CAG

Citizen consumer and civic Action Group

TECHNICAL
GUIDE

RESIDENTIAL ROOFTOP SOLAR PV SYSTEMS

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About CAG

Citizen consumer and civic Action Group (CAG) is a 39-year-old Chennai-based non-profit, non-political and professional organisation that works towards protecting citizens' rights in consumer and environmental issues, and promoting good governance processes including transparency, accountability and participatory decision-making.

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CONTENTS

LIST OF ABBREVIATIONS

AC	Alternating Current
ACDB	Alternating Current Distribution Box
AJB	Array Junction Box
ALMM	Approved list of Models and Manufacturers
BIPV	Building Integrated Photovoltaics
BIS	Bureau of Indian Standards
BoS	Balance of System
CEA	Central Electricity Authority
CFA	Central Finance Assistance
DC	Direct Current
DCDB	Direct Current Distribution Box
DCR	Domestic Content Requirement
EMI	Electromagnetic Interference
EPDM	Ethylene Propylene Diene Monomer
EVA	Ethyl Vinyl Acetate
FF	Fill Factor
GRP	Glass Reinforced Plastic
HIT	Heterojunction with Intrinsic Thin layer solar cells
IBC	Interdigitated Back Contact

IEC	**International Electrotechnical Commission**
ITRPV	**International Technology Roadmap for Photovoltaics**
LT	**Low Tension**
MCB	**Miniature Circuit Breaker**
MCCB	**Molded Case Circuit Breaker**
MPPT	**Maximum Power Point Tracking**
MMS	**Module Mounting Structure**
NABL	**National Accreditation Board for Testing and Calibration Laboratories**
NEC	**National Electrical Code**
NOCT	**Nominal Operating Cell Temperature**
PCU	**Power Conditioning Unit**
PERC	**Passivated Emitter Rear Contact**
PET	**Polyethylene Terephthalate**
PF	**Power Factor**
PPE	**Personal Protective Equipment**
PWM	**Pulse Width Modulation**
RCCB	**Residual Current Circuit Breakers**
RFID	**Radio Frequency Identification**
SPD	**Surge Protection Device**
SPV	**Solar Photovoltaic**

STC	**Standard Test Conditions**
THD	**Total Harmonic Distortion**
TOPCON	**Tunnel Oxide Passivated CONtact**
UV	**Ultra Violet**
Wp	**Watt peak**

1 HOW A SOLAR PV SYSTEM WORKS

1.1 Residential rooftop solar PV systems

Solar photovoltaic (PV) systems are designed to capture sunlight and convert it into usable electricity. Based on their connectivity to the electricity grid, residential rooftop solar PV systems can be broadly classified into three types:

1. Off-Grid (Stand-Alone) Systems: These systems operate independently of the electricity grid and rely entirely on battery storage. They are typically used in remote locations where grid connectivity is unavailable. Off-grid systems are considered conventional and are primarily suited for basic energy needs.
2. On-Grid (Grid-Tied) Systems: These systems are connected to the public electricity grid and do not require batteries. They allow households to draw power from the grid when solar generation is insufficient and export excess power back to the grid when generation exceeds consumption.
3. Hybrid Systems: These systems combine the features of both on-grid and off-grid systems. They are connected to the grid but also include battery storage to provide backup power during outages or when solar generation is low.

Currently, government subsidies are available only for on-grid and hybrid systems. As these support grid interaction and contribute to overall energy sustainability, there is more patronage for these systems. This booklet will also focus on providing technical guidance for on-grid and hybrid residential rooftop solar PV systems.

1.2 Working of On-Grid Solar PV system

An on-grid solar photovoltaic (PV) system, also known as a grid-tied system, is directly connected to the public electricity grid and operates without battery storage. The system consists of solar panels mounted on the rooftop, which capture sunlight and convert it into direct current (DC) electricity. This DC power is sent to an inverter, often termed as the heart of the system, which converts it into alternating current (AC), the form of electricity used in homes. The AC electricity is then fed into the home's electrical distribution board, where it powers the household appliances and devices. If the solar panels generate more electricity than the household is using at that moment, the excess power is automatically exported to the electricity grid through a bidirectional meter. This meter records the electricity drawn from the grid as well as the electricity sent back to it. At times when the solar generation is low, such as during the night or on cloudy days, electricity is imported from the grid to meet the home's energy needs. At the end of the billing cycle, the consumer is charged only for the net units, which is the difference between the total units imported and the units exported. If the exported power is more than the imported power, the extra units may be carried forward to the next billing cycle. An on-grid system is highly efficient for reducing electricity bills and requires less maintenance compared to other types, but it does not provide power during grid outage, as it shuts down automatically to ensure the safety of grid workers.

