing Structure
9	Thickness of roof:	Maximum Height of Building:	Number of floors:
10	Anchoring allowed?	☐ Yes ☐ No	
11	Roof Composition		

D. Electrical Assess					
1	Electrical Utility Company				
2	Electricity Bill attached	☐ Yes ☐ No			

D. Electrical Assess

3	Step Down Transformer	Is step-down transformer available? ❒ Yes ❒ No			
		If Yes, provide following details:			
		Transformer Rating			
		Voltage Rating			
		Manufacturer and Build Number			
		Fusing/ OCP/ Isolators sizes and types; if available			
4	Electrical Service Panel	AC Load Panel Rating		❒ 100 A	
				❒ 200 A	
				❒ 400 A	
				❒ Other	
		Type of incoming supply		❒ Single Phase	
				❒ Three Phase	
		Main Breaker Rating		________A	
		Breaker Space Available		Yes ❒ No	
		Specify: Location of Utility Meter Location of Service Panels			
5	Load Panel Details	Is AC Distribution Board Diagram Available?	❒ Yes ❒ No		
		Attach Picture of AC Distribution Board ❒			
6	Space Available for ACDB, PV meter, Net meter	Yes ❒ No			
7	Location and Height of existing Lightning Arrestor	Location:	Heights:		
8	Location of Earthing Pits				
9	Extra fuse way available in the main fuse box	❒ Yes ❒ No		Rating:	
10	Does the Building have Generator? ❒ Yes ❒ No	If yes; Generator Synchronization Required? ❒ Yes ❒ No No If Yes; collect following details:			
		Generator Model:	Rating:		

E. Measurement/ Location Checklist

1	Location of Inverter	
2	Distance from inverter to ACDB- Wiring path	
3	Distance from LT panel to transformer (if applicable)	
4	Location of ACDB	

F. Photograph Checklist (Please tick that are taken)			
1	Roof	❐ Parapets	❐ Parapets Mechanical/ Electrical Unit
		❐ Gas/ Condensation Lines	❐ Gas/ Condensation Lines Satellite Dishes
		❐ Access Ladder	❐ Roof Sections suitable for Array
		❐ Others	
2	General Details	❐ Shading Objects	❐ Building Elevations
		❐ Other Shading Concerns	❐ Surround Trees / Buildings
3	Electrical Connections	❐ Utility Transformer	❐ Electrical Room
		❐ Main Switchboards	❐ Conduits / Electrical shaft
		❐ Utility Meter Sections	❐ Main Breaker Section
4	New Proposed Locations/ Equipment	❐ Proposed location of inverter	❐ Proposed AC conduits Route
		❐ Proposed DC Conduit Route from Roof	❐ Potential Locations for AC Disconnect
		❐ Proposed Trenching paths	

Storage facility at site available	❐ Yes ❐ No
Dimensions of storage facility	
Dimensions of door at storage facility	
Risk of any hazard at storage, if any	
Security details	

G. Comments/Challenges at site

Evaluator/ Surveyor Name: Client/ Client Representative Name:

(Signature) (Signature)

Date: Time:

Roof Layout With Shading and Details

Roof Name	Latitude	Longitude	Orientation	Height of Roof

Roof Construct

Roof type:

Roof Pitch:

Slab Thickness:

Height of Parapet Wall:

Water Proofing:

