CONSUMER GUIDE

FOR

SOLAR PHOTOVOLTAIC

GRID CONNECTED ROOFTOPS

CONTENTS

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 in pricing, Solar photovoltaic technologies are central to this disruption.

India has set its eyes on an aggressive target of deploying more than 100GW of solar photovoltaic capacity. While government policies and innovative financial tools are playing a catalytic role in promoting adoption of solar through utility scale projects, similar efforts for promoting adoption of solar rooftops have failed to made targeted impacts. Transition towards clean and sustainable energy sources shall not be complete without the participation of masses. Solar photovoltaics systems are one of the most affordable instrument with a potential to seed the transition.

This techno-commercial guide has been designed to assist stakeholders in making informed decisions while sourcing services for installation of solar rooftop systems at their respective facilities. The guide shall also serves as an instrument for identification of typical project risks, de-risking investments by including recommended frameworks in decision making, and hence enabling swift and affordable finance for deserving projects. Further, the guide may also be use as a tool by project developers, integrators and integrators to upscale their technical capacities, build quality control and assurance protocols, and improve project management practices.

1. INTRODUCTION

In recent years, Renewable Energy technologies, especially wind and solar, are increasingly competing with fossil based power. While large scale solar projects have seen price of power purchase agreement falling to well below INR 3 per kWh, even distributed solar has achieved grid parity. Levelised cost of electricity for solar rooftop is below the grid electricity tariffs in many States.

It can be safely assumed that technology and cost are no longer a significant barrier to adoption of solar rooftops. While deployment of utility scale solar projects has witnessed significant year on year growth, contribution of solar rooftop has staggered around 10% of total installed capacity. This is in complete contrast to other nations which are global leaders in installed solar capacity. For example, in countries like Australia, Germany, Spain and United States, solar rooftops contribute to more than 50% of total installed capacity. Australia tops this capacity with 97% of total solar capacity installed as Solar Rooftop Systems.

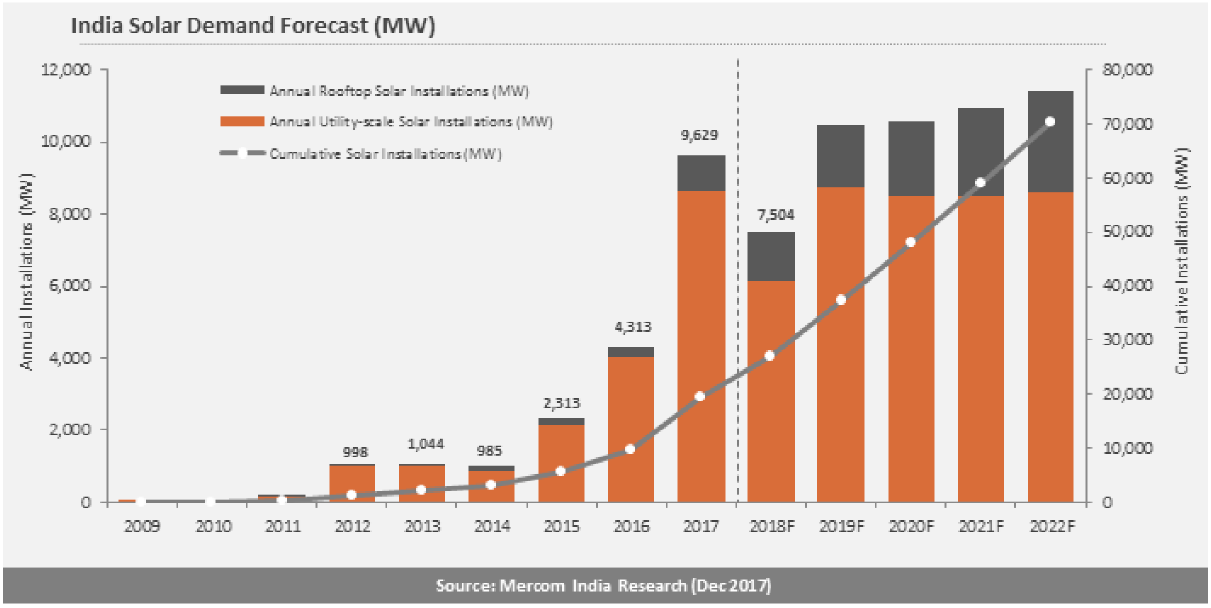

FIG 1: INSTALLED SOLAR CAPACITY AND DEMAND FORECAST FOR INDIA

Solar rooftop or distributed solar offer unique value proposition of last mile energy generation and consumption, and hence eliminate line losses. Further, they do not require heavy investments in transmission infrastructure for evacuation of power and they can serve as an effective tool for Demand Side Management. Increasing the contribution of distributed rooftop solar is integral for creating a more balanced renewable energy integration, and electricity distribution companies have a key role to accelerate the adoption. Simplifying and automating the process of net metering applications shall be one of the first step in direction. But there are more serious concerns which throttle the growth of solar rooftop segment in India.

While most consumers understand basics of solar today, their capacity to judge quality of components and services offered by a project developer is often very limited. In the absence of strong regulatory mechanisms and weak 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 environment factors. Understanding these risks is extremely critical for consumers and financing institutions to make a well informed investment decision.

This publication is designed to inform potential consumers and financing institutions about potential risks associated with a typical solar rooftop project. It also serves as a guide for mitigating these risks by ensuring quality of material and services offers by a project developer is as per International Standards. It also provides insights into basics of solar PV rooftop system, and recommends some best practices for fair structuring of contracts between clients and project developers.

2. SOLAR PHOTO-VOLTAIC SYSTEMS

Solar PV systems can power many different applications. The technology deployed depends on various parameters including the nature of application, loads and client expectations. While solar PV modules are central to all solar systems, its functionality is typically defined by charge controllers, inverters and variable frequency drives. Functionality, value proposition, economics and limitations of respective technologies differ a lot, and it is advisable that suitable technology is selected as per critical needs of the application. This section discusses broad classification of solar systems based on type of classification.

2.1. Off-grid Solar PV Systems

Off-grid is a system designed to help people or facilities function without the support of electrical grid infrastructure. Designed for powering applications in off-grid or underserved regions, system application may vary from basic lighting to community grids, education, healthcare and telecommunications systems.

Other than Solar PV modules, solar systems for off-grid applications will always consist of an energy storage unit. The shall also have a charge controller or an inverter, depending on whether the application is power by DC or AC current, respectively. Depending on availability of grid electricity, off-grid system may also absorb power from the grid for charging the batteries. Such systems are typically deployed in areas where power disruption of more than 6-8 hours is common.

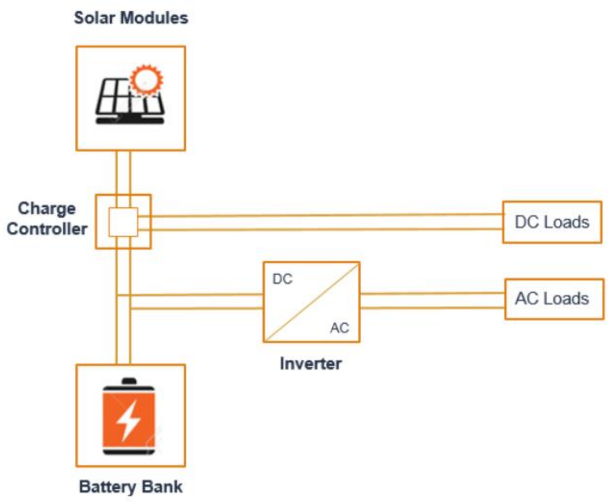

Fig 1: Single Line Diagram of Solar Power Pack

2.2. Grid Connected Solar PV 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 synchronization with main grid, where in the PV system acts as a Micro Power plant. While the Grid Connected SPV 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.

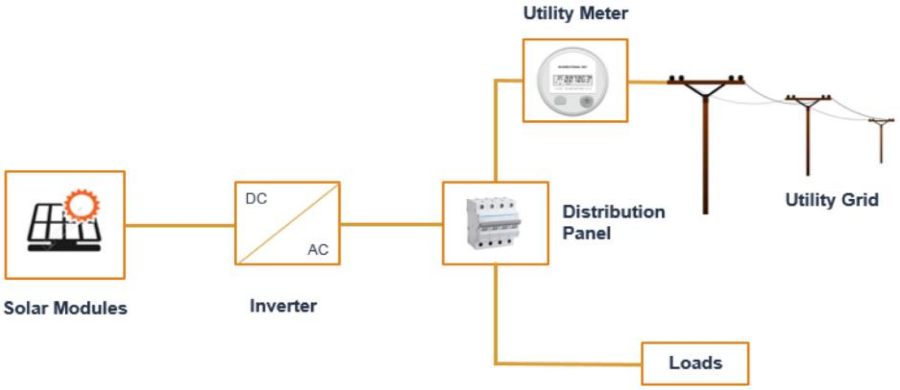

Fig 3: Single Line Diagram for Solar Grid Connect System

In rare cases, SPV systems are also designed to operate in synchronization 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 ensuring that minimum idling load is maintained.

2.3. Hybrid Solar PV Systems

Hybrid Solar Systems combine the functionalities of both off-grid and grid connected systems. They contain a battery bank to ensure power back-up in case of electric outages, as well as grid synchronized inverters enabling them to feed the power into the grid when battery banks are fully charged.

Hybrid systems ensure that better utilization of solar power in areas where power disruptions are frequent, but they also demand higher capital investment because of integration of battery banks. This also implies that operations and maintenance are significantly hired compared to grid-connected systems, which are discussed in Section 2.3.

