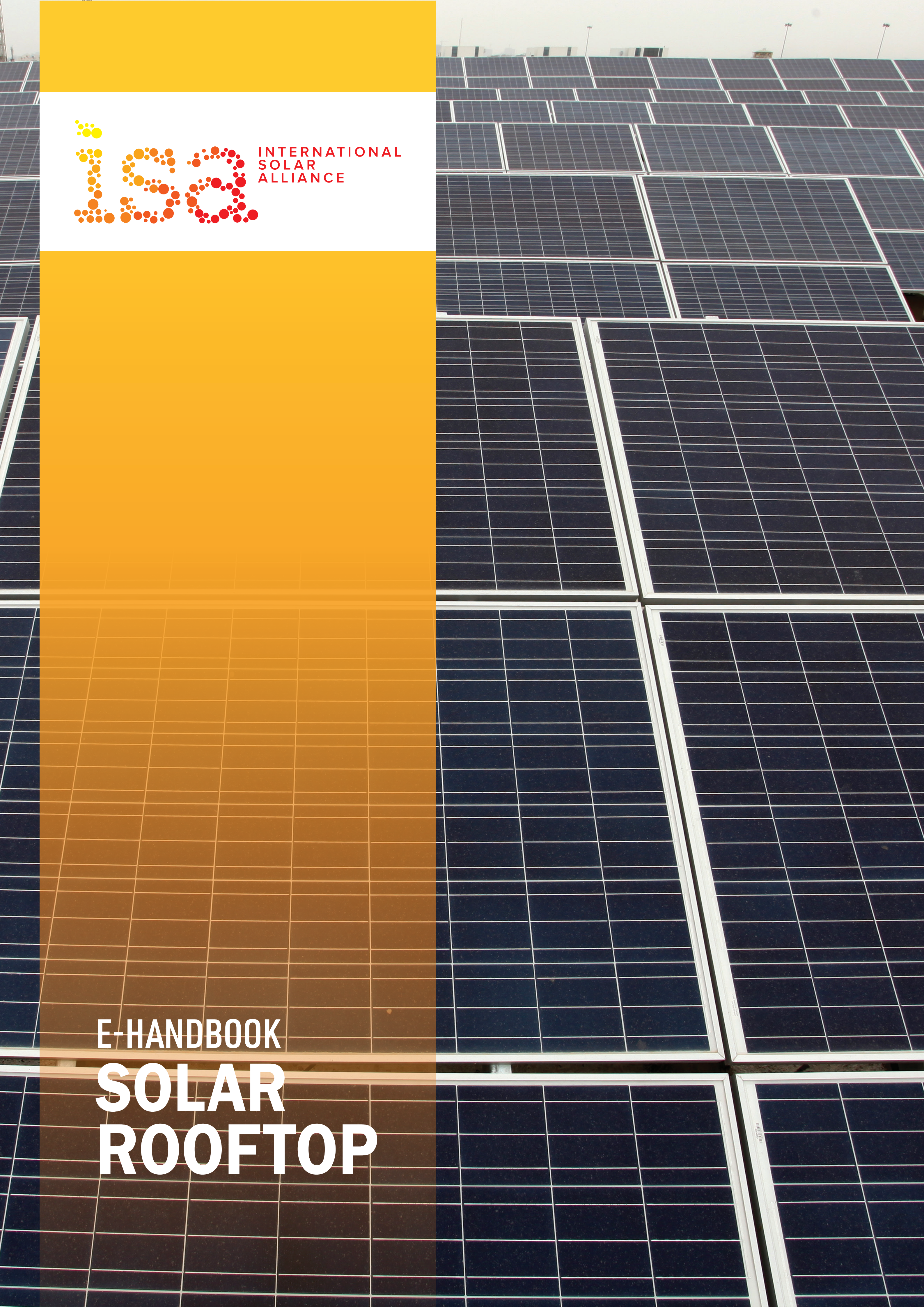


INTERNATIONAL SOLAR ALLIANCE

E-HANDBOOK

SOLAR ROOFTOP

KIND ATTENTION TO THE READERS

The purpose of publication of the E-Handbook for Solar Rooftop is to support ISA member Countries to understand the basics of the Solar Rooftop Projects. The details mentioned can help ISA member countries in creating awareness regarding the basic technical aspects of Solar Rooftop Systems. The feedback from the readers will help ISA Secretariat to update and improve the upcoming versions of this E-Handbook.

Disclaimer: The diagrams and photos in the E-Handbook are indicative and are not the only solutions. The drawings are not as per scale. The technical details are suggestive for optimization. The name of the organizations/departments/ institutions mentioned are as mentioned in the public domain.

CONTENTS

ABBREVIATIONS

AC	Alternating Current
ACDB	AC Distribution Box
BS EN	British Standard European Norm
CAPEX	Capital Expenditure
DC	Direct Current
IEC	Importer -Exporter Code
IP	Ingress Protection
Isc	Short-Circuit Current
LV	Low-Voltage
MPPT	Maximum Power Point Tracking
PV	Photovoltaic
RESCO	Renewable Energy Service Company
SPD	Surge Protection Devices
SRT	Solar Rooftop
UV	Ultraviolet
V	Voltage
Voc	Open-Circuit Voltage
%	Percentage
°C	Degree-Celsius
BoS	Balance of System

EXECUTIVE SUMMARY

Solar Rooftop Systems play a critical role in better utilization of rooftops to harness solar energy and supplementing the distribution utility's generation. While large scale solar PV plants require huge land and associated clearances, solar rooftop system could be installed on rooftops in less time without similar challenges that exist in case of large solar parks. Installation of Solar Rooftop Systems are even more relevant in urban areas where shadow free and cemented roofs are easily available. Such installations could be commonly seen on the roofs of institutions, offices, commercial buildings, industrial buildings, and residential buildings. This offers and opportunity for utilities to save in terms of transmission and distribution losses. Mostly, Solar Rooftop Systems do not require back-up support in form of batteries, since the time of solar electricity generation compliments with time of maximum electricity load requirement, specifically for commercial and industrial units. This could further contribute to savings of distribution utilities by reducing investments in distribution infrastructure upgrade. Thus, offering a win-win situation for end consumers and electricity distribution utilities.