Site Pictures

Roof 1

Roof 2

Roof access

LT panel

Building front elevation

Annexure B: Shadow Analysis Report

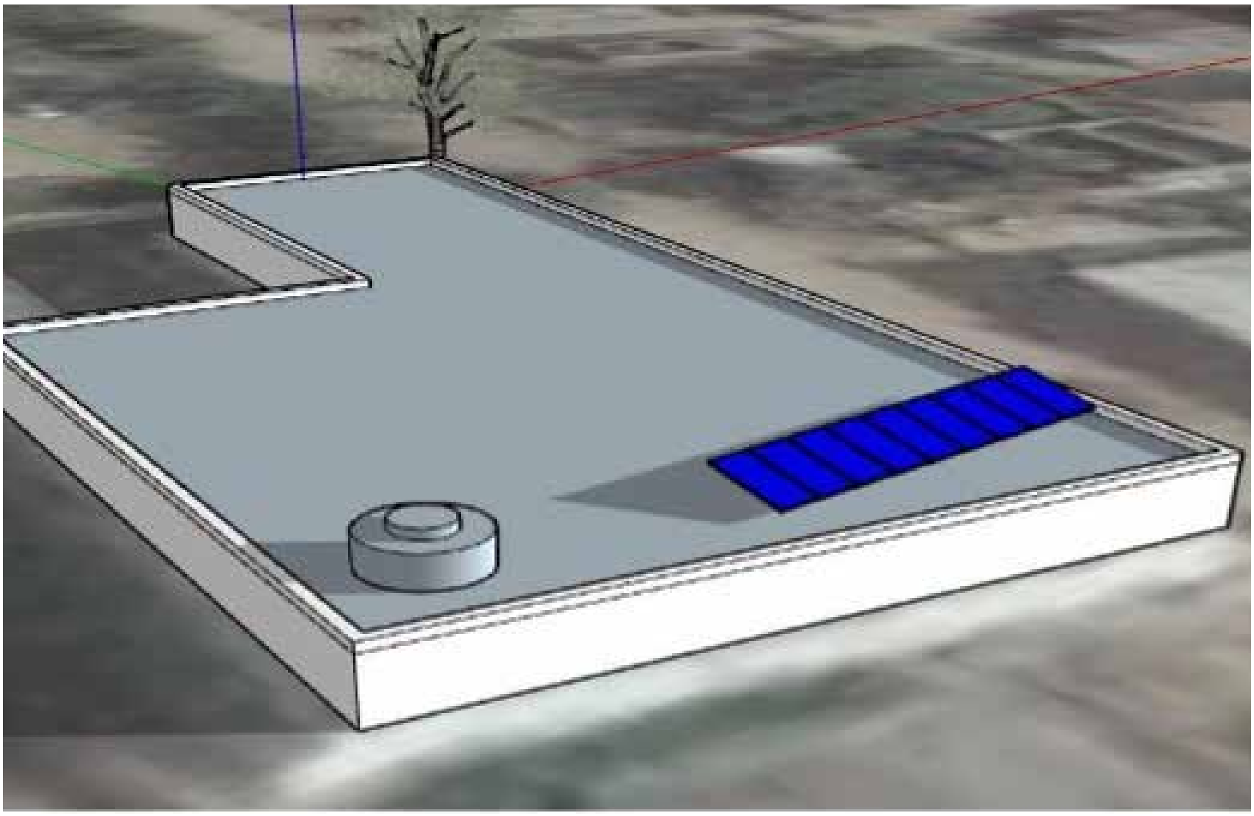


Figure 1: Shadow Profile at 9.00 am on Winter Solstice (December 22)

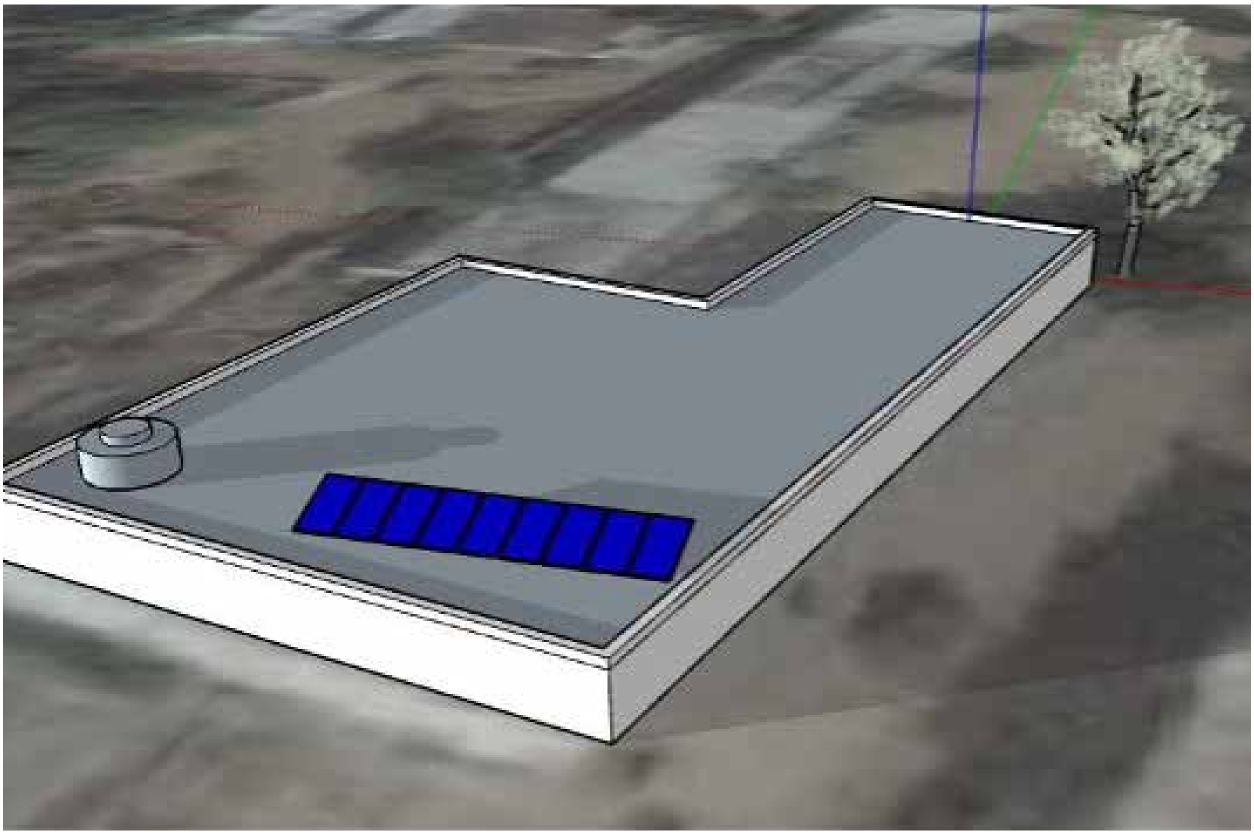


Figure 2: Shadow profile at 4.30 pm on Winter Solstice (December 22)