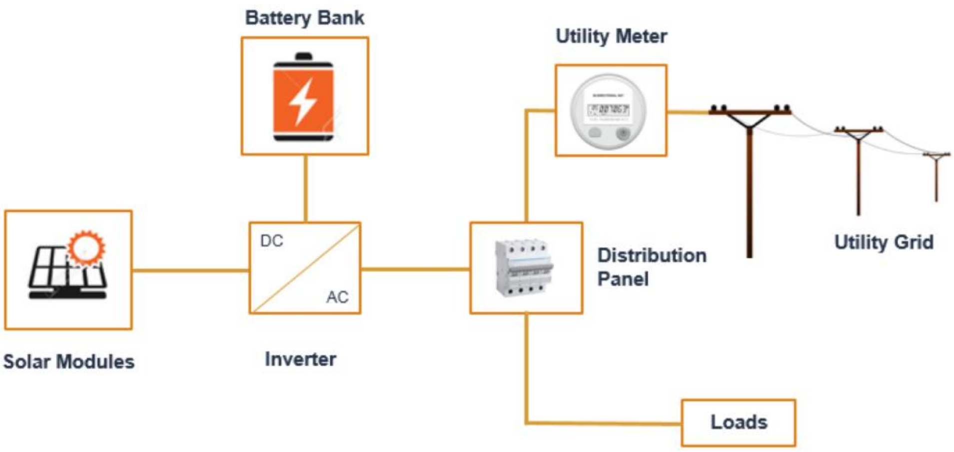

Fig 2: Single Line Diagram for Solar Hybrid System

3. METERING AND ENERGY ACCOUNTING

Traditionally, electricity consumers have just been receiver 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 modernization and integration of renewable energy.

The energy meters or electricity meters were originally designed for uni-directional flow of electricity, accounting for 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 2 popular metering mechanisms that are typically deployed with solar rooftop systems, unless they are designed for captive generation. These 3 mechanisms are explained below.

3.1. Captive Generation

Captive plants are typically deployed for facilities with very high energy consumption. They are designed in a manner that all energy produced serves the energy requirements of the facility only. In other words, the energy produced by a captive plant is never fed into to the grid. Hence, captive solar plants do not require bi-directional meters. However, energy accounting can be done using Remote Monitoring Systems and PV meters to monitor energy generated by the solar rooftop system.

In case of captive solar rooftop PV plants, the energy produced is always less than or equal to the energy requirement of the facility at any given instant. In case any excess energy is generated and fed into the grid, the *prosumer* does not receive any benefits against the energy fed into the grid. To ensure that at no instance any electricity is fed into the grid, following design philosophy is deployed:

where base load is the minimum load of the facility during day time.

Solar PV Capacity ≤ Base Load of the Facility,

3.2. Gross Metering

Gross metering mechanism is deployed when energy generated by 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.

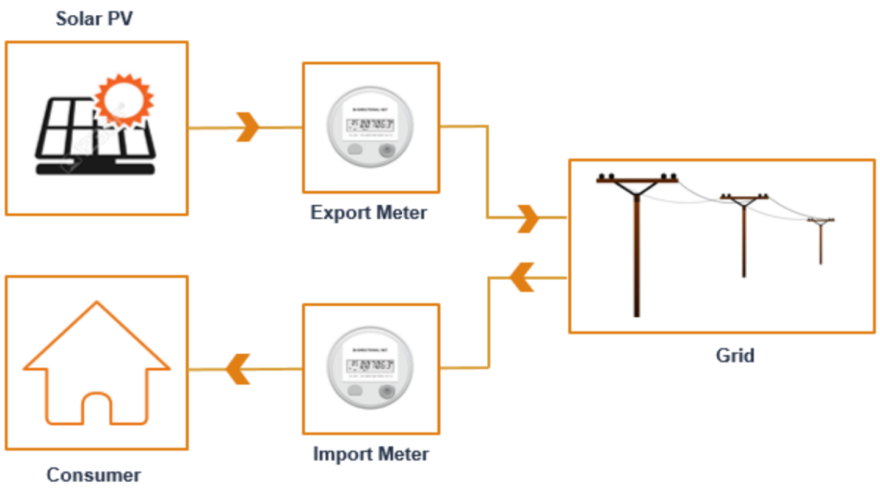

Fig 4: Gross Metering Mechanism

Gross metering mechanism mandates generation of 2 bills. The first bill accounts for electricity consumer 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 Distribution Company.

3.3. Net metering

Net metering is the preferred metering mechanism when there is no preferential feed-in-tariff, and hence accounting for net electricity consumption is more efficient. The electricity generated by the SPV system is preferentially consumed within the facility where it is installed, and any excess generation is fed into the main grid. There is only one bill generated in this case which gives a measure of total imported energy and total exported solar energy. The difference between both is taken and the payment is based on the net of import or export. This is helpful in offsetting the total energy consumed from the grid and reduces the cons

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

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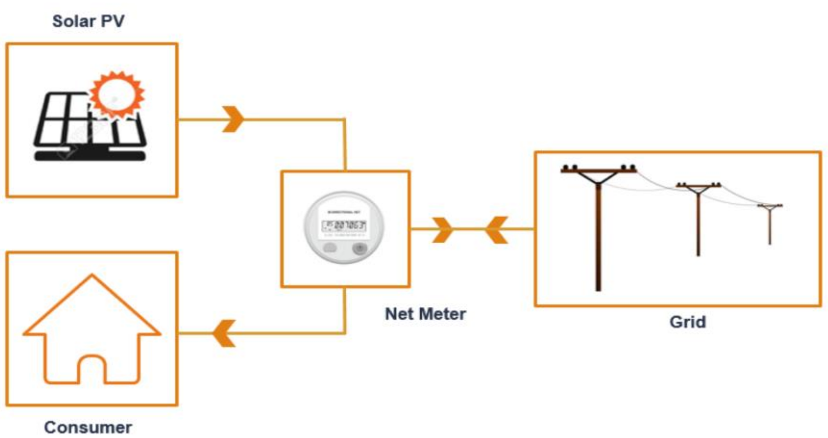


Fig 5: Net Metering Mechanism

’s electricity bill. Net meters are especially favoured when electricity price is higher than feed-in-tariff.

4. PROJECT FINANCING

Solar PV Rooftop systems are reliable, long term generation assets with proven technology. Salient features of the rooftop technology opens up multiple financing options financing solar rooftop PV systems. The financing options are though constrained by size of the project and financial or credit rating of the *prosumer*. A project can either be financed by the project developer, financial institution or third party investor. Key models for deploying solar rooftop systems are discussed below.

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*, and hence responsibility for operation and maintenance of the plant lies with the owner. The project is developed by an experienced EPC (Engineering, Procurement and Construction) contractor selected by the *Prosumer*. The plant may be maintained using his/her own resources, or alternatively it can be outsourced to an experienced contractor.

Institutional finance through up to 7 years' term loan is available through public and private banks. The interest rates for the loans can vary from 11-13%. In India, SPV project owners can benefit from capital subsidies currently provided by MNRE, SECI or other State Nodal Agencies when deployed at a residential facility or a facility of Not-for-Profit agency. However, subsidy is strictly subjected to 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 itself or sub-contracts installation and commissioning to an EPC contractor. He also signs a Power Purchase Agreement (PPA) with facility owner to recover its investments. The term of the PPA is typically anywhere between 15 to 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 case of 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 plant is either done by the project developer itself or through a competent sub-contractor deployed by it.

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

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. Project developer is compensated on basis of Power Purchase Agreement 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 on about space availability, structural and electrical information and user expectations in order to propose suitable technology solutions, optimal system capacity and simulate information related to performance of the PV system to be installed.

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

5.1. Roof Assessment

Mapping layout of the roof along with construction and equipment on the roof are extremely critical for designing solar array layout and ensuring performance of the plant throughout the year. Ideally, solar modules shall be facing true south for locations in northern hemisphere and true north for locations in Southern Hemisphere. In case of fixed tilt structures, ideal tilt angle is approximately equal to the latitude of the location. While variation in orientation or tilt angle impact 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 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 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 design is available based on whether the roof is flat or indented. Same are discussed in Section 8.3.1. 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 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 Section 8.3.2 and 8.3.3. Suitable options should be discussed with client and a formal approval should be attained, especially for penetrating type structures, to avoid issues during 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. In case of captive SPV systems, detailed consumption patterns need to be established to estimate base load for facilities. This shall ensure that solar generation does not exceed the captive needs of the facility. Route for cable shafts and location of LT panels is established to estimate length and gauge of cable to be used. Further, location for housing equipment such as DCDB, Inverter, ACDB and meters is established in consultation with client. It is recommended that cable route and location of equipment is mapped to ensure that length of cable is kept to minimum in order to minimize resistive losses.

5.3. Risk Assessment

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

TABLE 1: RISKS ASSOCIATED WITH SOLAR PV PLANT CONSTRUCTION

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.

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

5.4. Shadow Analysis

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

If the project site is located above *Tropic of Cancer*, shadow analysis shall be performed for day of Winter Solstice (or December 22). For project sites located between *Tropic of Cancer* and *Tropic of Capricorn*, shadow analysis shall be performed for both Summer (June 21) and Winter Solstice. Other than that, it should be ensured that partial or complete shadow is avoided during peak-sunshine hours. It is recommended that time window of 4 hours, before and after solar noon is considered for the analysis.

A typical shadow analysis report is shared in Annexure.

5.5. Capacity Estimation

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

Other than 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 80% of the sanctioned load or 30% of the capacity of the distribution transformer, whichever is less. In case when 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*. In this case, DISCOM considers total solar capacity installed on the LT side of the transformer. Hence, applications are typically approved on first come, first serve basis.

6. NO OBJECTION CERTIFICATE

In case Net Metering is required for installation solar PV rooftop, No Objection Certificate needs to be obtained from the local electric utility for installation of Net Meter. List of documents required for Net Metering Application and NoC from electric utility are provided below. Concerned form and list of documents are available on electric utility's website.

- Net Metering Application Form
- Net Metering Agreement on Judicial Stamp of suitable value
- Copy of 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 long term performance of the projects. In case of OPEX based projects, operational and performance risks are carried by RESCO company; but still savings and value generated for the client are directly linked to performance of the system. In case of CAPEX based project, 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, there is a significant dearth of competent project developers and EPC contractors in the markets. Absence of a recognizable brand makes the selection task difficult for a client. It is advised that a techno-commercial review of the project developer / EPC contractor is carried out using at least the following guidelines.