Solar Rooftop Systems are mostly deployed under either in CAPEX or RESCO models. Though, RESCO model is more appreciated because it offers electricity at a lower price in comparison to price offered by distribution utility at no upfront cost. There exist many players in the market, commonly known as energy service companies which offer such solutions to end consumers.

In rural set-up, Solar Rooftop Systems coupled with power back-up sources such as batteries could play an important role in improving reliability of power by supplementing the main grid and reducing diesel consumption, thus, reducing carbon footprint.

ISA is cognizant of the fact that the role of Solar Rooftop systems is paramount in reducing carbon footprint, accelerating solar deployment for creating a social impact without any requirement of huge portion of land and additional transmission infrastructure, which do exist in case of large solar parks and has therefore launched Scaling Solar Rooftop Programme. The objective of this programme is to address the challenges in upscaling Solar Rooftop Systems to support main electricity grid and promote rapid deployment of Solar Rooftop at scale in ISA member countries.

In this regard, the E-handbook seeks to provide a comprehensive knowledge repository of Solar Rooftop Systems covering the general aspects of Solar Rooftop including the advantages, types of Metering Arrangements, Business Models as well as key highlights to ensure the sustainable systems operation and maintenance. Further, succeeding versions of the E-handbook would be introduced based on the feedback and comments of relevant stakeholders.

01

INTRODUCTION

A solar rooftop photovoltaic (PV) system mounted on the roof / space frame / shed of a building / parking structure is a power plant that converts solar energy to electricity to meet the property's energy needs or to feed into the grid. While anyone can build a solar rooftop system, the size of the installation varies substantially depending on the amount of available space, electricity consumed by the property, and the owner's ability or willingness to invest the capital needed.

Figure 1: Overview of Solar Power Plant

Courtesy: MNRE Rooftop Manual 2017

02

BENEFITS FROM SOLAR ROOFTOP SYSTEM

- Improvement in quality of power.
- Utilization of available vacant roof space.
- Less installation time.
- Lower transmission and distribution losses.
- Long term energy and ecological security by reduction in carbon emission.
- Most suitable for Commercial and Industrial consumers as maximum generation takes place during the period of peak demand.
- Rooftop systems do not allow penetration of direct sun rays into the roof, thereby reducing the cooling requirement of the building.

03

OPERATION BASED CLASSIFICATION

3.1 Grid-connected solar rooftop PV system

As the name implies, a grid-connected solar rooftop photovoltaic system is one that is connected to the grid with or without any battery backup. The light from the sun is converted into DC electricity by the solar panels which is converted into AC electricity by grid-tied inverter and subsequently synchronized with main grid. Here it is consumed by local loads. Surplus power, if any, is injected to the main grid.

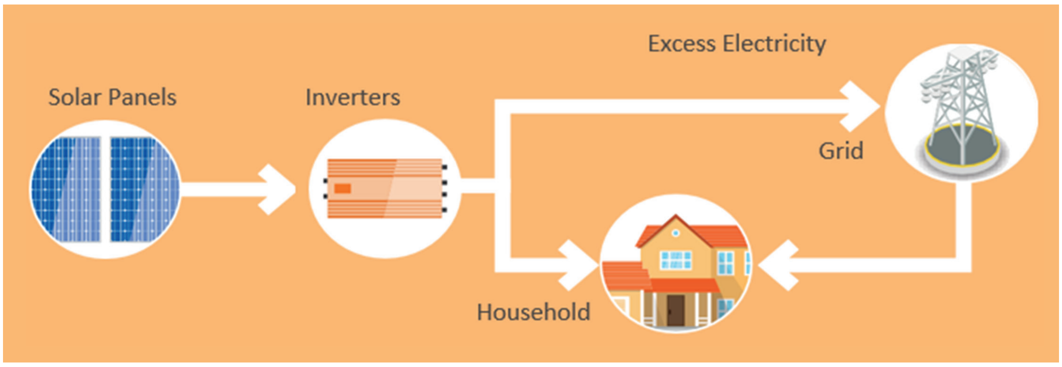


Figure 2: Grid-connected Solar Rooftop System
Courtesy-MNRE India

3.2 Hybrid plant

A hybrid rooftop system is similar to a grid-connected solar rooftop photovoltaic system, but it also includes a battery backup that can be charged from one or more different energy sources, such as wind, hydro, bio and fossil fuel based generator. During power outages, the backup provides electricity to the consumer's critical loads, something that cannot be done with a simple grid-connected solar rooftop system.

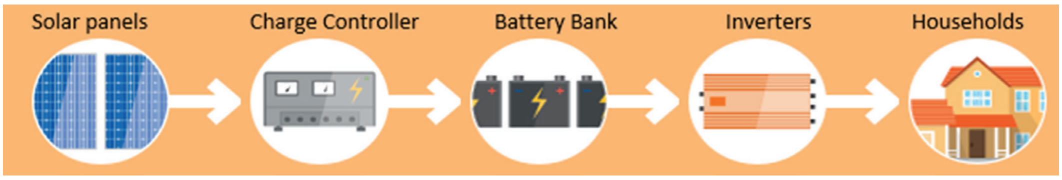


Figure 3: Off Grid (Standalone) Solar P.V Plant

3.3 Off Grid (Standalone) Solar PV Plants

The purpose of Off-grid (Standalone) Solar PV Plants is to provide electrical energy where the conventional electrical energy is not available or is erratic (if available). These plants are generally not connected to the mains grid. They are equipped with a storage battery. Due to additional expense of the battery bank, these plants are considered to be expensive. These plants are also installed at remote locations where back up power is required.

04

TYPES OF METERING ARRANGEMENTS

4.1 Net Metering

Net metering systems are primarily intended to enable consumers to offset their power bills by using a single meter wherein the generated electricity is supplied to the roof owner's end-use loads and the surplus power is fed into the grid. The utility can purchase the surplus power or provide banking facility for a particular period of time.