Annexure C: Sample Project Execution Plan

S. No.	Activity/Sub-Activity			Starting Time	Ending Time
1	**Project Creation**				
	1.1		Project PO/contract		
	1.2		Advance payment receipt		
2	**Project Execution Plan**				
	2.1		Project team list		
	2.2		Project gantt chart		
	2.3		Approval by management		
3	**Design and Engineering**				
	3.1	Detailed site assessment			
		a.	Site assessment report		
		b.	Risk assessment report		
	3.2		Engineering drawings		
		a.	Site plan		
		b.	Module layout		
		c.	Single line diagram		
		d.	String & equipment layout		
		e.	Earthing & LA layout		
		f.	Foundation layout		
	3.3		Design sheet with site challenges and risks		
	3.4		Structure design documents uploaded		
		a.	GA drawing		
		b.	Foundation drawing		
		c.	STAAD pro report		
		d.	Structure Bill of Materials		
	3.5		Bill of Materials uploaded		
4	NOC				
	4.1		Client documents		
	4.2		Application for NOC		
	4.3		Site electricity bill		
	4.4		Receipt		
5	**Procurement**				
	5.1		Procurement tracker		
		a.	Bill of Materials		
		b.	Vendor		
		c.	Rate		
		d.	Warranties		
		e.	Expected date of delivery		
		f.	PO Number/inventory		

S. No.	Activity/Sub-Activity			Starting Time	Ending Time	
6.	**Delivery of Material**					
	6.1	Pre-dispatch inspection report				
	6.2	Site receipt				
	6.3	Site inspection report				
7.	**Installation & Commissioning**					
	7.1		Resource allocation			
		a.	Finalising accommodation			
		b.	Travel plan			
	7.2		Kick-off meeting			
	7.3		Daily progress report			
	7.4		Punch list			
	7.5		Commissioing report			
8.	**Project Handover**					
	8.1	Project completion certificate				
	8.2	Final project payment				

Annexure D: Sample Datasheet for Solar Modules: 690-715W

Electrical Parameters | STC1,2						
Peak Power Pmax (Wp)	690	695	700	705	710	715
Maximum Voltage Vmpp (V)	39.7	39.9	40.1	40.2	40.4	40.6
Maximum Current Impp (A)	17.38	17.43	17.48	17.53	17.58	17.63
Open Circuit Voltage Voc (V)	47.3	47.5	47.6	47.8	48.0	48.1
Short Circuit Current Isc (A)	18.29	18.36	18.43	18.5	18.57	18.64
Module Efficiency (%)	22.21	22.37	22.53	22.70	22.86	23.02

1) STC:1000 W/M2 IRRADIANCE, 25°C CELL TEMPERATURE, AM1.5G SPECTRUM ACCORDING TO EN 60904 3 |
2) TOLERANCE OF RATING AT STC (PMPP/ I SC / VOC) [%] : 0 3/±5/±5 | ELECTRICAL MEASUREMENT UNCERTAINTY IS WITHIN ± 2%

Electrical Parameter | NOCT3						
Peak Power Pmax (Wp)	519.5	523.4	527.3	531.2	535.1	539
Maximum Voltage Vmpp (V)	37.1	37.2	37.3	37.4	37.5	37.6
Maximum Current Impp (A)	14.03	14.08	14.13	14.18	14.23	14.28
Open Circuit Voltage Voc (V)	44.4	44.6	44.8	45.0	45.2	45.4
Short Circuit Current Isc (A)	14.78	14.83	14.88	14.93	14.98	15.03

3) NOCT IRRADIANCE 800 W/M2, AMBIENT TEMPERATURE 20°C, WIND SPEED 1 M/SEC

Electrical Parameters | BNPI4,5						
Peak Power Pmax (Wp)	765	770	776	781	787	792
Maximum Voltage Vmpp (V)	39.7	39.9	40.1	40.2	40.4	40.6
Maximum Current Impp (A)	19.26	19.31	19.37	19.42	19.48	19.53
Open Circuit Voltage Voc (V)	47.3	47.5	47.6	47.8	48.0	48.1
Short Circuit Current Isc (A)	20.27	20.34	20.42	20.50	20.58	20.65

4) BNPI: 1000W/M2 + . 135, BIFACILITY COEFF. ( ) AT BNPI PMAX, ISC IS 75±5% & FOR VOC IS 99±10% , AM 1.5, 25°C | 5) TOLERANCE OF RATING AT BNPI (PMPP/ ISC/ VOC) [%] : 0 3/±5/±5

Temperature Coefficients (TC) Permissible Operating Conditions	
Tc of Open Circuit Voltage (ß)	-0.26%/°C
Tc of Short Circuit Current (α)	0.046%/°C
Tc of Power (ɣ)	-0.30%/°C
Maximum System Voltage	1500V
NOCT	45°C ± 2°C
Temperature Range	-40°C to +85°C

MECHANICAL DATA	
Length × Width × Height	2384 × 1303 × 35 mm (93.86 × 51.30 × 1.38 inches)
Weight	39.5 kg (87.08 lbs)
Junction box	IP 68, split junction box with individual bypass diodes
Cable & connectors#	200 mm (+ve terminal) and 300 mm (-ve terminal) cables, MC4 compatible/ MC4 connectors
Application class	Class A (Safety class II)