TABLE 2: GUIDELINES FOR EVALUATING EPC CONTRACTOR'S TECHNO COMMERCIAL COMPETENCY

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

7.2. Negotiations

While negotiating a contract price, it is important to understand project economics and boundary conditions. Contract price can vary based on final bill of material, quality of components to be used and scale of project. Table 3 provides typical price range (*computed on per watt basis)* for various components and their variation with size of the project. This may be treated as a fair indication of project pricing, and hence a benchmark of price negotiations. Developer margins are typically in the range of 10-15%, and haven't been accounted in the table.

TABLE 3: PRICE VARIATION FOR SPV ROOFTOP PROJECTS ON PER WATT BASIS

System Size Component	5kWp	20kWp	50kWp	100kWp
PV module[1]	26 - 28	25 - 27	24.5 - 25.5	23 - 24.5
Grid-tied Inverter[2]	14 - 17	6.0 - 9.0	4.0 - 4.5	4.0 - 4.5
Module mounting structure[3]	5.5 - 6.5	5 - 6	3.5 - 4.5	3 - 3.5
DCDB / AJB (including fuses with optional DC disconnect and SPD - Type I + Type II)	0.8 - 1.0	0.25 - 0.3	0.20 - 0.3	0.20 - 0.30
ACDB (AC MCB, Solar PV Meter and optional SPD)	2.4 - 3.0	0.6 - 0.75	0.24 - 0.30	0.20 - 0.25
DC Cable[4]	0.3 - 0.4	0.3 - 0.35	0.39 - 0.41	0.38 - 0.4
AC Cable[5]	0.3 - 0.4	0.1 - 0.11	0.07 - 0.09	0.06 - 0.07
Lightning Arrestor	0.8 - 1.2	0.2 - 0.25	0.1 - 0.2	0.10 - 0.15
Earthing arrangement	1.4 - 1.6	0.35 - 0.40	0.2 - 0.3	0.2 - 0.25
Data logger	1.2 - 3.0	0.4 - 0.75	0.3 - 0.6	0.15 - 0.30
Weather Monitoring System[6]			0.7 - 2.0	0.35 - 1.0
Net Meter	2.0 - 2.4	0.5 - 0.6	0.25 - 0.35	0.20 - 0.25
Fire Protection System[7]	0.1 - 0.2	0.04 - 0.05	0.02 - 0.03	0.15 - 0.02
Installation and Commissioning	3.0 - 4.0	3.0 - 3.5	2.5 - 3.0	2.5 - 3.0
Engineering	2.0 - 2.5	0.5 - 0.6	0.3 - 0.4	0.20 - 0.25
Total[8]	59.8 - 71.2	42.2 - 49.7	37.3 - 42.5	34.7 - 38.7

Notes:

[1] *Poly-crystalline Silicon Modules*

[2] *Inverter rating to solar DC capacity of 1:1 is assumed*

[3] *Non-elevated, hot-dip galvanised structures with 80micron coating thickness*

[4] *Solar / XLPE copper cable of suitable gauge, length of cable is estimated based on array size for respective solar capacities. Actual length may vary depending on designed array layout.*

[5] *Armoured 3.5 core aluminium cable of suitable gauge with a standard length of 20 meters*

[6] *Typically not deployed or advised for small projects*

[7] *Manual protection systems*

[8] *Does not account project margins and freight charges. Project margins may be in the range of 8-12%*

7.3. 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 interests of both parties, ie. EPC Company / Project Developer and the client in a fair manner. While a project contract largely safeguards payment risk for the EPC Company, it plays a crucial in safeguarding the client against technical and performance risks, along with possible delays in project execution. This section discusses structure for a fair contract between the concerned parties, for both CAPEX as well as OPEX models. Guidelines for selection of Project Developer / EPC Company and financial negotiations are also discussed.

7.3.1. Contracts & Obligations

- **Performance ratio and yield guarantees**—which stipulate plant performance levels such as a minimum amount of energy delivered based on the measured solar irradiation at a site, based on system design and modeled plant behavior. 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** reward/penalize plant performance that misses or exceeds projected production levels.
- **Energy-based contracts** link plant production (kWh/yr) with O&M service provider revenues so that associated expenses are extrapolated according to low and high generation periods.

7.3.2. O&M Contract Contents

The purpose of an O&M contract is to optimise the performance of the plant. To do this effectively, the O&M contract should clearly state:

- The services to be carried out by the contractor.
- Frequency of these services.
- Obligations and scope of the owner.
- Standards, legislation and guidelines with which the contractor must comply.
- Payment structure.
- Performance guarantees and operational targets.
- Methodologies for calculating plant availability and/or performance ratio.
- Methodologies for calculating liquidated damages/ bonus payments in the event of plant under- or over performance.
- Terms and conditions.
- Legal aspects.
- Insurance requirements and responsibilities.

7.3.3. O&M Contractor Services and Obligations

The O&M contract defines the terms for the contractor to perform certain checks and activities at predetermined intervals:

- Perform a visual check of the system components for visible damage and defects.
- Perform a functional test of the system components.
- Ensure that the required maintenance will be conducted on all components of the system in accordance with manufacturer recommendations and the conditions of equipment warranties.
- Perform cleaning of the modules.
- Make sure that the natural environment of the system is maintained to avoid shading and aid maintenance activities.
- Replace defective system components and system components whose failure is deemed imminent.
- Provide daily remote monitoring of the performance of the PV plant to identify any points when performance drops below the set trigger levels.
- Perform scheduled and unscheduled maintenance requirements.
- The contractor should also be contractually obliged to optimise plant performance.
- It must be ensured that all maintenance tasks should be performed in such a way that their impact on the system productivity is minimised.

The O&M contract defines the following terms as a part of the owner's scope of work:

- The obligations of the owner include granting the O&M contractor access to the system and all the associated land and access points,
- The owner must obtain all approvals, licenses and permits necessary for the legal operation of the plant
- The owner must also provide the O&M contractor all relevant documents and information that are necessary for the operation and management of the plant.

8. PROJECT EXECUTION

Project execution is an art which takes planning, foresight and intuition to ensure project are delivered on time and comply with the quality standards. This section discusses some of key deliverables which reflect 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 and every 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 is well managed.

A well detailed project execution plan is a good template for 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 control of a EPC contractor. Hence, it is advised that reasonable delays in project deployment should be excused. This shall help in ensuring quality and in avoiding unnecessary timesaving methods to hasten the pace of the project.

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

8.2. Quality Plan

A quality of project is not defined by quality of components only. Accurate engineering as per standards, handling of material and quality of construction are some of the key aspects that define a quality of project. A quality plan primarily lays our quality standards and process for engineering, procurement and construction, while also includes necessary checks and testing procedures to ensure compliance. Some key aspects of a quality plan are discussed in Table 4.

TABLE 4: KEY QUALITY GUIDELINES FOR PROJECT

Project Head	Key Quality Guidelines
Material	Compliance with Bill of Material • 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

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 engineering exercise.

8.3.1. Solar Resource Assessment

Energy from sun travels through space (in vacuum) at speed of light in form of electromagnetic waves, in stream of energy packets called photons. These photons releases heat when absorbed by any surface.

Solar Irradiance, measured in the unit of W/m^2, is defined as instantaneous measurement of solar power over a specific area. For estimation of yield of solar systems, Solar Insolation or Incident Solar Radiation is used, which is defined as cumulative energy measured over specified area for a defined period. The unit of Insolation is same as that of energy i.e. kWh per square meter.

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, tilt angle of the plain or the surface is also accounted. Some key definitions are as below.

- Direct Radiation: The solar radiation that reaches the surface of earth without being diffused is called direct beam solar radiation (DNI). It is measured by Pyrheliometer.
- Diffused Radiation: As sunlight passes through atmosphere, some portion of it is absorbed, scattered and reflected by water vapour, clouds, dust, pollutants, etc. is called diffuse solar radiation (DHI). It is measure by shaded pyranometer and thermopile detectors.

- Global Reflected Radiation: The radiation which is reflected by a ground is called Ground Reflected Insolation (GRI) or Albedo. It is more prominent at reflective region 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 Pyranometer.

8.3.2. PV array layout

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

As a best practice, it should be ensure that shadow casted 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 8am and 4pm. 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 below.

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

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.

8.3.3. Solar String / Array design

Solar string inverters are either designed for DC input as single array, multiple sub-array for respective MPPT inputs or individual string inputs. 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 the purpose of design necessary data can be obtained from technical specifications for solar modules and grid connected inverters. While designing solar PV strings or array, it is ensured that maximum and minimum voltage levels are with the mandated range for inverters. For this purpose, it is important that effect of temperature on electrical characteristics of solar PV module is considered. This can be estimated by use of temperature coefficients for voltage and current.

A. Maximum Operating Voltage for String / Array

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

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

B. Maximum Voltage at Maximum Power

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

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

C. Minimum Voltage at Maximum Power

Minimum voltage corresponding to maximum power point is calculated at maximum operating temperature. Formula for same is as below.

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

D. Maximum Input Current

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

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 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 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 degrees Celsius (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.

8.3.4. Circuit Protection Design

Design or sizing of various circuit protection systems is discussed below.

A. Isolators or Disconnect Switch

Circuit breakers that are used as PV array isolators are rated per pole. In case of non-isolated or transformerless inverters, the minimum voltage rating per pole shall correspond to maximum open circuit voltage for the solar array. This shall correspond to voltage corresponding to minimum expected cell temperature, as discussed in section 6.3.2. A safety factor of 1.15 is considered for same. The total I_{SC} 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 taken into account determines the rating of the disconnect switch under normal conditions.

B. Main Circuit Breakers (MCB)

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 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 below:

$$1.5 \times I_{SCMOD} =< I_{trip} =< 2.4 \times I_{SCMOD}$$

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 below:

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

C. Surge Protection Device

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

TABLE 5: SPD LOCATION AND OPERATING CHARACTERISTICS

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

8.3.5. Cable sizing

Cable sizing is done based on 2 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 current carrying capacity required.

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

$$CCC >= (Imp)_{Tmax} \times 1.25$$

where,

CCC: Current carrying capacity of the conductor

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

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

$$CCC >= I_{max,array} \times 1.25$$

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

It is recommended that 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 below. Length of cables shall be accurately provided based on site assessment and cable layout.

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

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

$L_{DC\ cable}$ = 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

8.3.6. Lightening Arrestor

Lightning arrestor's 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 PV array is within the radius of protection extended by LA. A plane of reference is defined corresponding to tallest equipment to be protected.