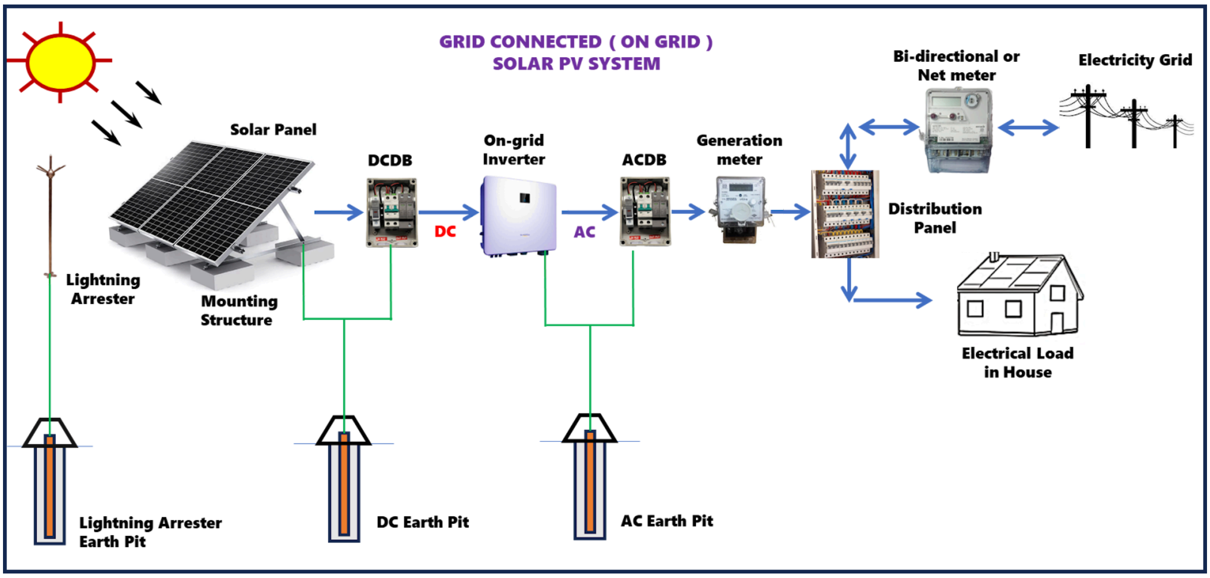

Fig 1.1 Schematic Layout of Grid connected rooftop solar PV system | CAG

1.3 Working of hybrid solar PV system

A hybrid solar PV system combines the features of both an on-grid system and a battery backup system, offering greater flexibility and reliability. Similar to other systems, it starts with solar panels installed on the rooftop, which convert sunlight into direct current (DC) electricity. This electricity is sent to a hybrid inverter, which not only converts DC into alternating current (AC) for home use but also manages the charging and discharging of a battery bank connected to the system. During the day, solar energy is used in a smart sequence: first, to run the home appliances; second, to charge the batteries if there is surplus generation; and third, any extra electricity beyond that is exported to the grid through a net meter, similar to an on-grid system. At night, or during a power cut, when solar panels are not generating electricity, the battery provides backup power, ensuring that essential appliances like fans, lights, and routers keep running smoothly. If both the battery and solar power are insufficient (for example, during long rainy days), then electricity is drawn from the grid as a last resort. The hybrid inverter intelligently balances between solar generation, battery storage, and grid power depending on the demand and availability. This system not only helps in reducing electricity bills but also ensures uninterrupted power supply, making it especially useful in areas with frequent power outages. However, hybrid systems are usually more expensive than regular on-grid systems due to the cost of batteries and additional control systems, and they may require slightly higher maintenance.