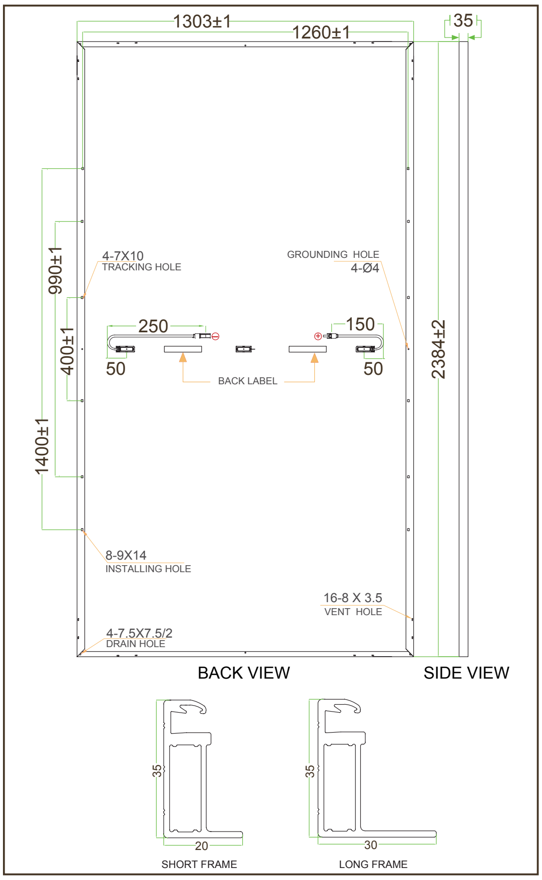
MECHANICAL DATA

Superstrate##	2.0 mm (0.098 inches) high transmission ARC semi-tempered glass (low iron content)
Cells	66 (132 half-cells) N-TYPE bifacial solar cells
Substrate	2.0 mm (0.098 inches) high transmission heat strengthened glass/mesh glass#* (low iron content)
Frame	Anodised aluminium/alloy steel frame#*
Mechanical load test	5400 Pa (Snow load), 2400 Pa (Wind load)
Cell encapsulant	EPE/EVA
Maximum series fuse rating	30 A
Hail test	45 mm | Impact velocity up to 27 m/s

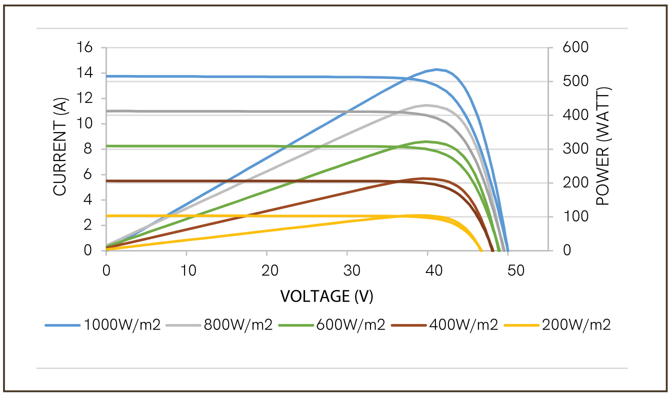
WARRANTY

Product warranty**	12 years
Performance warranty**	Linear power warranty for 30 years with 1% first-year degradation and 0.4% from year 2 to year 30

Dimensions in MM

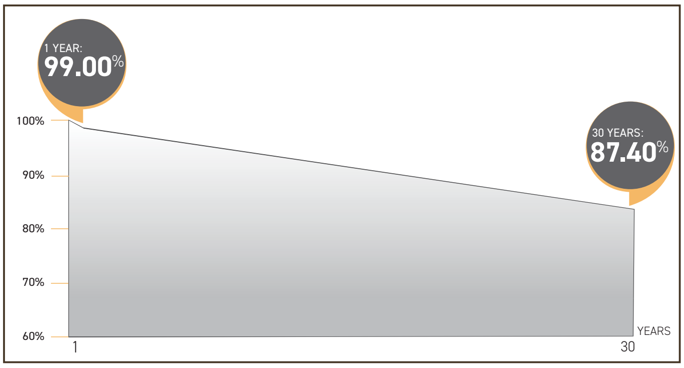


TYPICAL I V CURVES6



6) AVERAGE RELATIVE EFFICIENCY REDUCTION OF 5% AT 200 W/M2 ACCORDING TO EN 60904 1

Performance Warranty



Annexure E: Daily Site Progress Report Sample

Company name										
Daily site progress report (DSPR)										
Project report:						Site In-charge:				
Site address:						Contact Details:				
Date of work:						Project Code:				
	Unit	Qty.	Construction Count							
Classification				Cumm Prev.	Cumm Prev.	Count Planned	Actual Count	Total	Progress	
			Days - planned	Days - actual	For today	For today	Count	Planned	Actual	Remarks
Civil works										
Actual site marking	Nos.						0			
Pedestal fabrication	Nos.						0			
							0			
							0			
							0			
Mechanical works										
MMS installation	Pedestal						0			
SPV module installation	Nos.						0			
							0			
							0			
							0			
Electrical works										
Module interconnection							0			
Junction boxes							0			
DC cabling (String)							0			
Inverter installation	Nos.						0			
Data logger installation							0			
AC cabling	Mtr.						0			