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

$$H = h_{LA,reference\ plane} + h_{reference\ plane}$$

$$h_{LA,reference\ plane} = r_{prot\ rad} \times tan^{-1}\theta$$

$$r_{prot\ rad} >= Minimum\ radius\ of\ protection\ required\ to\ protect\ the\ equipment$$

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

☐ = Angle of protection of LA

8.3.7. Structure Design and Analysis

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

Some important checks for structural analysis are listed below.

1. Height of building where plant is being installed. Data is available for basic wind speed at 10m above the mean ground level and should be extrapolated using a correction factor to determine the design wind speed at the height the plant is located.
2. Wind speed data usually uses the peak gust velocity averaged over a short time interval (usually 3 seconds) for the location. These are estimated for a 50 year return period.
3. 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 an obstruction.
4. Angle of tilt of the plant - higher tilt angle will block more wind leading to higher design wind load. Hence the client must ensure that the tilt angle used in the wind analysis is as per the structure drawings.
5. Elevation: In some cases the structure is elevated to accommodate shadow impact or increase the installed capacity and hence needs to be elevated. In such cases wind load impact on the structure increases because of 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 re-designed. Further, it should also be ensured that maximum deflection of members should be less than "(span of the member)/150". This is to ensure that there is no undue stress on the solar modules, which can lead to formation of micro-cracks.

It is recommended, in case of doubt, structural analysis shall be verified by an independent and competent structural engineer.

8.3.8. Performance Ratio & Plant Yield

Plant yield is defied 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,

$$PR = (1-\alpha)\times(1-T_{loss})\times(1-S_{soilingloss})\times(1-V_{drop})\times\eta_{inverter}$$

$$Plant\ Yield = P_{sun}\times P_{rated}\times PR\times 365$$

where,

P_{sun} or Peak Sun is numerically equal to average solar irradiation per day (kWh/m^2/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 6 provides provide a brief summary of key deliverables of design and engineering.

TABLE 6: 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 Calcuations	• 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 engineering section) • 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

8.4. Safety Plan

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

Safety policies and practices should be proactive in nature. This involves assessing risks, hazards and unsafe behaviours in order 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 below.

TABLE 7: SAFETY GUIDELINES FOR DIFFERENT ASPECTS OF PROJECT DESIGN AND CONSTRUCTION

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 work spaces • 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 • Fire fighting equipment • Evacuation plan • Reporting procedure

8.5. Project Monitoring

Once a project is in execution phase, multiple teams shall be working together to deliver the desired outcome. Monitoring progress of project is a critical activity for any project developer, but it can be equally important for the client if it wishes to track progress and enforce quality by performing periodic checks. Table 8 briefly discussed various stages of 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 project. This shall be applicable to projects of capacity up to 100kWp.

TABLE 8: DELIVERABLES AND TIMELINES FOR PROJECT PHASES

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	20-45

	• Receipt of material	
Construction	• Team deployment details • Daily progress report (to include civil, mechanical and electrical works) • Deviation records • Safety incidences	10-30
Commissioning & Handover	• Comissioing 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

Some key tools for project monitoring are described below.

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

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

C. Commissioning Checklist enlists all the important tests, reviews and check 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 at 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 is typically the final phase of the project, especially in *CAPEX* projects. Client shall ensure that 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. COMPONENTS AND QUALITY PARAMETERS

This section discusses 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, attempt has been made to provide a practical approach for gauging 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 PERC and HIT are also gaining market share because of their better performance and higher efficiency. Mono and Poly crystalline solar modules are most commonly used, and for the purpose of this module, the information covers only aforementioned solar modules.

9.1.1. Bill of Material for Solar Modules

It is very difficult to predict quality of a solar module based on it visual and mechanical inspection. The performance of a module can depend on variety of reasons, which include component of materials used in its assemble, assembly process, handling of solar module during manufacturing, freight and installation. This section discusses key components used in construction of a solar module. Once installed, evaluating 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.

A. ***Solar cells*** are heart of a solar module as they largely define electrical and performance characteristics of a solar module. Various cell technologies are available today with polycrystalline and mono crystalline 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 and spots.

B. ***Back-sheets*** 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, burn holes and delamination. It is critical that back-sheets are designed for a life cycle of minimum 25 years. Good quality back-sheets have tough film with high surface tension, durable adhesion, good weatherability, high melting temperature (about 200 °C), UV resistance, and doest not react to any major solvent.

C. ***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. EVA (Ethylene vinyl acetate) is an encapsulant used most commonly in PV panel manufacturing process.

D. ***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 allows high transmission of light in the visible wavelength range. It also protects PV modules from ingress of water, vapours and dust particles.

E. Aluminium Frame are deployed to 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 key components mentioned above, solar modules use silver plater copper ribbons for interconnection of cells. Different busbar designs are used to which impact quantity of material uses and internal resistance of solar modules. Currently, 5BB design is popular because of less usage of material and better cell efficiency. Manufacturers also include different combinations of by-pass and blocking diodes which dictate 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 enhance the life of solar modules.

9.1.2. Parameters to assess a solar module

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

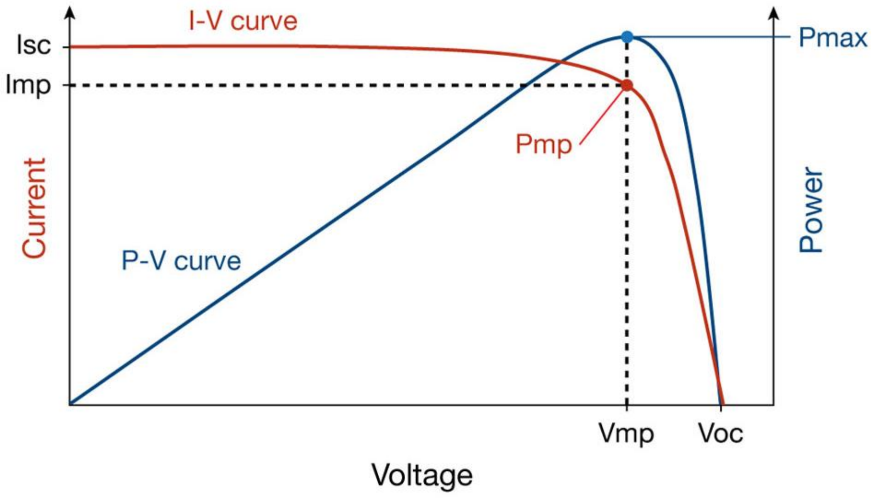
A. I-V curve

The current-voltage curve of a PV module, commonly known as its 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 zero volts, to zero 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.

In an operating PV system, MPPT algorithm continuously calibrate output current and voltage corresponding to maximum power yield. A sample IV curve is shared below.

FIG.2 SAMPLE I-V CURVE FOR SOLAR PV MODULE



B. Efficiency

A solar module efficiency is determined by its ability to convert energy in the form of sunlight into electricity. Typically solar module efficiencies lie between 14-21% these days. The efficiency of a solar module is 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 quality of material used in fabricating the module, and also quality of product processes. For different modules with same rated capacity at STC, the module with higher efficiency will be smaller in size.

C. 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 following

Fill Factor = $(VmpXImp)/(VocXIsc)$.

Although its 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 1. 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.

9.1.2.1.Derating coefficients

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 temperature.

9.1.3. Degradation in Solar PV module

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

A. **Time based degradation:** The efficiency of solar panels decreases over time automatically, but such degradation is typically accounted into their performance warranties. Typical causes for time based degradation of solar panels degrade are 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 minimum guaranteed output power of 90% for upto 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 year to year basis.D

B. **Potential induced degradation:** Potential Induced Degradation (PID) is an undesirable property of some solar modules that reduces panel efficiency and power output over time. PID is usually caused when modules have negative potential with respect to ground. Although its a reversible effect, it can reduce 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.

   Risk of PID can be mitigated by appropriate grounding as recommended by module and inverter manufacturer.

C. Cell Defects: Cells are exposed to various possible defects during manufacturing, handling and operations. These defects are discussed separately below.

- **Micro Cracks** are hair line fractures in PV cells caused by thermal or mechanical stress during fabrication, handling or operations. These cracks are not visible to naked eye, but they can critical 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 expose to risks of discolouration. Moreover, if EVA is stored under improper conditions or too long before manufacturing, the additive in the EVA partly disappears and hence increases the risk of discolouration when exposed to UV rays. Bleaching of browning cell may cause in bubble formation of EVA sheet and back-sheet, resulting in corrosion of cell.

  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 back-sheet. Poor soldering technology may also cause burning which is seen as a yellowish colour on ribbons.

- **Delamination** occurs when bond between the back-sheet and the glass separate. This results in air and moisture creeping into module causing corrosion and failure of cells. This phenomena may also occur if 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, exploring the cells to air and moisture.

- **Hot Spots** are cause because of localised excessive heat production in cells because of cell defects or partial shading. This causes damage of encapsulation material and cells, and in extreme cases may also cause a fire. They also seriously impact 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 the plants based on the power requirements/ plant capacity. A detailed comparison of grid connected inverters by different manufacturers is discussed in the table.

9.2.1. Types of Grid Connected inverters

1. **String inverter:** These are the most common form os solar inverters available in the market where each string of solar panels is connected to one input on the inverter. In case of large system capacities, there can be multiple string inverters each with multiple string inputs. While these are the most commonly 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 shading effect or different orientation, voltage of the entire string is reduced to that level resulting in low power generation.
2. **Micro inverter:** 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.
3. **Central inverter:** are similar to string inverters but offer a much larger capacity and can support 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 also most prone to failures and faults in a solar PV system. Some standard parameters such IP protection, efficiency, number of available MPPT and wide operating range are good indicators of quality of the system. But most important, feedback by former customers can provide best inputs on quality of 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 its customers.

Annexure H provides a comparative analysis of 50kW string inverter offered by multiple manufacturers. Other than electrical efficiencies, cost of inverters vary depending on in-built protections, monitoring and other features. A technical datasheet for typical on-grid inverter is shared in Annexure I.