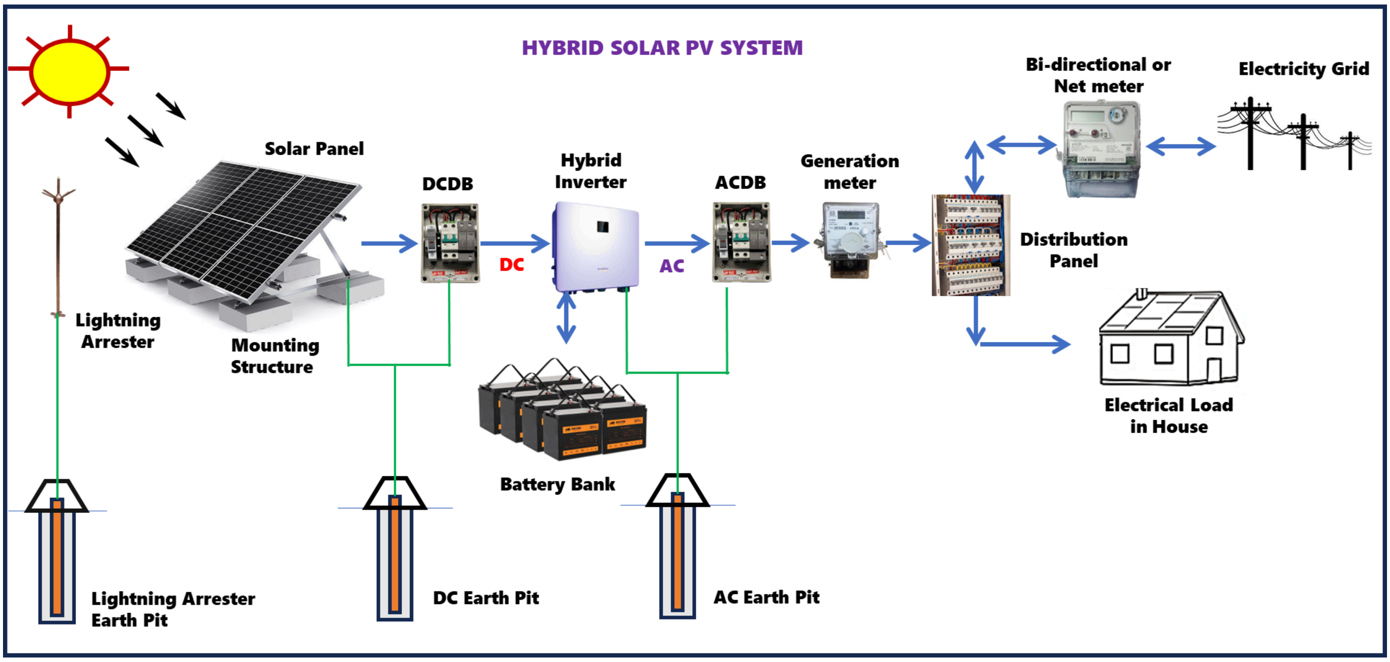

Fig 1.2 Schematic Layout of Hybrid rooftop solar PV system | CAG

1.4 Summary of Components used in solar PV system

Component	Description
Solar Panels	Capture sunlight and convert it to DC (Direct Current) electricity
Mounting Structure	Supports and secures solar panels on the rooftop
DC Distribution Box	Combines solar panel output and contains protection devices like safety fuse, MCB, surge protection device
Inverter	Converts DC to usable AC electricity for home use
AC Distribution Box	Manages power on the AC side before connecting to homes main distribution panel and contains protection devices such as safety fuse, MCB, Surge protection
Solar Generation meter	Measure the total energy produced by the solar panels
Distribution panel	Receives energy from solar and grid and distributes it to various circuits

Component	Description
	throughout the house
Net meter	Bi-directional energy meter that measures both power drawn from and sent to the grid
Wiring & Cabling	Carries current between the components and must be weather and fire resistant
Earthing system	Ensures electrical safety by directing faults safely into the ground
Lightning Arrester	Protects the system from voltage spikes caused by lightning
Battery (for Hybrid system)	Stores excess solar energy for use during power cuts or at night

1.5 Estimating the size and energy yield of a rooftop Solar PV system

Before installing a solar rooftop system, it's important for homeowners to understand the basics of estimating both the required system size and the expected energy generation. A well-sized system ensures maximum savings and efficient use of rooftop space, without unnecessary overspending or underperformance.

Calculating the required capacity

In general, a 1 kW solar PV system produces approximately 4 to 5 units (kWh) of electricity per day under typical tropical climatic conditions. This estimate may vary slightly depending on specific location, weather patterns, and system efficiency.

To estimate the solar system size it is required to determine the total annual energy consumption (this is usually found in electricity bills) of the residence. From the annual energy consumption and dividing by 365, the average daily energy usage can be determined. Knowing that a 1 kW system generates around 4.5 units/day, the required capacity can be determined by dividing the daily energy consumption by 4.5. Example: If your daily energy usage is around 18 units/day, you would require approximately a 4 kW system ($18 \div 4.5 \approx 4$).

Rooftop Space Requirement

A typical 1 kW solar PV system requires about 60 - 100 square feet of shade-free rooftop area. It is important to check if sufficient unshaded space is available. Often, rooftop area becomes a limiting factor when planning larger systems.

2 SOLAR PV PANEL

2.1 Introduction

Solar Photovoltaic (PV) modules, commonly known as solar panels, are the core component of any solar power system. These panels convert sunlight directly into electricity, making them essential for generating clean, renewable energy. Solar panels are rated by their peak power capacity, measured in Watt Peak (Wp), which indicates the maximum power they can produce under ideal conditions. Panels come in different sizes and capacities, suitable for small rooftops or large solar farms. The energy conversion efficiency of a solar panel determines how effectively it converts sunlight into electricity. Higher efficiency means more power from the same surface area. Solar panels are classified based on the type of solar cell technology used, such as crystalline silicon or thin-film. Most solar panels are built to last, with typical lifetimes exceeding 20 years. Manufacturers often provide warranties guaranteeing at least 90% of rated output for 10 years and 80% for up to 25 years, backed by third-party reinsurance to ensure reliability even if the manufacturer faces financial issues.

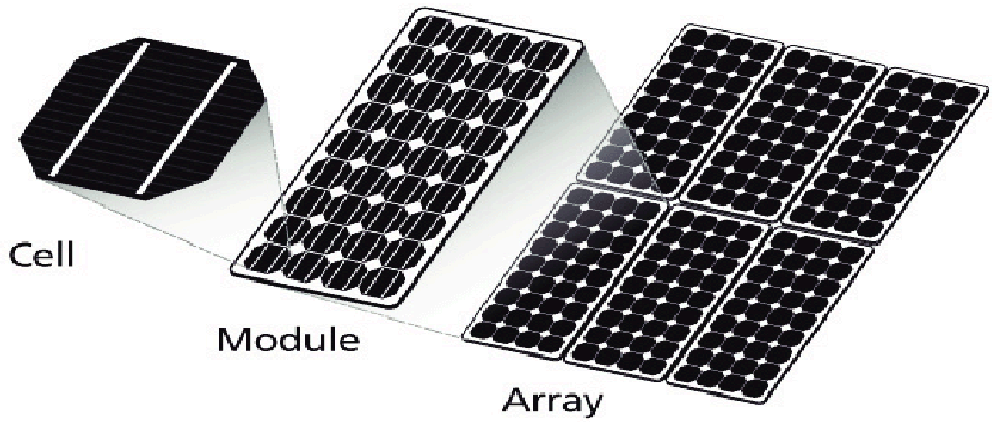

Fig 2.1 Solar cell, module and array | [SNV training manual]

2.2 Structure of Silicon-Based Solar PV Module

A typical crystalline silicon-based solar panel (used in most residential systems) consists of multiple layers, each playing a specific role in protecting the panel and improving its performance. These include:

1. Tempered Glass (Front Cover)
2. Encapsulant (Front Layer)
3. Solar Cells
4. Encapsulant (Rear Layer)
5. Backsheet (Back Cover)
6. Aluminium Frame
7. Junction Box (with Bypass Diodes)

Understanding the structure and components of a solar panel helps consumers make informed decisions about quality, durability, and performance before choosing one for their rooftop.