Company name

AC cabling	Mtr.						0			
Earthing & lightning arrestor	Nos.						0			
Personnel mobilisation plan						**Equipment mobilisation status**				
Title	Previous	Total	Total	Remarks		Particular	Prev.	Today	Remarks	
Driving Staff						Drilling machine				
Civil Staff						Cutter machine				
Supervisor						Multi meter				
Technician						Insulation tester				
Supporting staff						Megger meter				
Project manager						Torque wrench				
						ERT				
Total	0	0	0							
Content of works										
Today’s task list					Tomorrow’s task list					
Civil					Civil work					
1)					1)					
2)					2)					
Mechanical					Mechanical					
1)					1)					
2)					2)					
Electrical					Electrical					
1)					1)					
2)					2)					
Miscellaneous					Miscellanous					
1)					1)					

Company name										
2)					2)					
Today's Safety Slogan: "Accident hurts. Safety doesn't."										
NOTE:										
▪ Utmost importance to Health Safety Environment (HSE) requirements at site must be ensured/complied by Project Manager.										
▪ All personals at project site should comply with company HSE policy.										
▪ All personals at project site should use personal protective equipment (PPE) and no individual should be allowed inside project site with PPE.										
▪ First aid kit should be maintained at site office for medical emergency.										
▪ Any incidents or accidents to be reported to Project Manager, immediately without any delays.										

Annexure F: Pre-Commissioning Checklist and Commission Report Sample

Company logo	Company name Pre-commissioning checklist and commissioning report		
Project name		Date:	
Project location		Code:	
	Physical inspection	**Status**	**Comments**
Foundation and structure	Foundation alignment		
	Foundation dimensions		
	Signs for damage to roof		
	Foundation finishing		
	Structure assembly as per GA drawing		
	Damage to any structure member		
	Nuts and bolts are secured properly		
	Structure clamps are secured properly		
	Check structure BoM compliance		
	Check dimension of members		
	Check anti rust coating/galvanisation		
Array inspection	Orientation of the array as per drawing		
	Check module tilt		
	Check module alignment		
	Row spacing as per drawing		
Earthing	Module earthing check		
	Structure earthing check		
	LA earthing check		
	Inverter earthing		
	LT panel earthing		
	Check location and marking of earthing pits		
AJB/DCDB	Design as per drawing		
	Fuses/MCBs rating as per SLD		
	Continuity test for SPD		
	IP rating		
PCU	Environment conditions		
	Terminations		
	MCBs are functional		
	Record open-circuit array input voltage		
	Record open-circuit grid input voltage		
	LCD display		
ACDB	Design as per drawing/BoM		
	All MCBs are as per SLD and functional		
	Check termination connections		
	Check marking of all cable in LT panel		
	AC SPD continuity test		
Weather station	Connections as per drawing		
Data logger	Data logger energisation		
	Data logger synchronisation		

Company logo	Company name Pre-commissioning checklist and commissioning report		
DC wiring	Check cable termination point		
	Check guage and make		
	Cable labelling		
AC cabling	Check cable termination points		
	Check gauge and make		
	Check cable labelling		
Signage	Shutdown procedure		
	Warning/caution/danger sign boards		
Safety equipment	First aid box		
	Fire extinguisher type ABC		
Cleaning equipment	Booster pump		
	Spray gun		
	Flexible pipe		
	Wiper with extendable handle		

Annexure G: Project Handover Checklist

S. No.	Documentation list for project handover	Comments
	Engineering drawings and documentation	
1	Shadow analysis report	
2	Performance ratio and yield estimation	
3	PV system design calculations	
4	Single and three (if required) line diagram of the plant	
5	Array layout drawings	
6	String design	
7	Cable and earthing layout	
8	Lightning arrestor layout	
9	DCDB and ACDB drawings and BoM	
10	Mounting structure drawing	
11	Structure analysis report	
12	Foundation design and water-proofing plan	
13	Foundation layout drawing	
14	Bill of Material	
	Commissioning documents	
15	Pre-Commissioning check and commissioning report	
16	Punch list and cleaning record	
17	Net meter acceptance	
	Warranty documents	
18	Solar module warranty	
19	Inverter warranty	
20	Other electrical component warranty	
21	Civil work warranty	
	Other documents	
22	Project completion certificate	
23	Operations and maintenance manual	

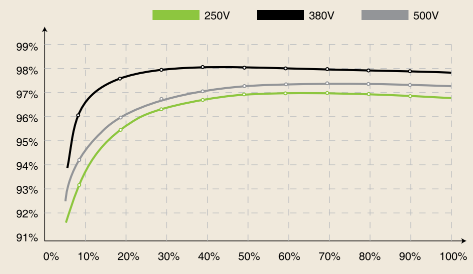
Annexure H: Technical Datasheet for a Typical On-Grid Inverter