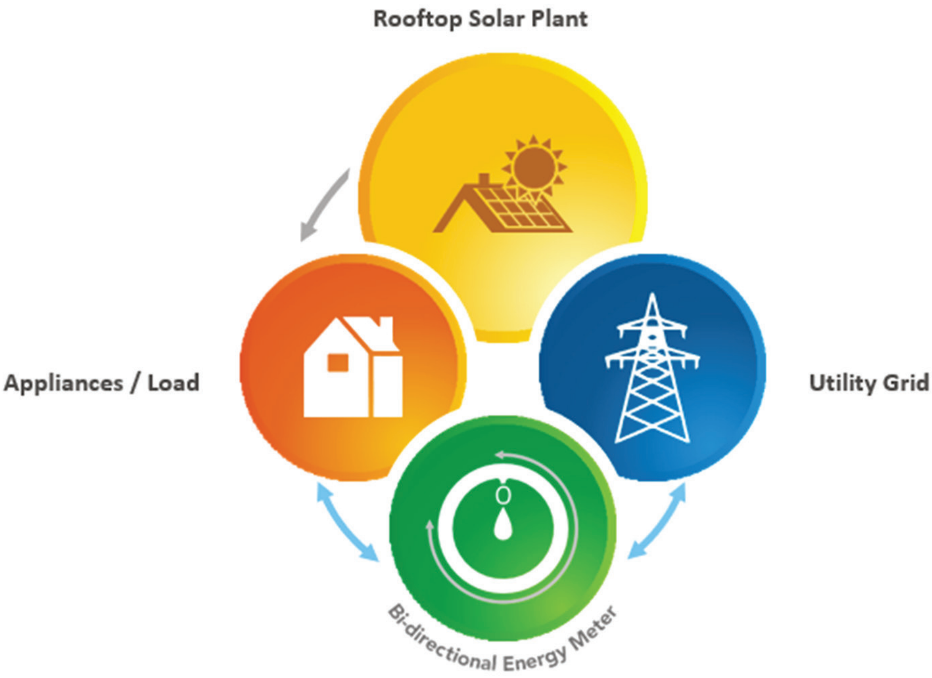


Figure 4: Overview of Net Metering

4.2 Gross Metering

Gross metering is used when the entire amount of energy generated by a rooftop power plant is sold to the corresponding DISCOM or captive consumer via the Feed in Tariff (FIT) mechanism or pursuant to a power purchase agreement (PPA). Under such a system, all the energy generated by the PV system is exported to the grid and recorded separately via a separate 'feed-in meter.' The developer sells the solar energy to the utility at a predetermined feed-in tariff (FiT) that has been approved by the regulator, and the third-party investors / RESCO developers enter into a long-term Power Purchase Agreement (PPA) with the utility.

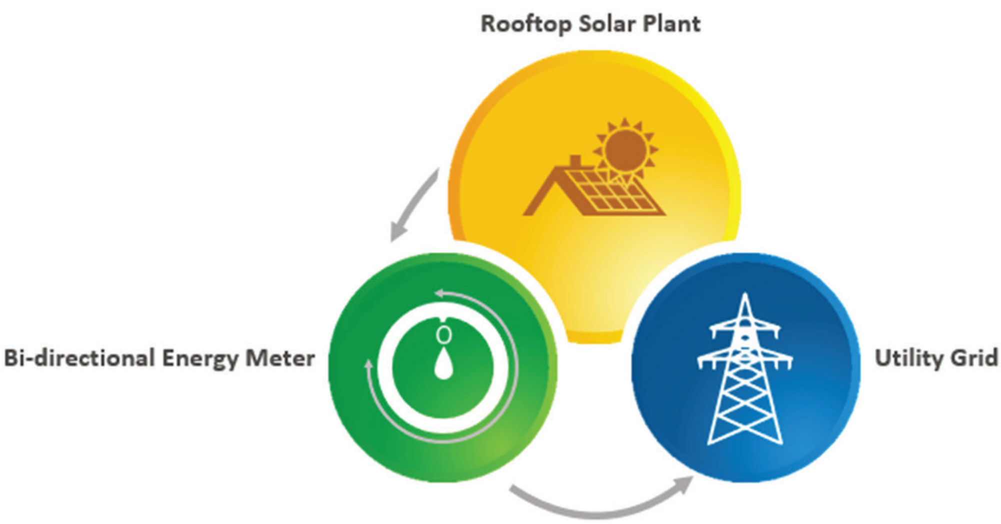


Figure 5: Overview of Gross Metering
Courtesy-MNRE Rooftop Manual 2017

05

BUSINESS MODELS

Principally there are two business models:

- CAPEX- capital expenditures are provided by the rooftop owners.
- RESCO- capital expenditures are covered by third party / developer.