9.3. SPV Mounting Systems

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

A. Mounting Structure for Pitched Roofs

Pitched roofs are mostly found on industrial sheds, farm houses or residential roofs in hilly regions. The most common mounting configurations are railed, rail-less and shared-rail structures. These structured are riveted to the tin shed. Waterproofing is done using EPDM rubber and water proofing 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 use a bolt/screw to connect the module to a hardware attached to the roof without any rails. As there aere no rails, the overall cost of the system is lower than that of a railed structure. It also allows for flexibility in installation of panels as the panels are not limited to the direction

of rails and can be positioned in any manner..

FIGURE 3: TYPES OF MOUNTING STRUCTURES

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 rails are used which provides the flexibility of installation.

B. Flat roof mounting structure

Flat roof mounting structures are the most common in India and they are highly customizable. 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 case of rooftops, mounting structures are either designed for fixed tilt or seasonal tilt.

In 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 3 positions: optimal fixed tilt angle, and angles of +/- 15 degree from fixed tilt angle.

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

I.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 PCC foundations are constructed on top to add dead load and provide water proofing.

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

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

Figure 4: ballast type mounting structure

C. Carport mounting structure

Carport mounting structures are special application variant of elevated flat roof mounting structure. These are quite popular for parking spaces and multiple variants of design are available suiting the needs of customer. Mostly these are ground mounted but can also be installed on a rooftop parking.

9.3.1. Selection of Structure material

Mounting structures are typically made of galvanized iron or anodized aluminum. Though recently the market has seen many more new variants, most of which are alloys (like POSMAC). 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, that 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 reinforced cement concrete (RCC) or plain cement concrete (PCC) depending on the strength required. Following points dictate strength and quality of the concrete block. Additional adhesives may be mixed to enhance mechanical, waterproofing and anti-corrosion properties of the foundation blocks. Some of the key elements to ensure quality of civil work are discussed below.

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 not be corroded. 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 may ensure that the contractor is using an industry grade mix of cement to ensure 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 such 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. Typically contractors may not allow adequate curing time to the concrete to hasten the work. This may result in cracks and chips in the foundation over time leading to poor structure strength. In cases where wet curing 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 are able to sustain the wind loads. Also, stainless steel fasteners are recommended or else exposure to environmental elements may lead to corrosion and degradation over time, compromising structural integrity of the mounting structures. The bolts should be tightened as per recommended torque and if required connection design should be verified by structural engineer.

9.4. Cables or Wires

Cables or wires connect different components of 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 application. The environmental and electrical parameters for the respective applications can be very different, and hence required carefully design and selection of material. A well designed cabling system is engineered to optimize efficiency, while ensuring that it withstands thermal, electrical and mechanical stress throughout the life of the system..

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.

9.4.1. 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 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 salt water resistant and resistant to common acids and alkaline solutions.

9.4.2. AC cables

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

- Withstand mechanical stress such as compression, tension, bending and shear loads.
- Abrasion-resistant, therefore most sheaths are made of plastics cross-linked using an electron
- Resistant to acids and alkalies.
- Withstand high dielectric strength (depending on the type of application)
- Flame-retardant and halogen-free. This prevents 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

PV plants are typically designed as long term assets for 25 years or more. The plants are exposed with many unknowns which impact long-term system reliability and necessitate maintenance exercise. These concerns are further intensified for plants that are located in remote areas with difficult access. This often mandates use of protection devices tone installed in the systems to ensure the plant functions efficiently and reliably for its design life. These products are particularly useful in keeping the plant safe from any current or voltage surges, lightning damage and grid harmonics. Inclusion of this protection devices prevents system downtime and keep the system running.

9.5.1. Miniature Circuit Breakers

Miniature circuit breakers (MCBs) are a current based protection device widely used in electrical systems to protect the system in case of faults and over current. An important characteristic 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 use of thermal device. Another characteristic is magnetic fault protection, which is intended to operate when the fault reaches a predetermined level and trips the MCB within one tenth of a second. The third characteristic is short circuit protection, which protects equipment against heavy faults (in thousands 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, 6kA fault level is adequate whereas for industrial boards, 10kA fault capabilities or above may be required. MCBs are rated in amps which is the amount of current it will pass 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. Generally, these are designed to guard against over current 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 & four poles with neutral poles if necessary. The normal current rating is ranges from 0.5 - 63 A 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.

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 main circuits of inverters, solar PV arrays or battery banks as all these equipments and circuits use DC current. The DC MCB uses a magnet to attract the arc, pulling it from the air gap, and extinguishes it. Only DC MCBs should be used for DC applications.

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, AC breaker is not equipped with a magnet, and cannot extinguish a DC arc. It breaks the connection at 0V thus protect the wiring from high much current.

Most dual rated breakers have their DC voltage rating different from AC voltage rating, for the same amps.

Further, based on application and surge current implications, MCBs are classified into 3 common categories.

1. Type B MCB, which is most commonly used in domestic and light load applications. The MCB has capacity to manage surge current that is 3 and 5 times of full load current.

2. Type C MCB, used for commercial and industrial applications wherein higher value of in-rush current is expected. The MCBs can accommodate surge currents between 5 and 10 times of full load current. The connected loads in such cases are typically inductive in nature.

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

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

9.5.2. Surge Protection Device

Surge protection devices are used in electrical systems to provide a low resistance discharge path to ground the system components which might be damaged due to exposure from high-voltage transients. These transients will 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 and must be adequately designed, sized and installed as per the plant requirements. SPD acts like a clamp and are connected in parallel across the live wires with another wire going to the ground. Protection level of an equipment is proportional to the value of admissible surge current of the SPD. Hence, if the surge exceed 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 the 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 external lightening arrestor is used, type I AC SPDs are used as these ground direct lighting surges. In case of absence of 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 below.

A. **Type I SPD** 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 external lightning protection system and also via 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 are relatively cheaper, Type I DC SPD which can carry lightning current are extremely costly.

B. **Type II SPD** is deployed in low voltage systems and protects against spread of over-voltage in solar installations primarily arising from in-direct lightning. These SPDs have a lower value for admissible surge current resistance.

C. **Type III SPD** are typically knows as 'point of utilisation SPDs' and protect equipment against nominal surges. They have 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 are capable of handling these surges independently.

Depending on point of connection and protection required, single pole, bi-pole and 4 pole SPDs are used. Single pole SPDs are used for single phase systems, two pole for a split phase system and three pole SPD 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.

The Important aspects of installing SPDs

SPDs perform many important functions with regards to providing protection to the PV plant

1. The strategic placement of SPDs mitigates transient voltage surges by ground them.
2. Multiple inverters can be protected with one SPD on the AC side since they are connected to the same grid voltage making this process more cost-effective also.
3. In case the contractor is using string fuses, the SPD must be installed at the point of interconnection of the combined strings after the fuses.
4. If external lightning protection equipment is used, a type I +II SPD should be used.
5. Type 2 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.
6. The surge arrestors should be connected to both positive and negative outgoing terminal of the string junction box (if the inverter already does not have an equivalent in-build DC surge arrestor).
7. 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.

9.5.3. Earthing system

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

1. Lightning
2. Switching surges
3. Static
4. Contact with a high voltage system
5. Line to ground fault

An earthing system comprises of 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 DC side, AC side and lightning arrestor. A single DC side earthing may be used, in conjunction with lightening arrestor, in combination with a type-I SPD. Equipments are typically connected to a grounding copper rod using 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 practices for grounding are as following

1. It is required to ground all PV systems. A properly grounded system will helps protect the user from unintentional shocks and possible deaths. It also prevents any fires in the system post-installation.
2. 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.
3. 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 percent safety margin and 25 percent to protect from any factor resulting in increased current.
4. The minimum cross section 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.
5. For lightning arrestor grounding, wider cross sections are used as compared to that for grounding PV array. The grounding conductor should not be less than 16 mm^2 for copper or 70 mm^2 for hot-dipped galvanized iron.
6. It should also be ensured that the resistance between any point of the PV system and earth should not be greater than 5 Ω.
7. The grounding system should be installed before the system is energised.

9.5.4. Ground Fault Protection

In a SPV system, earth fault can occur when grounding wire or equipment body comes in contact with live wire, resulting in high current flowing to the ground via 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 risk of fire. Intermitted ground faults can also occur because of flooding, for example after rains. Another cause could be expansion or contraction of metal during hot or cold ambient conditions respectively. Intermittent can be extremely difficult to identify and troubleshoot. In some case ground fault can disappear as soon as Solar PV system is shutdown. This can happen when ground fault is caused because of arcing and resulting carbon built up.

Following best practices for cable laying and using cables with appropriate insulation and protection can help in completely avoiding ground faults.

9.5.5. 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 lightening can also cause transient voltage and current surges which may travel for many kilometres, and hence pose a potential threat to safety of equipment. A lightning arrestor, also called 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, following lightning arrestors are used:

1. 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 mm^2 copper), firmly fixed, follow 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) which is itself connected to the earth of the installation.

2. 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.

3. Lightning conductors with 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.

4. 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. 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 arrestor's 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, LA extends a cone of protection from its tip. To ensure that all equipment are protected with desired level of protection, it shall be ensure that equipment lies between the area of protection. This requires taking into account location of equipment and its height to ensure that the plan of protection covers the equipment at its point of maximum height. Either LA height is calculated to provide the necessary protection, and multiple LA are strategically deployed to ensure that LA height is within manageable limits. While installing LA for a solar PV system, care should be taken to avoid shadow of LA on PV modules.

Typically three lightening protection levels are defined depending on degree or criticality of protection required. These are discussed below.

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 200kA, 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.

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 case of a four-wire system, 19 kA is distributed to each wire, whereas for a five-wire system, that would correspond to 15 kA. This lightning protection class covers multiple areas like parts of hospitals, shipping warehouses with fire alarm systems and telecommunication towers.

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 J discusses the different buildings and zones and 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 DC and AC side. More advanced monitoring solutions may include monitoring of sub-arrays in case of multiple MPPT, string monitoring and module monitoring. Implementing these typically depend on 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 yield of SPV plant, data logging or remote monitoring solutions can also provide performance monitoring of SPV plants and it components. Depending on architecture of data monitoring solution, technical and under performance issues at module and string level can also be identified. To enable tracking performance ratio of the system, installing a weather monitoring solutions is pertinent.