	Model 01	Model 02	Model 03	Model 04	Model 05	Model 06
Input Data						
Max. recommended PV power (for module STC)	3350W	4000W	4800W	5600W	6150W	6650W
Max. DC voltage	500V	500V	550V	550V	550V	550V
Start voltage	100V	100V	100V	100V	100V	100V
MPP work voltage range	80V - 500V	80V - 500V	80V - 500V	80V - 500V	80V - 500V	80V - 500V
Nominal voltage	360V	360V	360V	360V	360V	360V
Max. input current of tracker A/ tracker B	10A/10A	10A/10A	10A/10A	15A/15A	15A/15A	15A/15A
Max. input current per string of tracker A/ tracker B	10A/10A	10A/10A	10A/10A	15A/15A	15A/15A	15A/15A
Number of independent MPP trackers/ strings per tracker	2/1	2/1	2/1	2/1	2/1	2/1
Output (AC)						
Rated AC output power	2500W	3000W	3600W	4200W	4600W	5000W
Max. AC apparent power	2500VA	3000VA	3600VA	4200VA	4600VA	5000VA
Max. output current	11.3A	13.6A	16.3A	19A	20.9A	22.7A
AC nominal voltage; range	220V/230V /240V; 180-280Vac	220V/230V /240V; 180-280Vac	220V/230V /240V; 180-280Vac	220V/230V /240V; 180-280Vac	220V/230V /240V; 180-280Vac	220V/230V /240V; 180-280Vac
AC grid frequency; range	50Hz/60Hz, ±5Hz	50Hz/60Hz, ±5Hz	50Hz/60Hz, ±5Hz	50Hz/60Hz, ±5Hz	50Hz/60Hz, ±5Hz	50Hz/60Hz, ±5Hz
Displacement power factor (configurable)	0.8 leading ... 0.95 lagging	0.8 leading ... 0.95 lagging	0.8 leading ... 0.95 lagging	0.8 leading ... 0.95 lagging	0.8 leading ... 0.95 lagging	0.8 leading ... 0.95 lagging
THDi	<3%	<3%	<3%	<3%	<3%	<3%
AC connection	Single phase	Single phase	Single phase	Single phase	Single phase	Single phase
Efficiency						
Max. efficiency	97.6%	97.6%	97.9%	97.9%	97.9%	97.9%
Euro weighted efficiency	97%	97%	97.4%	97.4%	97.4%	97.4%

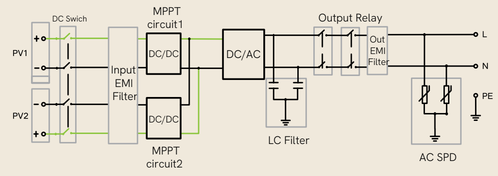
	Model 01	Model 02	Model 03	Model 04	Model 05	Model 06
MPPT efficiency	99.5%	99.5%	99.5%	99.5%	99.5%	99.5%
Protection Devices						
DC reverse polarity protection	Yes	Yes	Yes	Yes	Yes	Yes
DC switch rating for each MPPT	Yes	Yes	Yes	Yes	Yes	Yes
Output over current protection	Yes	Yes	Yes	Yes	Yes	Yes
Output over voltage protection – varistor	Yes	Yes	Yes	Yes	Yes	Yes
Ground fault monitoring	Yes	Yes	Yes	Yes	Yes	Yes
Grid monitoring	Yes	Yes	Yes	Yes	Yes	Yes
Integrated all-pole sensitive leakage current monitoring unit	Yes	Yes	Yes	Yes	Yes	Yes
General Data						
Dimensions (W/H/D) in mm	355/419/138	355/419/138	355/419/138	355/419/138	355/419/158	355/419/158
Weight	14 KG	14 KG	14 KG	14 KG	14.5 KG	14.5 KG
Operating temperature range	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C
Noise emission (typical)	≤25 dB(A)	≤25 dB(A)	≤25 dB(A)	≤25 dB(A)	≤25 dB(A)	≤25 dB(A)
Altitude	2000m without derating	2000m without derating	2000m without derating	2000m without derating	2000m without derating	2000m without derating
Self-consumption night	< 0.5W	< 0.5W	< 0.5W	< 0.5W	< 0.5W	< 0.5W
Topology	Transformerless	Transformerless	Transformerless	Transformerless	Transformerless	Transformerless
Cooling concept	Natural	Natural	Natural	Natural	Natural	Natural
Environmental Protection Rating	IP65	IP65	IP65	IP65	IP65	IP65
Relative humidity	100%	100%	100%	100%	100%	100%
Features						
DC connection	H4/MC4 (opt)	H4/MC4 (opt)	H4/MC4 (opt)	H4/MC4 (opt)	H4/MC4 (opt)	H4/MC4 (opt)
AC connection	Connector	Connector	Connector	Connector	Connector	Connector
Display	LCD	LCD	LCD	LCD	LCD	LCD
Interfaces: RS232/RJ45/RF/Wi-Fi/LAN/GPRS	Yes/Yes/Opt/Opt/Opt/Opt	Yes/Yes/Opt/Opt/Opt/Opt	Yes/Yes/Opt/Opt/Opt/Opt	Yes/Yes/Opt/Opt/Opt/Opt	Yes/Yes/Opt/Opt/Opt/Opt	Yes/Yes/Opt/Opt/Opt/Opt

	Model 01	Model 02	Model 03	Model 04	Model 05	Model 06
Warranty: 5 years/10 years	Yes/Opt	Yes/Opt	Yes/Opt	Yes/Opt	Yes/Opt	Yes/Opt