CAPEX MODEL

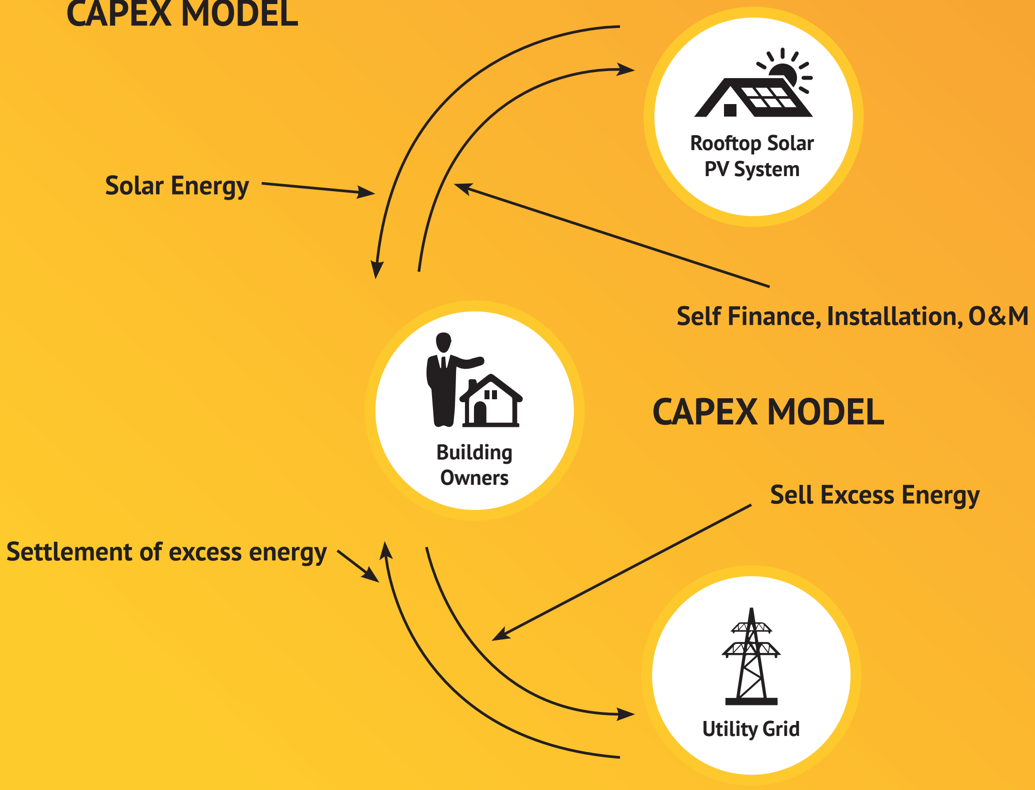


Figure 6: Capex Model

In this model, the rooftop solar PV system is installed by the EPC company on the building owner's roof against full payment of the system. The ownership, operation and maintenance of the Rooftop solar PV system lies with the building owner. The compensation against feeding the surplus power into the grid will be decided as per the prevailing rule of the utility company.

Renewable Energy Service Company (RESCO) Model

Under this model, a RESCO developer installs, operates, and maintains the rooftop solar power plant in the premise of the building owner. The developer invests in solar rooftop asset and sells the generated power to the building owner at a tariff which is derived through competitive bidding process or mutually agreed between buyer and the seller.

06

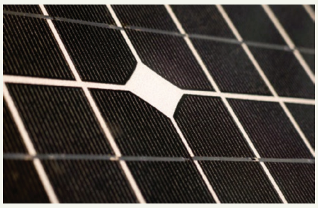
COMPONENTS OF SOLAR ROOFTOP

The components of a Solar Rooftop systems are as follows:

1. **Solar Photovoltaic (SPV) Modules**

   SPV modules are the devices that when exposed to the Sun light, convert it into electricity, which is DC Power. There are a wide variety of modules available today which differ in the type of Semiconductor used, the manufacturing process, and the product quality. The vast majorities of commercially available PV modules are made from Semiconductor and differentiated into the three main varieties: mono-crystalline, polycrystalline and thin-film solar cells (refer figure 2). The different types of PV module vary significantly by cost, efficiency, capacity, and appearance. The choice is highly dependent on the application; however, the most important thing is to ensure that they are compliant to the relevant national/international codes and standards, with respect to the need of the project.

SINGLE/MONO CRYSTALLINE



- Mono-crystalline have a black hue and are made from a single silicon crystal structure
- Most expensive manufacturing processes.
- Monocrystalline solar cells are more efficient than polycrystalline solar cells

POLYCRYSTALLINE/MULTI-CRYSTALLINE

- Poly crystalline have a blue hue and are formed from many fragments of silicon that are melted together to form the wafer for the panels
- Less expensive then mono-crystalline
- Polycrystalline solar cells have lower efficiency ratings than monocrystalline solar cells.

THIN FILM


Image Credit: Ken Fields

- Thin film PV modules are manufactured by depositing layer of PV substances on a solid surface like glass
- A combination of substances is used to form a cell, e.g., Amorphous Si, Dye-sensized solar cell, Copper indium gallium selenide (CIGS) solar cell, Cadminium telluride (CdTe), etc.
- Manufacturing cost is lower than crystalline technology.
- Least efficient in comparison to Mono and Poly crystalline cells

Solar PV module manufacturers use the standard test conditions (STC) output parameters for display on their nameplates. At STC, PV modules are exposed to artificial sunlight with an intensity of 1000 W/ m^2 at 25°C and air mass 1.5 (AM1.5) to measure the output. The performance of a solar PV module in site conditions differs from those of the STC. Selection of array configuration is based on location specific irradiance, in a software-based simulation or based on the local available metrological data.

2. Battery storage – type and classifications

In a standalone Solar Rooftop Systems, battery storage is required if electrical loads are required to operate at nighttime/Non Sunshine hours, or during extended periods of cloudy or overcast weather when the PV array by itself cannot supply enough/desired power. The primary function of a storage battery is to provide stored electricity during non-Sunshine hours.

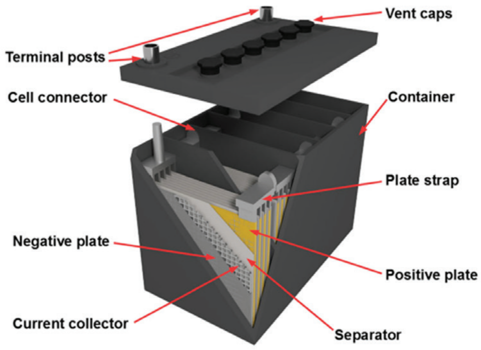
Some of the Secondary batteries that are commercially available and viable for use in photovoltaic system include.

- Flooded Lead Acid Batteries
- Valve Regulated Lead Acid (VRLA) Batteries
- Lithium Ion (Li-ion)

The different types of batteries commonly used in PV systems are described below:

a) Flooded Lead-Acid Batteries

Tubular Positive Plates type flooded lead-acid batteries are the most common lead-acid batteries for PV application. They contain vents which allow the resulting hydrogen gas from electrolysis to escape. As a result, the electrolyte level will fall over a period, and must be monitored and topped up with water, preferably distilled water. The hydrogen gas produced is highly flammable. Care must be taken to ensure that there is adequate ventilation above and around flooded batteries.



b) Valve Regulated Lead-Acid (VRLA)

Valve regulated lead acid (VRLA) batteries are also known as captive electrolyte (maintenance-free) batteries and as the name implies, the electrolyte is immobilized in some manner and the battery is sealed under normal operating conditions. Under excessive overcharge, the normally sealed vents open under gas pressure through a pressure regulating mechanism.