Weather monitoring solutions provides data for solar irradiation, ambient temperature, module temperature, humidity and wind speed. To calculate 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 weather monitoring solutions will typically consist of following hardware:

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

B. *Anemometer and Wind Vane* for measuring speed

C. *Hygrometer* for measuring wind speed

D. *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 assembly and installation of a solar PV systems. Complete list of Balance of System is provided in Annexure K.

Further, Annexure L provides list of critical IEC certificates for quality compliance for various components.

10. PLANT PERFORMANCE AND YIELD

For comparing 2 solar PV plants with same technical specifications and environmental conditions, Performance Ratio is one of the key indicators, along with Annual Solar Generation. Although Capacity Utilisation Factor (CUF) is also often used, but this term is more suitable for comparing performance of fossil fuel powered plants which operate 24x7, rather than solar PV plants.

Performance Ratio

Performance ratio is a comparison of plant output w.r.t. to the plant output could have achieved by taking into account irradiation, panel temperature, availability of grid, size of the aperture area, nominal power output, temperature correction values. Latest softwares are capable of accurately simulation performance of a solar PV plants based on weather data for the site, if all design inputs and variables are accurately accounted for.

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

Typically, performance ration of SPV plants in India vary from 72-78%, depending on various factors discussed above below.

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

Tilt & Orientation

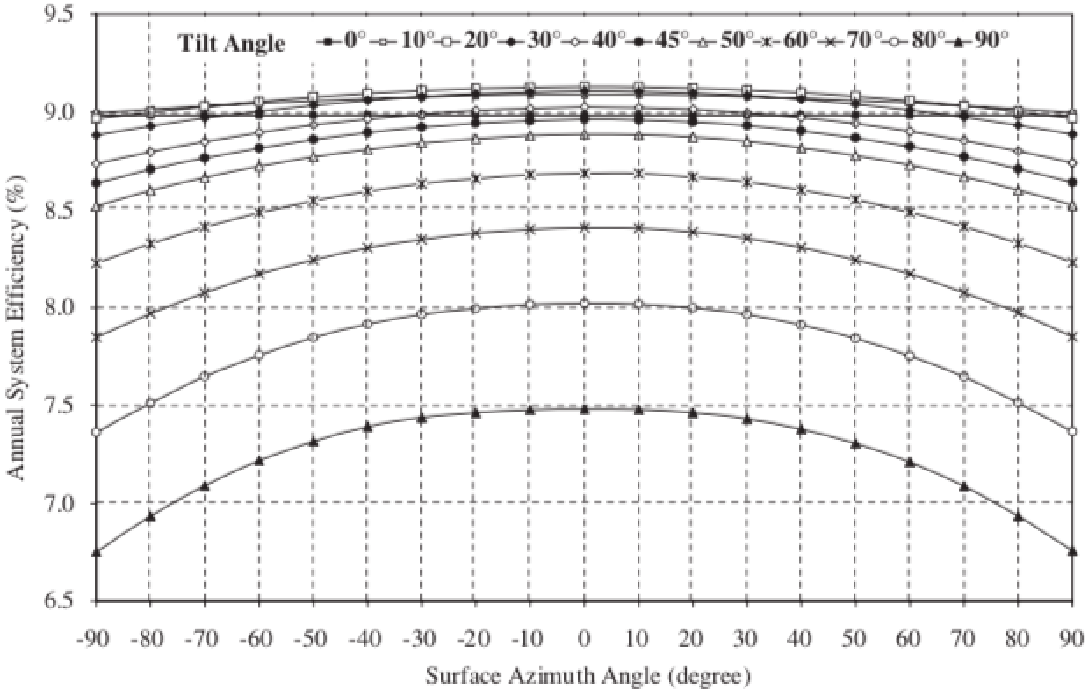


FIG 5: VARIATION OF ANNUAL SYSTEM EFFICIENCY AS FUNCTIONS OF SURFACE AZIMUTH AND TILT ANGLE

Ideally, when orientation of solar modules is fixed, they should be installed facing true south direction in northern hemisphere and vice-versa for southern hemisphere. Optimal fixed tilt angle for solar modules is approximately equal to the latitude of the location. But is shall be noted that depending on site parameters, solar modules may be installed at 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 cost of system.

Shadow loss

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

Soiling loss

Soiling losses occur due to 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 emission 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, soiling loss is assumed to be around 5%. It can increase significantly if solar modules are not cleaned on periodic basis.

Environmental conditions

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

Light-induced degradation

This represents loss incurred due to change in 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. Impact of LID is lower on high quality modules.

Module Mismatch

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

Ohmic Loss

Ohmic losses are basically because of impedance of cable used for connecting the system, as well as point of connections. 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.

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.

Other losses

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

System availability

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

A sample PVSyst report is shared in Annexure M.

11. OPERATIONS AND MAINTENANCE

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

11.1. O&M Approach

Traditionally, maintenance is divided in to 2 categories described below.

- **Scheduled maintenance:** which 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 requirement basis.

A more effective and scientific categorisation of maintenance activity is discussed below. This approach helps in reducing system downtime, avoid failure of any critical component, and enables the plant to perform at its ideal capacity .

- **Preventive maintenance** includes routine inspection and servicing of equipment at intervals determined by 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 higher upfront costs and needs to be designed optimally to avoid any unnecessary labor activity. Preventive maintenance usually includes scheduled activities like PV module cleaning, managing water drainage, vegetation growth prevention, retro-commissioning (which includes identifying and solving problems that have developed during 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 also increases the risk of component failure and imply higher downtime costs. Though some amount of corrective maintenance will occur over a plants 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 higher upfront costs since it requires more communication, monitoring software and hardware. Sometimes, the maintenance process also experiences challenges caused due to monitoring equipment malfunction or erratic data collection. This usually includes active monitoringsuch asremote and on-site equipment replacement and warranty enforcement.

Some key maintenance activities for a solar PV plant are described in the Table 9 below.

TABLE 9: COMPONENTS AND O&M ACTIVITY

Component	O&M Activity	Periodicity
Solar Module	Cleaning of solar modules	Daily / Weekly / Bi-weekly[1]
	Visual inspection of solar modules - Inspection for any damage to module backsheet - Visual inspection for discoloration, 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 - Visual inspection of inter-connectors and DC cable for damage	Quarterly or six monthly
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
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	Quarterly or six monthly

Component	O&M Activity	Periodicity
	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)	
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 fo system	Quarterly or six monthly
Earthing system	- Check continuity for earthing system - Inspect earthing cable (GI strips, if applicable) got 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 to calibrated equipment	Quarterly or six monthly
Safety	- Check for the fire extinguisher's expiry - 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

[1] As warranted by environmental conditions.

11.2. Solar PV module cleaning procedure

The following procedure should be followed for cleaning modules. These guidelines minimize impact to plant power generation, reduce safety hazards, and minimize 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 currents, and the risk of shock increases when modules are wet.

Before cleaning, thoroughly inspect 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 be damaged by 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 minimizes impact on production and risk of electrical shock hazard is minimized. Do not apply water that is more than 20°C warmer or colder than module surface temperature.
- Include spraying the modules with low-pressure water that is closely matched in temperature to the temperature of the module or to use a dry brushing technique.
- Clean modules only when in open circuit or when 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 odors.
- 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 deionized water may be used.
- Do not use cleaning solutions containing hydrochloric acid, D-Limonene, ammonia, or sodium hydroxide.
- Do not spray pressurized water directly at sealed interfaces of module (junction box, edge seal, and connectors). Water pressure must not exceed 35 bar (500 psi) at the nozzle.
- Do not brush or clean backside of module to avoid accidental stress to 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, aluminum, or steel.
- Ensure any brushes or agitating tools are constructed with non-conductive materials to minimize risk of electric shock

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	
8	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)		
7	Type of Building structure	☐ Framed Structure ☐ Load Bearing Structure	
8	Thickness of roof:	Maximum Height of Building:	Number of floors:
9	Anchoring allowed?	☐ Yes ☐ No	
10	Roof Composition		

<table>
<tr><th colspan="4">D. ELECTRICAL ASSESS</th></tr>
<tr><td>1</td><td>Electrical Utility Company</td><td colspan="2"></td></tr>
<tr><td>2</td><td>Electricity Bill attached</td><td colspan="2">☐ Yes ☐ No</td></tr>
<tr><td rowspan="6">3</td><td rowspan="6">Step Down Transformer</td><td colspan="2">Is step-down transformer available? ☐ Yes ☐ No</td></tr>
<tr><td colspan="2">If Yes, provide following details:</td></tr>
<tr><td>Transformer Rating</td><td></td></tr>
<tr><td>Voltage Rating</td><td></td></tr>
<tr><td>Manufacturer and Build Number</td><td></td></tr>
<tr><td>Fusing/ OCP/ Isolators sizes and types; if available</td><td></td></tr>
<tr><td rowspan="8">4</td><td rowspan="8">Electrical Service Panel</td><td rowspan="4">AC Load Panel Rating</td><td>☐ 100 A</td></tr>
<tr><td>☐ 200 A</td></tr>
<tr><td>☐ 400 A</td></tr>
<tr><td>☐ Other</td></tr>
<tr><td>Type of incoming supply</td><td>☐ Single Phase
☐ Three Phase</td></tr>
<tr><td>Main Breaker Rating</td><td>_______________A</td></tr>
<tr><td>Breaker Space Available</td><td>☐ Yes ☐ No</td></tr>
<tr><td>Specify:
Location of Utility Meter

Location of Service Panels</td><td></td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Load Panel Details</td><td>Is AC Distribution Board Diagram Available?</td><td>☐ Yes ☐ No</td></tr>
<tr><td colspan="2">Attach Picture of AC Distribution Board ☐</td></tr>
<tr><td>6</td><td>Space Available for ACDB, PV meter, Net meter</td><td colspan="2">☐Yes ☐No</td></tr>
<tr><td>7</td><td>Location and Height of existing Lightning Arrestor</td><td>Location:</td><td>Heights:</td></tr>
<tr><td>8</td><td>Location of Earthing Pits</td><td></td><td></td></tr>
<tr><td>9</td><td>Extra fuse way available in the main fuse box</td><td>☐Yes ☐No</td><td>Rating:</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Does the Building have Generator?
□Yes □No</td><td colspan="2">If yes; Generator Synchronization Required? ☐ Yes ☐ No
If Yes; collect following details:</td></tr>
<tr><td>Generator Model:</td><td>Rating:</td></tr>
</table>