Model 05 efficiency



2.5-5.5k topology



Annexure I: LA Zones and Protection

Building, Facility, Zone, Areas	Lightning Protection Level
a) Buildings that have rooms with a large number of occupants (e.g. theatres, concert halls, dance halls, cinemas, multi-purpose sporting/exhibition arenas, retail stores, restaurants, churches, schools, transportation facilities such as railway stations and similar sites of public assembly, including the associated buildings, which can be adversely affected by a lightning strike); Note: Especially multi-purpose sports/exhibition arenas, theatres, cinemas, restaurants and similar sites with rooms where there could be 100 or more persons; sales sites with a total sales area of less than 1,200 m2, if the calculated number exceeds 100 persons, sales sites with a total sales area of more than 1,200 m2.	II
b) Accommodation facilities (e.g. hotels, nursing homes, institutions, hospitals, prisons, military barracks); Note: Especially hospitals, nursing homes where there are permanently or temporarily 10 or more persons who depend on outside help; especially hotels, inns and boarding houses where there are permanently or temporarily 15 or more persons that do not depend on outside help.	II
c) Particularly tall buildings, including the adjoining buildings of normal height; high-rise buildings used as residential and commercial buildings, high chimneys and towers (church steeples). Note: Buildings which are considered tall according to building legislation or where the top floor is more than 22 metres above the surrounding terrain serviced by firemen or where the eaves have a height of more than 25 metres.	III
d) Buildings made from combustible materials with a total volume of more than 3,000 m^3;	III
e) Large agricultural and operational buildings (more than 3,000 m^3) including the adjoining silos and adjacent residential buildings which could be adversely affected by a lightning strike; fermenting facilities or biogas plants;	III
f) Industrial and commercial buildings in high-risk areas (such as plants and equipment where flammable or explosive materials are handled or stored), wood processing factories, mills, chemical plants, textile and plastics factories, explosives and ammunition depots, pipelines, gas stations; - Areas at risk of fire - Explosion-risk zones under a roof	II-I II I
g) Containers for flammable or explosive substances (such as, flammable liquids or gases), warehouses for solid or liquid fuels and associated buildings and facilities (e.g. machine buildings, gas stations, storage buildings with filling equipment);	
h) Buildings and facilities which house content with special value items (e.g. archives, museums, collections);	II
i) Buildings and facilities which house sensitive technical equipment (e.g. IT and telecommunications facilities); data centres;	II
j) Buildings and installations in exposed topographic positions (e.g. free-standing building [alpine huts] in the mountains	III-I

Annexure J: Specifications and Details of Balance of System

Component	Specifications
MC4 connectors	
DCDB	▪ Box should be IP 65, FRP material with Lockable door. The input cable glands must be compatible for single core, flexible, copper, 6 sq. mm of solar cable ▪ The fuses should be in draw-out fuse holders such that the fuses can be changed in future ▪ The DC isolator/breaker located inside the junction box should be rated at 1000V DC
ACDB or combiner Box	Shall have necessary surge arrestors. Panel shall be metal clad, completely enclosed, rigid, floor mounted on stand, air - insulated, cubical type suitable for operation on three phase, 415 volts, 50 Hz
GI strip	Hot dip galvanised MS earthing strip - 50mm x 6mm
Fire extinguishers	The firefighting system for the proposed power plant for fire protection shall consist of - (i) Portable fire extinguishers for fire caused by electrical short circuits, (ii) Sand buckets
Cable tray	GI perforated cable tray with cover, support and required accessories
Cable conduit	HDPE DWC conduits
Cable tie	Nylon, 66 UL94V-2, 300mm, UV stabilised
Cable lugs	Copper coated with insulated sleeves
Ferrules	
Cable route marker, cable tags, cable gland, heat shrink sleeve, electrical tape etc.	As per standard
Inverter canopy, stand and cage with lock	As per detail design
ACCB canopy, stand/foundation and cage with lock	As per detail design
Tools and tackles	Necessary tools and tackles for purpose of maintenance
Danger boards and signages	As per IE Act/IE Rules, amended up to date
Cleaning system	Circulation pump with piping arrangement

Annexure K: List of International Electrotechnical Certificates for Key Components

PV module/panels/systems	
IEC 61215/IS 14286	Design qualification and type approval for crystalline silicon terrestrial photovoltaic (PV) modules
IEC 61701	Salt mist corrosion testing of photovoltaic (PV) modules
IEC 61853- Part 1/IS 16170: Part 1	Photovoltaic (PV) module performance testing and energy rating – irradiance and temperature performance measurements, and power rating
IEC 62716	Photovoltaic (PV) modules – ammonia (NH3) corrosion testing (as per the site condition like dairies, toilets)
IEC 61730-1,2	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction, Part 2: Requirements for testing
Solar PV Inverters	
IEC 62109-1, IEC 62109-2	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements, and safety of power converters for use in photovoltaic power systems Part 2: Particular requirements for inverters. Safety compliance (Protection degree IP 65 for outdoor mounting, IP 54 for indoor mounting)
IEC/IS 61683 (as applicable)	PV systems – Power conditioners: Procedure for measuring efficiency (10%, 25%, 50%, 75% & 90-100% loading conditions)
IEC 62116/UL1741/IEEE 1547 (as applicable)	Utility-interconnected photovoltaic inverters - test procedure of islanding prevention measures
IEC 60255-27	Measuring relays and protection equipment – Part 27: Product safety requirements
IEC 60068-2/IEC 62093	
(as applicable)	Environmental testing of PV system – Power conditioners and inverters
PV roof mounting structure	
IS 2062/IS 4759	Material for the structure mounting
Cables	
IEC 60227/IS 694, IEC 60502/IS 1554 (Part 1 & 2)/IEC 69947(as applicable)	General test and measuring method for PVC (Polyvinyl chloride) insulated cables (for working voltages up to and including 1100 V, and UV resistant for outdoor installation)
BS EN 50618	Electric cables for photovoltaic systems (BT(DE/NOT)258), mainly for DC cables
Junction boxes	
IEC 60529	Junction boxes and solar panel terminal boxes shall be of the thermo-plastic type with IP 65 protection for outdoor use, and IP 54 protection for indoor use
Fuses	
IS/IEC 60947 (Part 1, 2 & 3), EN 50521	General safety requirements for connectors, switches, circuit breakers (AC/DC): a) Low-voltage Switchgear and Control-gear, Part 1: General rules b) Low-Voltage Switchgear and Control-gear, Part 2: Circuit breakers disconnectors, switch-disconnectors and fuse-combination units d) EN 50521: Connectors for photovoltaic systems – Safety requirements and tests
IEC 60269-6	Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
Surge arrestors	