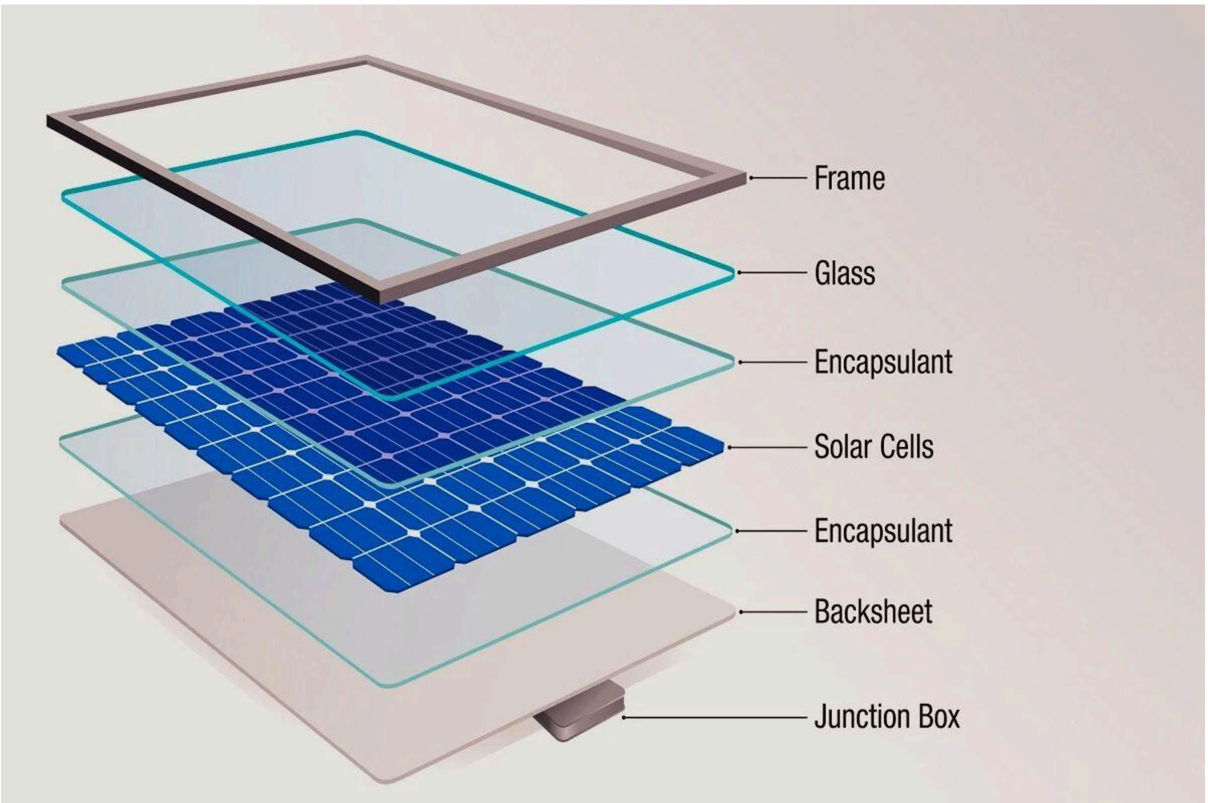

Fig 2.2 Structure of Solar PV panel | Clean Energy Reviews

Detailed description of components used in solar panels is discussed in the upcoming sections.

2.3 Solar Cells

At the heart of every solar photovoltaic (PV) panel lies its most essential component: the solar cell. These tiny units are responsible for the direct conversion of sunlight into electricity through a process known as the photovoltaic effect. When sunlight, made up of energy particles called photons, strikes a solar cell, it excites electrons and causes them to move—creating an electric current. Solar cells operate silently, contain no moving parts, require no fuel, and produce no emissions, making them one of the cleanest energy technologies available today. Among the different types of solar cells, crystalline silicon solar cells are the most common and reliable. Silicon, being the second most abundant element on Earth, helps make the panel relatively inexpensive. However, it must be purified to an extremely high degree — 99.9999% for solar applications, making the process energy-intensive.

2.3.1 Basic structure of a standard silicon solar cell

A standard silicon-based solar cell is structured similar to a PN junction diode. It consists of a p-type silicon wafer at the base and a thin n-type silicon layer on top, formed through a process called gas diffusion. The top layer is coated with an anti-reflective layer to maximize sunlight absorption. Electrical contacts—known as busbars on the front and an aluminium layer on the back—help capture and carry the electricity generated. These cells are then interconnected and assembled into modules to form solar panels.