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)	
5	Location of ACDB	

F. PHOTOGRAPH CHECKLIST (Please tick that are taken)			
1	Roof	☐ Parapets	☐Mechanical/ Electrical Unit
		☐ Gas/ Condensation Lines	☐ Satellite Dishes
		☐ Access Ladder	☐ Roof Sections suitable for Array
		☐ Others	
3	General Details	☐ Shading Objects	☐ Building Elevations
		☐ Other Shading Concerns	☐ Surround Trees / Buildings
4	Electrical Connections	☐ Utility Transformer	☐ Electrical Room
		☐ Main Switchboards	☐ Conduits / Electrical shaft
		☐ Utility Meter Sections	☐ Main Breaker Section
5	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

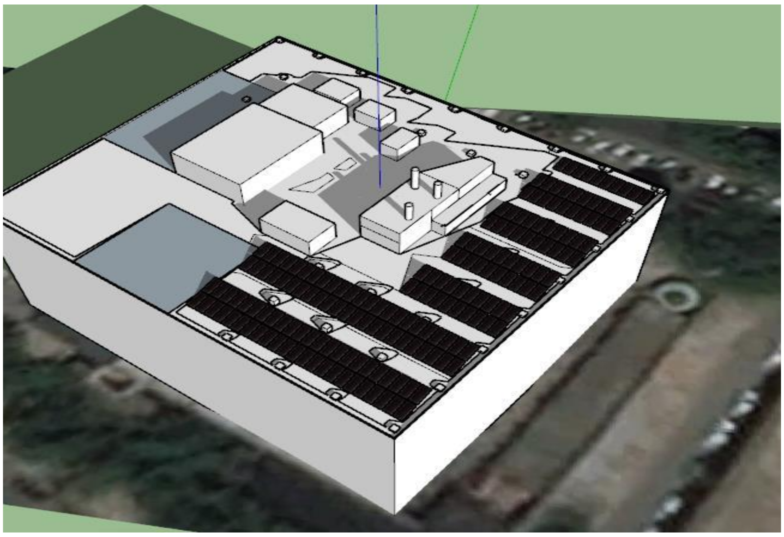
ROOF ACCESS

LT PANEL

BUILDING FRONT ELEVATION

ANNEXURE B: Sample Shadow Analysis Report using Sketch-up Modelling Tool

	Number of Panels	Power (kW)	Azimuth	Tilt (degrees)	Shading Loss (%)
Roof 1	158	50kW	206.43	15	1.26



Shading 9AM

Monthly Shading Losses											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.68	0.76	2.08	0.56	0.56	0.42	0.41	0.36	0.82	0.71	5.24	2.66

ANNEXURE C: Sample Project Execution Plan

SNo	Activity			Timeline
1	**Project Creation**			
	1.1		Project PO / Contract	
	1.2		Advance payment reciept	
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	

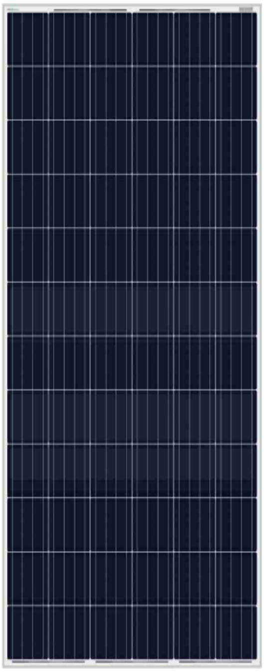
SNo	Activity			Timeline
5	**Procurement**			
	5.1		Procurement Tracker	
		a.	Bill of materials	
		b.	Vendor	
		c.	Rate	
		d.	Warranties	
		e.	Expected date of delivery	
		f.	PO number / inventory	
6	**Delivery of Material**			
	6.1		Pre-Dispatch Inspection Report	
	6.2		Site Receipt	
	6.3		Site Inspection Report	
7	**Installation & Commissioning**			
	7.1		Resource allocation	
		a.	Finalizing accommodation	
		b.	Travel plan	
	7.2		Kick-off meeting	
	7.3		Daily Progress Report	
	7.4		Punch List	
	7.5		Commissioning Report	
8	**Project Handover**			
	8.1		Project Completion Certificate	
			Final Project Payment	

ANNEXURE D: Sample Solar Module Data Sheet

GOLDI GREEN™
SOLAR PV MODULES & EPC

GOLDI 72 SERIES
POLYCRYSTALLINE MODULE

KEY FEATURES



- Excellent module conversion efficiency of up to 16.79%.
- PID resistant. (IEC 62804 certified)
- Certified for extreme weather conditions. (snow load 5400 Pa, wind load 2400 Pa)
- Salt mist and ammonia corrosion resistant. (IEC 61701 & IEC 62716 certified)
- Multiple times EL inspection (Pre & Post Lamination) to ensure micro crack - free modules.
- Up to +3% positive power output guaranteed.

Reliable Quality

- Powerful and stable: manufactured as per GOLDI GREEN's strict quality norms.
- 25 years output warranty.
- Certified from TUV SAAR & UL India.
- IP67 rated junction box for long-term weather endurance.
- 4BB design module improves reliability & module conversion efficiency.
- Certified for hail resistance.
- Manufactured in an ISO 9001:2015, ISO 14001:2015 & OHSAS 18001:2007 certified facility.
- Manufactured using highest grade raw materials from reputed international suppliers.

Application

- On-grid large scale utility system
- On-grid & off-grid residential system
- On-grid commercial / industrial roof top
- Solar Pumping System

w : www.goldigreen.in e : info@goldigreen.in
India Toll Free No. : 1800 833 5511

Electrical Parameter at STC#

Module Type GOLDI	300PM	305PM	310PM	315PM	320PM	325PM
Capacity rating - Pmax(Wp)	300	305	310	315	320	325
Power Tolerance (%)	0 ~ 3	0 ~ 3	0 ~ 3	0 ~ 3	0 ~ 3	0 ~ 3
module efficiency (%)	15.50	15.76	16.02	16.28	16.53	16.79
Rated Voltage- Vmp(V)	36.60	36.80	36.90	37.00	37.10	37.20
Rated Current- Imp(A)	8.20	8.30	8.42	8.52	8.63	8.74
Open Circuit Voltage- Voc(V)	45.20	45.40	45.70	46.00	46.20	46.40
Short Circuit Current- Isc(A)	8.60	8.70	8.80	8.90	9.00	9.10

Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

Electrical Parameter at NOCT@

Capacity rating - Pmax(Wp)	216.01	219.61	223.21	226.81	230.41	234.01
Rated Voltage- Vmp(V)	33.41	33.60	33.69	33.78	33.87	33.96
Rated Current- Imp(A)	6.46	6.54	6.64	6.72	6.80	6.89
Open Circuit Voltage- Voc(V)	41.57	41.75	42.03	42.31	42.49	42.67
Short Circuit Current- Isc(A)	6.84	6.92	7.00	7.08	7.16	7.24

@NOCT irraiance of 800 W/m², ambient temperature of 20°C Wind speed 1m/sec

Temperature coefficients (TC)

Temperature Coefficient (Voc)	-0.33 % /°C
Temperature Coefficient (Isc)	0.034% /°C
Temperature Coefficient (Pmax)	-0.42 % /°C

Permissible Operating Conditions

Temperature range	-40°C to + 85°C
Maximum system voltage	1000 V DC
NOCT	45± 2°C
Maximum surface load	Tested up to 5400 Pa according to IEC 61215
Hail resistance	Maximum diameter of 25 mm with velocity 23 m/s

Mechanical Specification

Solar Cell	72 pcs Polycrystalline Silicon (156 mm x 156 mm, 0~+1mm),4BB, PID free
Cell encapsulation	Ultra - clear PID free EVA (Ethylene-Vinyl- Acetate)
Backside	UV protected reflective backsheet
Frame	Silver Anodised Aluminum Alloy (screwless)
Front glass	3.2 mm, High transmission, AR Coated Tempered Glass
Dimensions (L x W x H)	1955 mm x 990 mm x 42 mm
Weight	22.0 kgs
Junction box	IP 67 certified 4-rail, 3 diodes junction box
Cable & Connectors	Solar cable 1200 mm length, 4 mm², MC4 compatible connectors
Application Class	Class A
Electrical Safety	Class II
Fire Safety	Class C (Type 1)

Guarantees and Certifications

Product warranty**	10 years
Performance guarantee**	Guaranteed Output power :- 90% for 10 years, and 80% for 25 Years
Approvals and certificates	IEC 61215, IEC 61730, UL 1703, IEC 61701, IEC 62716, IEC 62804, CE