Electrolyte cannot be replenished in these battery designs; therefore, they are intolerant of excessive overcharge. VRLA batteries are available in two different technologies: Absorbed Glass Mat (AGM) and Gelled Electrolyte. These type of batteries does not need topping up and are compact do to which it requires less space than Flooded LA Battery Bank of same capacity.

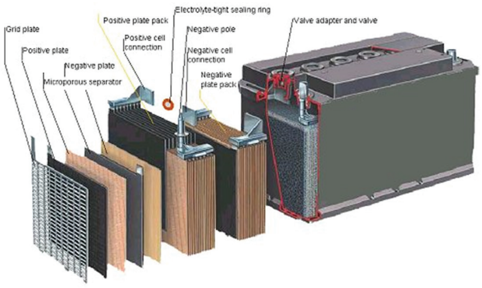


Figure 8: Valve Regulated Lead-Acid Batteries
(Credit: https://sites.google.com/site/acidsandbasesindepth

c) Lithium-ion Batteries

Lithium-ion batteries have several advantages over other batteries, especially lead acid batteries. They are generally smaller and lighter for the same capacity, are faster at charging, and are less susceptible to degradation due to charging and discharging. However, lithium-ion batteries have a very high up-front cost, and they can be sensitive to extreme temperature and voltages. This type of batteries requires even less space than VRLA Battery Bank of same desired output.

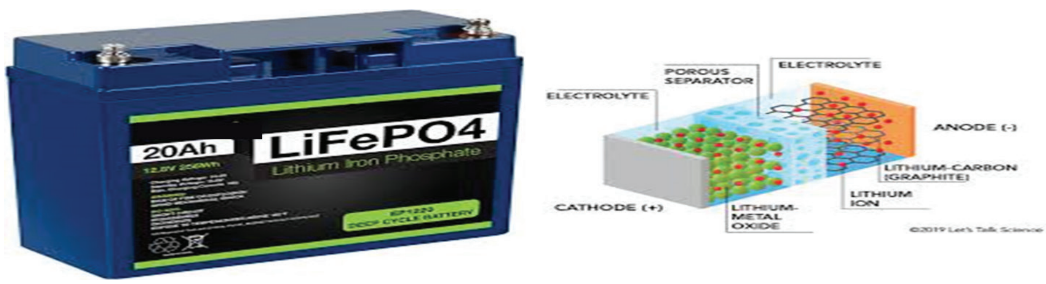


Figure 9: Li-ion Batteries for use photovoltaic system

Image Source: ExpertPower-12V-100Ah-Lithium-LiFePO4.jpg (969×744) (nerdtechy.com)

3. Charge Controller

The charge controllers are included in most PV systems to protect the batteries from overcharge and/or excessive discharge. The minimum function of the controller is to disconnect the array when battery is fully charged and disconnect the load when the battery is discharged up to a predefined level (Low voltage cut-off)..

Figure 10: Charge Controller

(https://www.powerstream.com/pv-control-extreme.htm)

4. Inverters & other Electronic Equipment

The photovoltaic array and battery produce DC current and voltage. The purpose of an inverter (refer figure 7) is to convert the DC electricity into a form suitable for AC electrical appliances and/or exportable to the AC grid. The typical low voltage (LV) supply electrical load will be either 230V AC single phase or 415V AC three phases.

The inverter in a stand-alone power system takes its power from the batteries to supply the AC circuit(s). The

Figure 11 Solar Off-grid Inverter

Image Source: 2-1.jpg (1513×1657) (didisolar.com) system controller (voltage regulator) itself can have an MPPT. The advantage of the MPPT controller is to optimize the battery charging. This function has no impact on whether the inverter itself will supply power to any AC circuits. Stand-alone inverters are typically voltage-specific, i.e., they are manufactured to operate from a specific nominal battery voltage e.g. 12V, 24V, 48V, 96V, 120V DC or above, as per their power handling capacities. The inverter will convert the solar DC power to an AC sine wave that matches the AC supply in voltage and frequency to which it is connected.

Image Source: 2000W Single Phase Grid Tie Solar Inverter | inverter.com

The rooftop systems could be grid tied as well. There are some important changes in terms of connections and equipment such as inverters due to connection with distribution power system. Such installations also need to comply the safety measures, Regulations and Grid Protocols of respective Country.

The key role of the grid-connected inverters is to synchronize the phase, voltage, and frequency of the AC inverter output with that of the grid. Solar grid-tie inverters are designed to instantly disconnect from the grid if the utility grid goes down to ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are working on power grid. This feature is known as islanding property of the inverter which is a mandatory safety norm as per international standards and have to be compiled by every grid connected inverter manufacturers.

Connecting Solar Rooftop system to the main grid may provide multiple benefits as below:

- Solar Rooftop Systems are typically designed with extra capacity to take care of energy demand during the months when solar radiation is low. If the system is connected to the main grid, surplus power can be injected into the grid, which will increase capacity utilization factor of the plant.
- The electrical load connected to the system will have more flexibility in use of electrical appliances when Solar Rooftop System is connected to the main grid.
- Due to availability of grid, battery capacity may be reduced or even removed if grid is reliable.

Such type of technical provision can also be done, as and when the main grid is extended to the areas where Standalone Solar Rooftop Systems are installed. If the main grid is extended to such locations Solar Rooftop systems may become obsolete or have less importance due to its limited power generation capacity in comparison to the main grid. The best way to avoid such situation is to make the Solar Rooftop Systems compatible to interface the main grid.