PV module/panels/systems	
BFC 17-102:2011	Lightening protection standard
IEC 60364-5-53/ IS 15086-5 (SPD)	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - isolation, switching and control
IEC 61643- 11:2011	Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - requirements and test methods
Earthing/lightning	
IEC 62561 Series (Chemical earthing) (as applicable)	IEC 62561-1, Lightning protection system components (LPSC) - Part 1: Requirements for connection components IEC 62561-2, Lightning protection system components (LPSC) - Part 2: Requirements for conductors and earth electrodes IEC 62561-7, Lightning protection system components (LPSC) - Part 7: Requirements for earthing enhancing compounds

Annexure L: List of International and Indian Standards for Solar Photovoltaic (SPV) Systems

International standards	Description
IEC 60228:2004	Conductors of insulated cables
IEC 60269-6 Low-voltage fuses – Part	Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
IEC 60364 IEC 60364-4-41:2005	Low-voltage electrical installations (all parts) Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock
IEC 60364-5-54:2011	Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors
IEC 60364-7-712:2002	Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
IEC 60529	Degrees of protection provided by enclosures (IP Code)
IEC 60898-2	Circuit-breakers for over current protection for household and similar installations – Part 2: Circuit-breakers for AC and DC operation
IEC 60947-1	Low-voltage switchgear and control gear – Part 1: General rules
IEC 60947-2	Low-voltage switchgear and control gear – Part 2: Circuit breakers
IEC 60947-3	Low-voltage switchgear and control gear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units
IEC 61215: 2005	Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
IEC 61646	Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval
IEC 61730-1: 2004	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction
IEC 61730-2: 2004	Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing
IEC 62109-1 IEC 62109-2	2010 Safety of power converters for use in photovoltaic power systems – Part 1: General requirements Safety of power converters for use in photovoltaic power systems – Part 2: Particular requirements for inverters
IEC 60287 (all parts)	Electric cables – Calculation of the current rating
IEC 60332-1-2:2004	Tests on electric and optical fibre cables under fire conditions – Part 1-2: Test for vertical flame propagation for a single insulated wire or cable – Procedure for 1kW pre-mixed flame
IEC 62305-2	Protection against lightning – Part 2: Risk management
IEC 62305-3	Protection against lightning – Part 3: Physical damage to structures and life hazard
IEC 62305-4	Protection against lightning – Part 4: Electrical and electronic systems within structures
IEC 62446	Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection
EN 50521	Connectors for photovoltaic systems – Safety requirements and tests
IEC 60904-3	Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data
IEC 61215:2005	Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
IEC 61646	Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval

International standards	Description
IEC 61730-2:2004	Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing
ISO 6988:1985	Metallic and other non-organic coatings sulphur dioxide test with general condensation of moisture

Indian standards	Description
IS 8130:2013	Conductors for insulated electric cables and flexible cords (second revision)
DOC.ETD 39 (6430)	Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
IS 60898(Part 2): 2003	IS 60898(Part 2): 2003 Electrical accessories - circuit breakers for over protection for household and similar installations Part 2 Circuit breakers for AC and DC operation
IS 12762 (Part 1): 2010	IS 12762 (Part 1): 2010 Photovoltaic devices: Part 1 Measurement of photovoltaic current voltage characteristics
IS 12762 (Part 2): 2013	IS 12762 (Part 2): 2013 Photovoltaic devices: Part 2 Requirements for reference solar cells
IS 12762 (Part 3): 2013	IS 12762 (Part 3): 2013 Photovoltaic devices: Part 3 Measurement principles for terrestrial photovoltaic (PV) solar devices with reference
IS 14286	2010 Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval (first revision)
IS 61730 (Part 1):	2004 Photovoltaic (PV) module safety qualification: Part 1 Requirements for construction
IS 61730 (Part 2)	2004 Photovoltaic (PV) module safety qualification: Part 2 Requirements for testing
Doc: ET 28 (6417)	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements (under print)
Doc: ET 28 (6418)	Safety of power converters for use in photovoltaic power systems – Part 1: Particular requirements for inverters (under print)
IS 14286	2010 Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval (first revision)
IS 16077	2013 Thin-film terrestrial photovoltaic modules design qualification and type approval
IS 61730 (Part 2)	2004 photovoltaic (PV) module safety qualification: Part 2 Requirements for testing
IS/ISO/IEC 17025	2005 General requirements for competence of testing and calibration laboratories