Packing information

Container	20'GP	40'HC
Pallets/ container	10	24
Modules / container	250	600

ANNEXURE E: Sample Solar Grid Connect Inverter Data Sheet

ABB string inverters
TRIO-TM-50.0-400
TRIO-TM-60.0-480
50 to 60 kW

—
Technical data and types

Type code	TRIO-TM-50.0-400	TRIO-TM-60.0-480
Input side		
Absolute maximum DC input voltage ($V_{max,abs}$)	1000 V	
Start-up DC input voltage (V_{start})	420...700 V (Default 420 V)	420...700 V (Default 500 V)
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0,7xV_{start} ...950 V (min 300 V)	0,7xV_{start} ...950 V (min 360 V)
Rated DC input voltage (V_{dcr})	610 Vdc	720 Vdc
Rated DC input power (P_{dcr})	52000 W	61800 W
Number of independent MPPT	3 (SX and SX2 version) / 1 (standard and SX version)	
Maximum DC input power for each MPPT ($P_{MPPT,max}$)	17500 W	21000 W
MPPT input DC voltage range ($V_{MPPTmin}$ ... $V_{MPPTmax}$) at P_{acr}	480-800 Vdc	570-800 Vdc
Maximum DC input current (I_{dcmax}) for each MPPT	36 A	
Maximum input short circuit current for each MPPT	55 A (165 A in case of parallel MPPT)	
Number of DC input pairs for each MPPT	5	
DC connection type	Screw terminal block (Standard and -S version) or PV quick fit connector [3] (-SX and SX2 version)	
Input protection		
Reverse polarity protection	Yes, from limited current source	
Input over voltage protection for each MPPT - varistor	Yes, 1 for each MPPT	
Input over voltage protection for each MPPT - plug In modular surge arrester	Type 2 (option) with monitoring	
Photovoltaic array isolation control	According to local standard	
DC switch rating for each MPPT (version with DC switch)	60 A / 1000 V for each MPPT (180 A in case of parallel MPPT)	
Fuse rating (version with fuses)	15 A / 1000 V	
Output side		
AC grid connection type	Three-phase (3W+PE or 4W+PE)	
Rated AC power (P_{acr} @cosϕ=1)	50000 W	60000 W
Maximum AC output power (P_{acmax} @cosϕ=1)	50000 W	60000 W
Maximum apparent power (S_{max})	50000 VA	60000 VA
Rated AC grid voltage ($V_{ac,r}$)	400 V	480 V
AC voltage range	320...480 V [1]	384...571 V [1]
Maximum AC output current ($I_{ac,max}$)	77 A	
Contributory fault current	92 A	
Rated output frequency (f_r)	50 Hz / 60 Hz	
Output frequency range ($f_{min}...f_{max}$)	47...53 Hz / 57...63 Hz [2]	
Nominal power factor and adjustable range	> 0.995; 0...1 inductive/capacitive with maximum S_{max}	
Total current harmonic distortion	<3%	
Maximum AC cable	95 mm² copper only (150 mm² copper/alluminum with TRIO-AC-WIRING-KIT)	
AC connection type	Screw terminal block, cable gland	
Output protection		
Anti-islanding protection	According to local standard	
Maximum external AC overcurrent protection	100 A	
Output overvoltage protection - varistor	Yes	
Output overvoltage protection - plug In modular surge arrester	Type 2 (option) with monitoring	
Operating performance		
Maximum efficiency (ηmax)	98.3%	98.5%
Weighted efficiency (EURO)	98.0% / -	98.0% / -
Communication		
Embedded communication interfaces	2x RS485, 2x Ethernet (RJ45), WLAN (IEEE802.11 b/g/n @ 2,4 GHz)	
Communication protocols	Modbus RTU / TCP (Sunspec compliant); Aurora Protocol	
Remote monitoring services	Standard level access to Aurora Vision monitoring portal	
Advanced features	Integrated Web User Interface; Display (option); Embedded logging and direct transferring of data to Cloud	
Environmental		
Ambient temperature range	-25...+60°C (-13...140 °F) with derating above 45 °C (113 °F)	-25...+60°C (-13...140 °F) with derating above 45 °C (113 °F)
Relative humidity	4%... 100% condensing	
Sound pressure level, typical	75 dB(A) @1 m	
Maximum operating altitude	2000m / 6561ft	
Physical		
Environmental protection rating	IP65 (IP54 for cooling section)	
Cooling	Forced air	
Dimension (H x W x D)	725 mm x 1491 mm x 315 mm / 28.5" x 58.7" x 12.4"	
Weight	95 kg / 209 lbs overall, 66 kg / 145 lbs electronic compartment, 15 kg / 33 lbs AC wiring box (full optional), 14kg / 31 lbs DC wiring box (full optional)	
Mounting system	Wall bracket, horizontal support	

ANNEXURE F: Multi Brand Comparison of 50kW Solar Grid Inverters

	Delta	KACO	SMA	Sun Grow	Power One	ABB
Max DC Power	62.5kWp		51kWp		55kW	52kW
DC voltage range	200-1000	200-1000	150-1000	300-1000	330-600	300-950
MPPT voltage range	520-800	480-850	150-800	300-950	330-600	480-800
No of MPPT trackers	2	1	6	4	1	1
AC power output	50kVA	50kW	50kVA	55kVA	50kW	50kVA
Efficiency	98.6%	97.5%	>98%	98.9%	>99%	98.3%
AC/DC disconnect switch	Integrated AC/DC disconnect switch	Integrated AC/DC disconnect switch	DC disconnect switch	DC disconnect switch	Integrated AC/DC switch	DC switch
DC side protection	PV fuse 1000V, 15A DC reverse polarity protection DC over current DC short current protection		DC reverse polarity protection, DC residual current monitoring	DC fuse DC reverse current protection	DC Reverse polarity protection,	DC fuse (15A/1000V), DC reverse polarity protection. PV array isolation, DC input over voltage protection
AC side protection	AC short circuit AC over current		AC short circuit	AC short circuit	Integrated AC magnetic breaker	AC over-current AC o/p over voltage
Ground Fault protection	Ground fault monitoring		Ground fault monitoring			
Surge Protection	Type 2: DC (one for each MPPT) and AC i/p			Type 2 DC SPDC (40kA), AC Type II		Surge protection type II
Anti-islanding capability				Anti -islanding LVRT capability		Anti- islanding
Degree of Protection	IP 65	NEMA 3R	IP 65	IP 65	IP20	IP 65 (IP 54 for cooling section)
Communication interface	RS 485	Ethernet, Modbus (TCP IP), USB, RS485	Ethernat, WLAN	RS 485	RS 485	2x RS485, 2x Ethernet (RJ45), WLAN
Price per unit Watt						

ANNEXURE G: Sample Template for Daily Progress Report

COMPANY NAME											
DAILY SITE PROGRESS REPORT (DSPR)											
Project							Site In-charge				
Site Address							Contact Details				
Date of Work							Project Code				
		Unit	**Qty.**	**Construction Count**							
				Cumm Prev.	**Cumm Prev.**	**Count Planned**	**Actual Count**	**Total**	**Progress**		
Classification				**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			
								0			
MECHANICAL WORKS											
MMS Installation		Pedestal						0			
SPV Module installation		Nos.						0			
								0			
								0			
								0			
ELECTRICAL WORKS											
Module Interconnection		Nos.						0			
Junction Boxes		Nos.						0			
DC Cabling (String)		Mtr.						0			
Inverter Installation		Nos.						0			
Data Logger Installation											
AC Cabling		Mtr.						0			
AC Cabling								0			
ACCB / LT Panel Installation		Nos.						0			
Earthing & Lightning Arrestor		Nos.						0			
Personnel Mobilization Plan							**Equipment Mobilization Status**				
Title		**Previous**	**Totay**	**Total**	**Remarks**		**Particular**	**Prev.**	**Today**	**Remarks**	
Driving Staff							Drilling Machine				
Civil Staff							Cutter Machine				
Supervisor							Multimeter				
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						**Miscellaneous**					
1)						1)					
2)						2)					
"Accident hurts. Safety doesn't "											

NOTE:

1. Importance to Health Safety Environment (HSE) requirements at site must be been ensured / complied by Project Manager
2. All personals at project site shall comply with company HSE policy.
3. All personals at project site shall use personal protective equipment (PPE) and no individual should be allowed inside project site with PPE.
4. First Aid Kit should be maintained at site office for medical emergency.
5. Any incidents or accidents to be reported to Project Manager, immediately without any delays.

ANNEXURE H: Sample Template for Commissioning Checklist

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 dwg		
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 energization		
	Data logger synchronization		
DC WIRING	Check cable termination point		
	Check guage and make		
	Cable cable labeling		
AC CABLING	Check cable termination points		
	Check gauge and make		
	Check cable labelling		
SIGNAGE	Shutdown Procedure		
	Warning / Caution / Danger sign boards		
SAFETY EQUIPMENTS	First aid box		
	Fire extingusher Type ABC		
CLEANING EQUIPMENTS	Booster pump		
	Spray gun		
	Flexible pipe		
	Wiper with extendable handle		

ANNEXURE I: Sample Project Handover Checklist

PROJECT HANDOVER CHECKLIST		
Project Code:		
S.No.	**Documentation 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	

Date:

(Name of Company Representative) (Name of the Client)

____________________________ ____________________________

(Signature of Company Representative) *(Signature of the Client)*

ANNEXURE J: Recommendations for Lightening Protection

Building, Facility, Zone, Areas	Lightning Protection Level
a) Buildings that have rooms with many 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 m^2, if the calculated number exceeds 100 persons, sales sites with a total sales area of more than 1,200 m^2	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 II
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 K: 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 galvanized 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 Stabilized
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 & 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 L: List of Certifications required for respective Component

SPV Modules	
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 Grid-Connected Inverter	
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)	Photovoltaic 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 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 c) Low-voltage switchgear and Control-gear, Part 3: Switches, 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	
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 M: Sample PVsyst Report and Loss Diagram

Grid-Connected System: Simulation parameters

Project :	**50kW Grid Connedcted Solar Project**			
Geographical Site	**SNI LHO, Jaipur**		Country	**India**
Situation	Latitude	26.90° N	Longitude	75.79° E
Time defined as	Legal Time	Time zone UT+5	Altitude	300 m
	Albedo	0.20		
Meteo data:	**SNI LHO, Jaipur**	Meteonorm 7.1 (2001-2010), Sat=100% - Synthetic		

Simulation variant : SBI_LHO

Simulation date 05/04/18 15h32

Simulation parameters	System type	**No 3D scene defined**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-poly	Model	**Poly 320 Wp 72 cells**		
Custom parameters definition	Manufacturer	Goldi Green		
Number of PV modules	In series	16 modules	In parallel	10 strings
Total number of PV modules	Nb. modules	160	Unit Nom. Power	320 Wp
Array global power	Nominal (STC)	**51.2 kWp**	At operating cond.	43.4 kWp (50°C)
Array operating characteristics (50°C)	U mpp	513 V	I mpp	85 A
Total area	Module area	**313 m²**		

Inverter	Model	**SG50KTL-M**		
Original PVsyst database	Manufacturer	Sungrow		
Characteristics	Operating Voltage	300-950 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	50 kWac
			Pnom ratio	1.02

PV Array loss factors

Array Soiling Losses			Loss Fraction	3.0 %
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	106 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

Loss diagram over the whole year