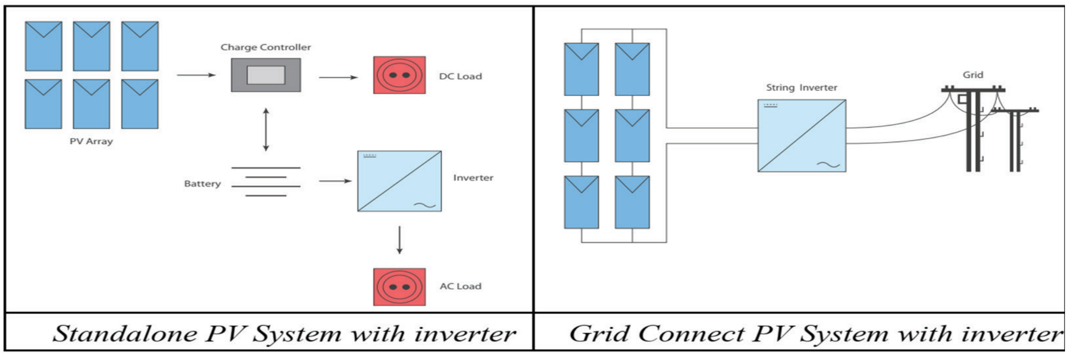


Figure 12: Standalone PV System Inverter vs Grid Connected PV System Inverter

5. **Balance of Systems Equipment**

In addition to the PV modules, battery, inverter and charge controller there are other components required in a Solar Rooftop System; these components are referred to as Balance of Systems (BoS) equipment.

BoS equipment includes:

a) **Solar Array Mounting Structure:** The equipment used to safely secure the PV modules to the mounting surface or ground. These Structures are normally customized/designed with respect to the need of the location capacity of Solar PV Systems and place of installation. It can be on ground or rooftop.

b) **Cabling:** Both DC and AC cabling is required to connect components. The selection of size and type of cables will be based on the technical design of the Solar PV System, and must conform to the relevant national / international standards.

c) **Array Junction Box (String Combiners):** This may or may not be required depending on the type of inverters e.g., Central / String Inverters. Whereas, PV strings can be directly connected to string inverters, for Central Inverters the strings have to be combined in the combiner boxes. Combiner boxes are required to connect the module-strings in series or parallel depending upon the requirement of the design of the Solar Power Plant.

Image Source: nordic-one-page-flyer-7-500x500.jpg (500×500) (imimg.com)

d) Protection and Disconnect Switches: These components ensure the isolation and safety of the Rooftop Solar Power Plant. The prevailing codes of practices must be followed while incorporating these devices in the design of the SRT syatems.

Image Source: https://th.bing.com/th/id/OIP.Q6f2NcH2OtXizZ8eZPUJtAHaHa?pid=ImgDet&rs=1

e) Earthing:

Earthing system is a protection system for Solar Rooftop Systems, through which all the electrical installations are connected to the earth to protect living beings from getting electric shocks.

Image Source: industrial-earth-pit-500x500.jpg (500×500) (imimg.com), earth-pit-chamber-500x500.jpg (500×281) (imimg.com)

f) Lightning Protection: May be installed depending on the requirement to protect the system from lighting strikes as per international / local standards.

Image Source: lightning-arrestor-150930.jpg (210×210) (exportersindia.com)

g) Metering: Measures the quantity of electricity generated by solar or quantity of electricity consumed by a customer.

Image Source: secure-3-phase-net-bidirectional-meters-for-solar-application-500x500.png (500×429) (imimg.com)

h) System Monitoring: It displaye the amount of energy generated by an SRT, energy consumed by the connected loads and the amount of surplus energy exported to the grid. It can also be helpful in diagnosis of faults within the system.

Image Source: solar-monitoring-system.jpg (800×345) (foxsolarsystems.com)

i) Control Panels: These Control Panels can include one or more of the following

- AC Distribution Board
- DC Distribution Board
- Battery Protection Panel
- Any other Panel for precise monitoring and O&M activities

j) **Signage:** PV systems installed requires various signs or displaysb to ensure safety and for general information..

07

OPERATIONS & MAINTENANCE

ISA always recommend the use of best components, systems (conforming to the relevant National/international standards and codes of practice) in the design and installation of Solar Rooftop which are locally / internationally available in the market. The adoption of the best workmanship will always result in the minimum maintenance requirement and long-lasting service from the installation. Still regular operation and maintenance activities for desired output from Solar Rooftop Systems is very much necessary and mandatory.

Operations and Maintenance (O&M) is very important for the sustainability of the project and ideally should be planned well in advance of the start of operations, rather should be part and parcel of the SRT project form designing level. For O&M of Solar Rooftop Systems, capacity building of relevant stakeholders should be the first step towards ensuring sustainability and economic viability throughout the life of the project. The relevant stakeholders may include, consumers/ end Users, technicians, supervisors, policy makers etc. There are various approaches to implement a successful O&M schedule:

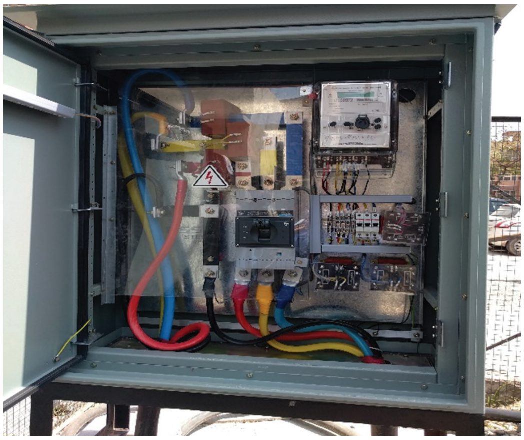
a) Trained local manpower

b) Outsourcing to third party service provider

c) The developer or system integrator, the one responsible for installation and commissioning of the system

d) A separate government entity

However, trained local manpower could be the most economically viable option. It would not only hone the skills of local population but would also generate employment. The O&M schedule of following components of Solar Rooftop Systems must be periodically maintained and monitored.