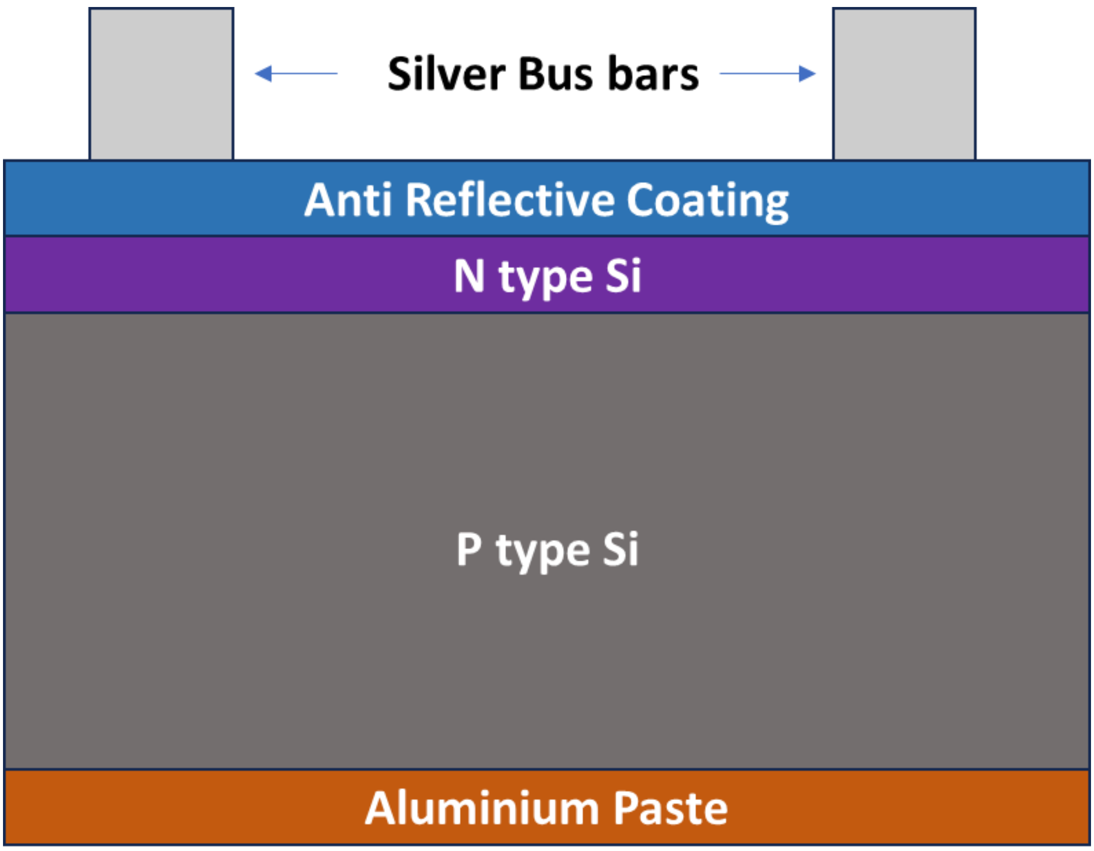

Fig 2.3 Cross section view of solar cells | CAG

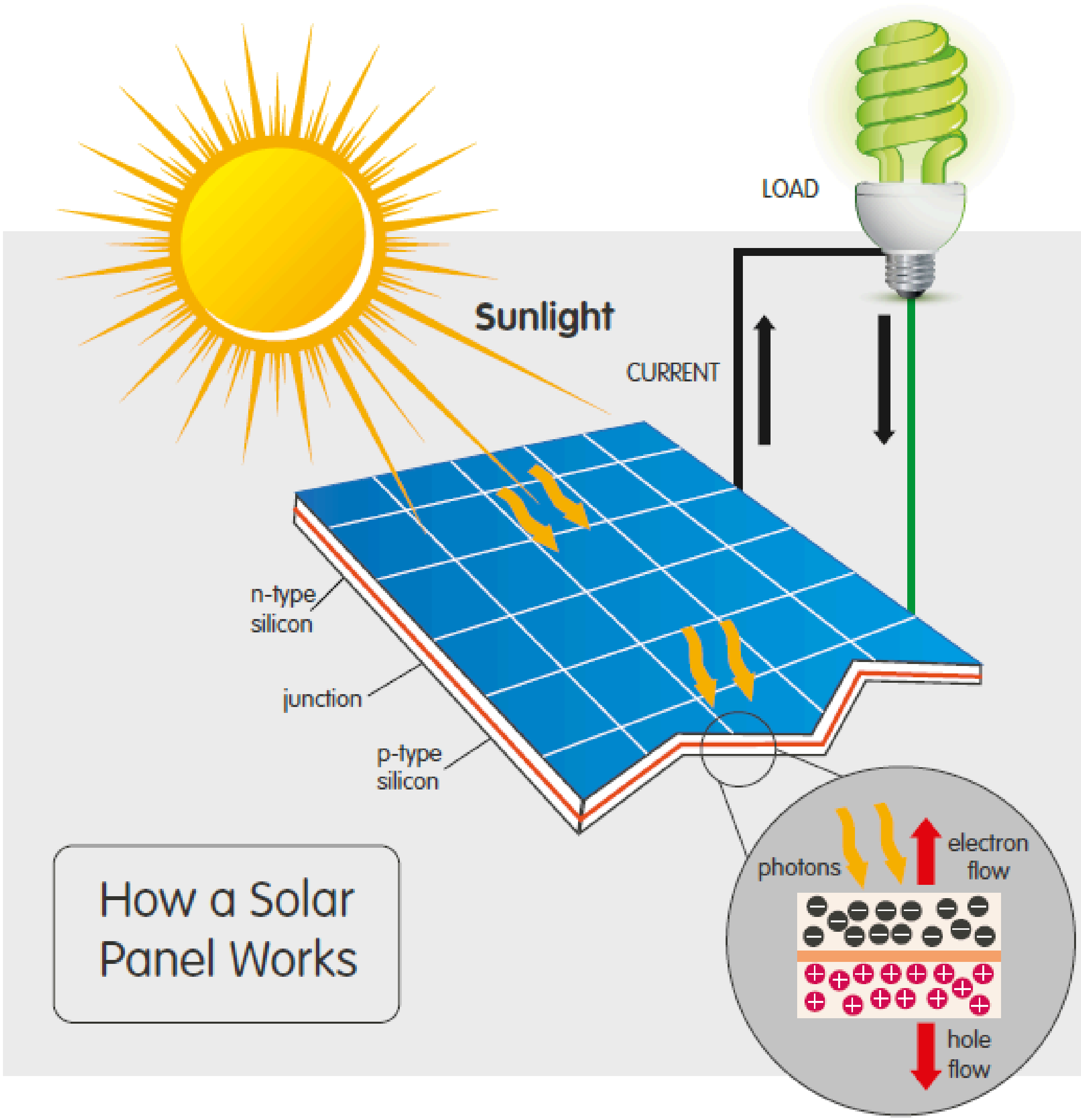

Fig 2.4 Working of solar panel | [SNV training manual]

Table 2.1 : Solar Cell Technologies and its characteristics

Cell Technology	Characteristics
Crystalline Silicon Solar Cells	
Polycrystalline Silicon	• Made by wafering Polycrystalline silicon ingot • Efficiency : 13 % to 16 % • Appearance : Blue with grainy shades / texture • Availability : Currently not used widely
Monocrystalline Silicon	• Made from a single continuous crystal structure • Efficiency : 15 % to 20 % • Appearance : Uniform Black • Availability : Commonly used technology

Advanced Crystalline Silicon Cell Technologies	
Monocrystalline Passivated Emitter Rear Contact (Mono PERC) Solar Cells	● Mono crystalline cell with additional passivation layers to capture more light ● Good Efficiency : 23 to 24 % even at low light ● **Mono PERC technology currently dominates the market** ● Performance Degradation rate : 0.45% / year ● Bifacial Capacity : 70 %
Heterojunction with Intrinsic Thin layer (HIT) solar cells	● Combines crystalline and amorphous silicon layers ● Performs well even in high temperature regions
Tunnel Oxide Passivated Contact (TOPCON) solar cells	● Merges advantages of PERC and HIT ● Excellent efficiency upto 26 % ● High Thermal stability ● **Emerging Technology. TOPCON is forecasted to lead the market by 2031.** ● Performance Degradation rate : 0.4 % / year ● Bifacial capacity : > 80 %
Interdigitated Back Contact (IBC) solar cells	● No bus bars on the top surface, all electrical contacts are at the back. Maximizing sunlight absorption on the front surface. ● Market share will increases after 2030
Other Cell Technologies	
Thin Film Solar Cells ● Amorphous silicon ● Cadmium Telluride (CdTE) ● Copper Indium Gallium Selenide (CIGS)	● Manufactured by depositing thin film of PV materials onto substrates. ● Low cost, shorter lifespan and easy to manufacture ● Lower efficiency : 7 % to 18 % ● Flexible and Lightweight. Hence used in portable or curved applications.
Tandem or Multi - Junction Solar cells	● Single cell have multiple layers of PN junctions to absorb various wavelengths of sunlight ● Highest Efficiency : 45 % ● Currently in R&D stage and used in niche applications like satellites, space probes, concentrated solar PV systems
Emerging solar cell technologies in R & D stage	● Perovskite solar cells ● Dye sensitized solar cells ● Organic Solar cells ● Quantum dot based solar cells

Market share of different solar cell technologies :

According to the 2024 International Technology Roadmap for Photovoltaics (ITRPV), PERC technology currently dominates the rooftop solar market due to its cost-effectiveness and balanced performance. However, its market share is expected to decline after 2025. By 2031, TOPCON, which offers better efficiency and thermal behavior—especially in warmer climates like India is expected to lead the global solar market, followed closely by HJT (Heterojunction) and back-contact cells like IBC. Tandem technologies, currently in research, are projected to become commercially viable post-2030, signaling a shift toward ultra-high efficiency modules.