Operation and Maintenance Schedule of Major Components

S.NO.	Inspection	Action Required	Inspection Frequency
A	**Solar Modules**		
1	Dust Deposition	Cleaning of modules	Weekly
2	Module & Junction-Box malfunction, visual inspection	Replace the module in case of breakage/cracks of glass, Burning of terminal boxfailure	Monthly
3	Module Cable connectors melting, deforming	Replace cable/connectors	Monthly
B	**Solar Module Mounting Structure**		
1	Inspection of mounting structure and hardware	Check Fastners- take remedial measures in case of any issues	Quarterly
		Check Lugs of earthing conductors for corrosion	
C	**Junction Boxes**		Monthly
D	**Solar Inverter/Charge Controller / Power Conditioning Unit**	Schedule Maintenance as indicated by inverter supplier	Quarterly
1	Loose cable termination	Tighten the connection	Quarterly
2	Air Filters	Cleaning	Weekly
3	Performance Monitoring		Daily
4	Report preparation		Monthly
E	**Battery / Battery Charger**		
1	Schedule Maintenance	As indicated by OEM	Monthly
2	Battery maintenance	Tightness, Battery topping up with distilled water (in case of flooded lead acid battery)	Quarterly
		Terminal Cleaning & Applying Gel	
	Note: The battery should never be allowed to remain in deep discharged condition for more than 2 to 3 days, necessary steps may be taken to provide external boost charge if need arises.`		
F	**Cables (AC & DC)**	Visual inspection	Bi-Weekly
G	**Earthing**		Half Yearly
H	**Lightning Arrestors**		Half Yearly
I	**Power Distribution Network**	Schedule Maintenance	Half Yearly
J	**Control Room (Wherever Required)**	Schedule Maintenance	Quarterly
K	**All other equipment's**		Monthly

Operation and Maintenance Schedule of Major Components

Note: The above-mentioned O&M schedule is indicative and may vary as per site conditions and adapted technology.

The basic suggestive equipment's/ tools required to perform O&M effectively are mentioned below:

- Multimeter or Clamp Meter
- A set of screw drivers including testers
- Safety equipment such as Insulated gloves, rescue rods, earthing and short circuit kits, warning signs and tapes, insulated ladders etc.
- Spanners as per requirement
- Compass

Spare Parts Management is also an inherent and substantial part of O&M aimed at ensuring that spare parts are available in a timely manner for Corrective Maintenance to minimize the downtime of a Solar Rooftop System. The spare parts should be owned by the asset Owner while normally maintenance, storage and replenishment should be the responsibility of the O&M Contractor. It is considered a best practice not to include the cost of replenishment of spare parts in the O&M fixed fee. The list of spare parts that are considered essential are below:

- SPV modules (if viable)
- Spare inverter/Charge controller/Power conditioning unit or spare PCB's
- MC4 Connectors
- MCBs as per requirement
- Junction Boxes (if viable/required)
- Glass fuses/Diodes/SPD's for required capacity wherever necessary
- Distill water, Gel or Grease, Hydrometer, Cell tester, Hand gloves, Rubber Boots etc. in case of flooded lead acid batteries
- Cables of required size and capacity
- Luminaries of required size and capacity
- Spares to maintain overhead/Under Ground cable network

ANNEXURE I

S.No.	Component	Standard
1.	Solar PV Modules, Arrays and Systems	◆ IEC 61215-1:2021 Terrestrial Photovoltaic (PV) modules – Design qualification and type approval-Part 1: Test Requirements. ◆ IEC 61215-1-2:2021: Terrestrial Photovoltaic (PV) modules – Design qualification and type approval-Part 1-2: Special requirements for testing of Thin-film Cadmium Telluride (CdTe) based terrestrial PV modules. ◆ IEC 61701:2020 Photovoltaic (PV) modules- Salt mist corrosion testing. ◆ IEC 62548:2016 Photovoltaic (PV) arrays- Design requirements. ◆ IEC 61724-1:2021 Photovoltaic System Performance Part 1 – Monitoring. ◆ IEC 61724-2:2016 Photovoltaic System Performance Part 2 - Capacity Evaluation Method. ◆ IEC 61724-3:2016 Photovoltaic System Performance Part 3 - Energy Evaluation Method. ◆ IEC 61829:2015 Photovoltaic (PV) Array – Onsite measurement of Current – voltage characteristics. ◆ IEC 61730-1:2016 Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction. ◆ IEC 61730-2:2016 Photovoltaic (PV) module safety qualification - Part 2: Requirements for Testing. ◆ IEC 62716:2013 Photovoltaic (PV) Modules – Ammonia Corrosion Testing. ◆ IEC TS 62804-1:2015 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation Part 1: Crystalline Silicon. ◆ IEC TS 62804-1-1:2020 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation Part 1-1: Crystalline Silicon - Delamination. ◆ IEC TS 62804-2:2022 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation Part 2: Thin-Film ◆ IEC 62759-1:2015 Photovoltaic (PV) modules - Transportation testing - Part 1: Transportation and shipping of module package units. ◆ IEC TS 62782:2016 Photovoltaic (PV) Modules- Cyclic (Dynamic) mechanical load testing. ◆ IEC 60891:2021 Photovoltaic Devices – Procedure for temperature and irradiance corrections to measured I-V Characteristics. ◆ IEC 61836:2016 Solar Photovoltaic Energy Systems – Terms, Definitions and Symbols. ◆ IEC 62253:2011Photovoltaic pumping systems- Design qualification & performance measurements. ◆ IEC 60904-1:2020 Photovoltaic Devices – Part 1: Measurement of Photovoltaic Current – Voltage Characteristics. ◆ IEC 62446-1:2016 Photovoltaic (PV) Systems Requirements for testing, Documentation & Maintenance- Part 1: Grid connected Systems – Documentation, Commissioning tests & inspection. ◆ IEC 62446-2:2020 Photovoltaic (PV) Systems Requirements for testing, Documentation & Maintenance- Part 2: Grid connected Systems – Maintenance of PV systems. ◆ IEC 62446-3:2017 Photovoltaic (PV) Systems Requirements for testing, Documentation & Maintenance- Part 3: Photovoltaic Modules and Plants – Outdoor infrared thermography. ◆ IEC 62738:2018 Ground mounted Photovoltaic Power Plants- Design guidelines & Recommendations. ◆ IEC 62941:2019 Terrestrial Photovoltaic (PV) Modules – Quality system for PV Module manufacturing. ◆ IEC 63049:2017 Terrestrial Photovoltaic (PV) Systems – Guidelines for effective quality assurance in PV system installation, operation & maintenance.