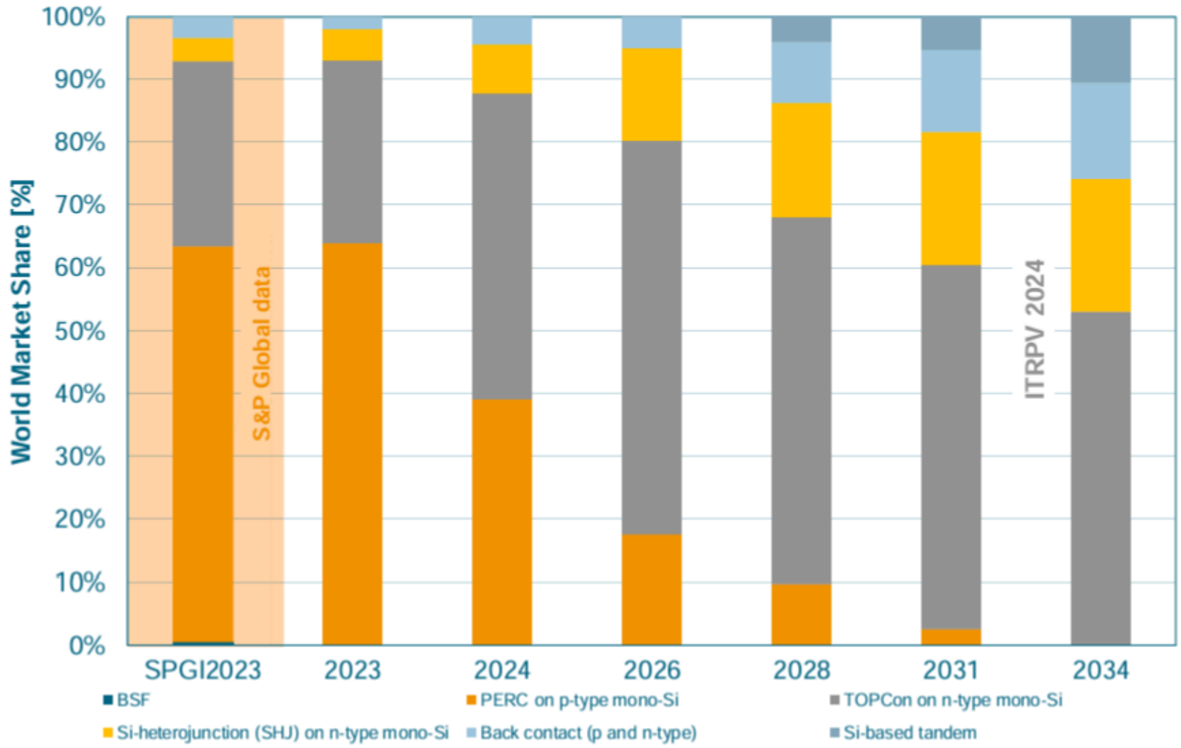

Fig 2.5 Market share of different solar cell technologies | ITRPV 2024

CONSUMER FOCUS

MONO PERC technology currently dominates the market due to its cost - effectiveness, but by 2031, TOPCON is expected to lead, offering better efficiency and thermal performance, especially in warmer climates like India.

2.4 Solar Glass

The solar glass is the top layer of the panel, acting as a protective shield for the solar cells. It is designed to let sunlight through while trapping energy to direct it towards the solar cells, protect against environmental factors like rain, dust and hail, enhance panel strength and make cleaning easier and promote recyclability for sustainability.

Unlike regular glass, solar glass is typically low-iron, high transmission glass with an anti-reflective coating to capture more sunlight. It ranges in thickness from 1.6 to 4 mm. Common types of glass used in solar applications includes :

- Tempered glass (Standard, high performance and most commonly used)
- Borosilicate or Lead crystal glass (Premium, better clarity)
- Flat plate or soda-lime glass (Lower cost, less efficient)

2.5. Aluminium Frame

The anodized aluminium frame provides structural support, making the panel sturdy yet lightweight. Aluminium is commonly used for its key features, including, corrosion resistance for long term outdoor use, strength and durability to withstand wind, snow and external forces, and recyclability.

2.6 Encapsulation

The encapsulant is a protective layer that surrounds the solar cells, holding them in place like a sandwich between the glass and backsheet. It protects fragile solar cells from moisture, heat, and physical stress, ensures adhesion between the glass, cells, and backsheet, and remains stable under high temperatures and UV exposure. The most common encapsulant is EVA (Ethyl Vinyl Acetate), a transparent polymer sheet that is heated to bond the panel layers together. Other materials, like POE (Polyolefin Elastomer) or PVB (Polyvinyl Butyral), are used in advanced panels for better durability. Encapsulants must be optically clear and have low thermal resistance to maintain efficiency.

2.7 Backsheet

The backsheet is the rear layer of the panel, providing insulation and protection. It shields solar cells from moisture, dust, and mechanical stress. It is used to dissipate the heat produced in the solar cells and prevents overheating and also ensures electrical insulation to protect the panels wiring. Backsheets are typically multilayer laminates made of polymers like Tedlar, PET, or fluoropolymers. Some panels use glass instead of a polymer backsheet for added durability, especially in bifacial panels. A high-quality backsheet is critical for long-term performance, as poor materials can crack or degrade, reducing efficiency.

2.8 Junction Box

The junction box, glued to the backsheet, connects the panel to external wiring. It contains bypass diodes, which prevent damage from shading by rerouting current around shaded cells to avoid hot spots (overheating that can harm the panel). Most panels use one diode per 20–24 cells for cost-effectiveness. The box also includes MC4 connectors, waterproof (IP67-rated) plugs for safe, easy connections to the inverter. Always use genuine MC4 connectors to avoid risks like fires or short circuits. The junction box must be weatherproof and compatible with the panel's current and voltage.