S.No.	Component	Standard
2.	Hybrid systems	• IEC TS 62257-7:2017 Recommendations for small renewable energy and hybrid systems for rural electrification Part 7 Generators. • IEC TS 62257-7-1:2010 Recommendations for small renewable energy and hybrid systems for rural electrification Part 7-1 Generators – Photovoltaic Generators. • IEC TS 62257-7-4:2019 Recommendations for small renewable energy and hybrid systems for rural electrification Part 7-4 Generators – Integration of solar with other forms of power generation within hybrid power systems. • IEC TS 62257-9-1:2016 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–1 integrated systems - Micropower systems. • IEC TS 62257-9-2:2015 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–2 integrated systems - Mini grids • IEC TS 62257-9-3:2016 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–3 integrated systems - User interface. • IEC TS 62257-9-4:2016 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–4 integrated systems - User installation. • IEC TS 62257-9-5:2018 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–5 integrated systems - Laboratory evaluation of stand-alone renewable energy products for rural electrification. • IEC TS 62257-9-6:2019 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–6 Recommendation for selection of Photovoltaic individual electric systems (PV-IES) • IEC TS 62257-9-7:2019 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–7 Recommendation for selection of Inverters • IEC TS 62257-9-8:2020 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 9–8 Integrated Systems- Requirements for standalone renewable energy products with power ratings less than or equal to 350 W. • IEC TS 62257-12-1:2020 Recommendations for renewable energy and hybrid systems for rural electrification – Part – 12-1 Laboratory evaluation of Lamps and Lighting appliances for off-grid electricity systems. • IEC 60364-7-712:2017 Low voltage electrical installations- Part 7-712: Requirement for special installations or locations – Solar Photovoltaic (PV)power supply systems.
3.	Inverters & Charge Controllers	• IEC 62093:2022 Photovoltaic System Power conversion equipment – Design qualification & Type approval. • IEC 62109-1:2010 Safety of power converters for use in photovoltaic power systems- Part – 1 -General Requirements. • IEC 62109-2:2011 Safety of power converters for use in photovoltaic power systems- Part – 2 -Particular Requirements for inverters. • IEC 62109-3:2020 Safety of power converters for use in photovoltaic power systems- Part – 3 -Particular Requirements for electronic devices in combination with photovoltaic elements. • IEC 62509: 2010 Battery Charge Controllers for photovoltaic systems – Performance & Functioning. • IEC 62891:2020 Maximum Power Point tracking efficiency of grid connected photovoltaic inverters. • IEC 62910:2020 Utility-interconnected photovoltaic inverters- Test procedure for under voltage ride-through measurements. • IEC 61683: 1999 PV systems – Power conditioners – Procedure for measuring efficiency • IEC 62116:2014 Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures.

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4.	Battery Storage	• IEC 61427-1:2013: Secondary cells and batteries for renewable energy storage - General requirements and methods of test -Part 1: Photovoltaic Off-grid application. • IEC 61427-2:2013: Secondary cells and batteries for renewable energy storage - General requirements and methods of test -Part 2: On-grid applications • IEC 63056:2020 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries for use in electrical energy storage systems. • IEC 62133-2:2017 : Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications - Part 2: Lithium systems
5.	Switches, Connectors and Enclosures	• IEC 62790:2020 Junction Boxes for photovoltaic modules -Safety requirements & tests. • IEC 60529:1989/AMD2:2013/COR1:2019 Corrigendum 1- Amendment 2- Degrees of protection provided by enclosures (IP Code) • IEC 60898-2:2016 Circuit-breakers for overcurrent protection for household and similar installation – Part 2: Circuit-breakers for AC and DC operation • IEC 60947: Low voltage switchgear and control gear • Part 1: General rules • Part 2: Circuit breakers • Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units • IEC 60269-6:2010+AMD1:2021CSV Consoidated version:Low voltage fuses Part-6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
6.	Safety protection including electrical insulation, protection from lightning, load bearing capacity and earthing	• IEC 63227:2020 Lightening and surge voltage protection for Photovoltaic (PV) power systems
7.	Utility Inter-connection	• IEC 61727: 2004: Photovoltaic (PV) systems – Characteristics of the utility interface.
8.	Cables	• IEC 62930:2017 Electric cables for photovoltaic systems with a voltage rating of 1.5 KV DC. • IEC 60227: Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V • IEC 60502-1:2021 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) Part-1 Cables for rated voltages of 1 kV (Um = 1,2 kV) & 3 kV (Um = 3.6 kV) • IEC 60502-2:2021 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) Part-2 Cables for rated voltages of 6 kV (Um = 7.2 kV) & 30 kV (Um = 36 kV) • IEC 60502-4:2021 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) Part-4 Test requirements on accessories of Cables for rated voltages of 6 kV (Um = 7.2 kV) & 30 kV (Um = 36 kV)

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9.	Meters	**Single Phase Smart Meters** • IEC 61036- Alternating Current Static Watt-Hour Meters for Active Energy (Classes 1 and 2) • IEC 1107- Data Exchange for Meter Reading, Tariff and Load Control and direct local data. Exchange • IEC 735- Testing equipment for electrical energy meters • IEC 62052–11- Electricity metering equipment (AC) – General requirements & test conditions Part II metering equipment. • IEC 62053-21- Electricity Metering equipment (AC)- particular Requirements – Part – 21 Static meters for active Energy (class 1 & 2). • IEC 514- Acceptance inspection of Class 1 alternating current watt hour meters • IEC 1038- Time switches for tariff and load control **Three Phase Smart Meters** • IEC 62052-11 (2003)- Electricity Requirements (AC) General Requirements Tests and Test conditions for A.C Static Watt hour meter for active energy Class 1.0 and 2.0. • IEC 62053-21 (2003)- A.C. Static Watt hour meter for active energy Class 1.0 and 2.0 • IEC 60068- Environmental testing

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