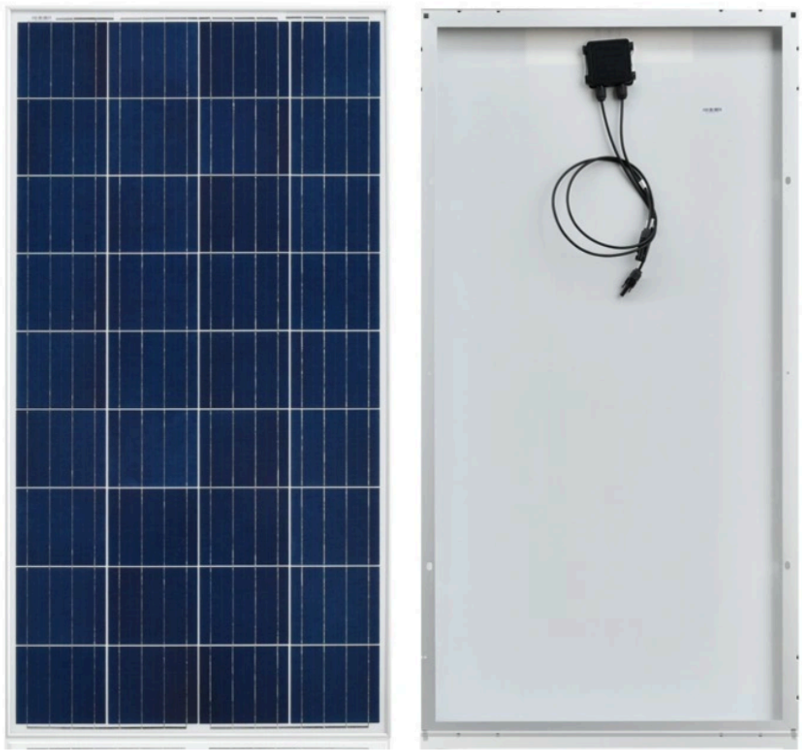

Fig 2.6 Solar PV module front and back side, Junction box | Sunket Solar

2.9 Bifacial panels

Bifacial solar panels are designed to capture sunlight on both the front and back surfaces, increasing overall energy generation. Unlike traditional monofacial panels that feature an opaque backsheet, bifacial modules use a transparent backsheet or dual-glass construction, enabling them to absorb direct sunlight on the front side and reflected sunlight—known as albedo—from the ground or nearby surfaces on the rear. This dual-surface design can boost energy output by 5% to 30%, depending on the reflectivity of the installation environment, such as white rooftops, gravel, or snow-covered ground. Bifacial panels are often constructed with durable glass backs, which provide added resistance to environmental degradation and improve longevity. To achieve optimal results, panels should be elevated and tilted to allow sunlight to reach the rear surface, and both sides may require periodic cleaning to maintain peak efficiency. While bifacial panels typically come at a higher upfront cost than traditional modules, they offer better returns over time due to their increased energy yield. As the technology matures and prices decline, bifacial panels are becoming an increasingly popular choice for maximizing solar energy output across diverse installation settings.

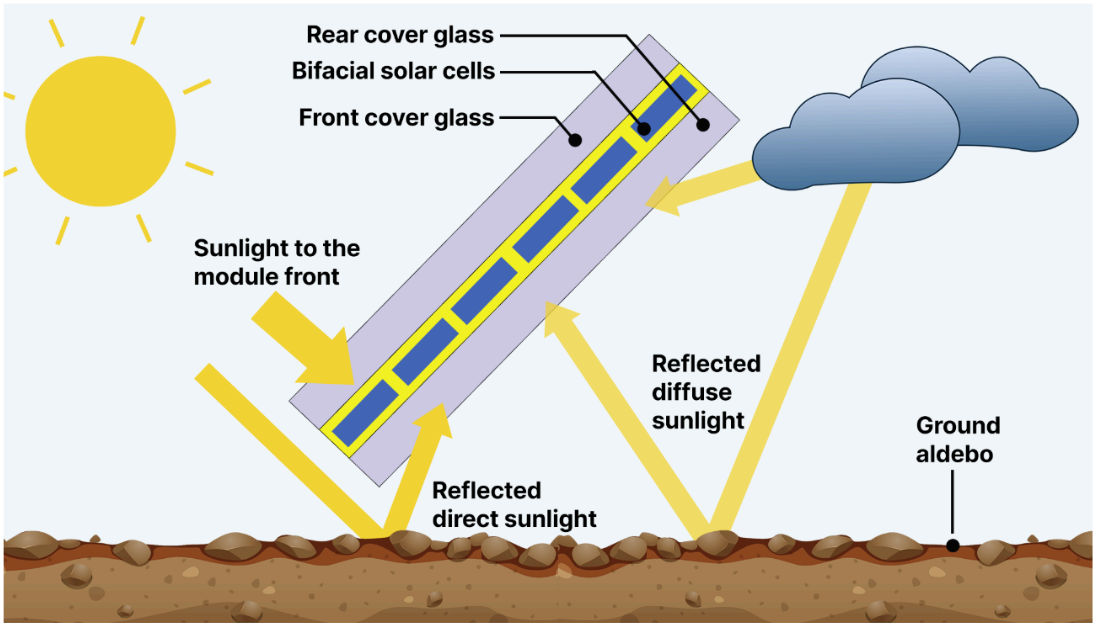

Fig 2.7 Bifacial Solar panels working | [Solar Reviews]

2.10 Traditional vs Half Cut solar cell PV panels

Traditional solar panels generally use full-size, square-shaped solar cells and typically offer a power rating between 300 to 350 Wp, with each panel containing about 60 to 72 cells, each around 15 x 15 cm^2 in size. However, with the advent of advanced module design techniques such as half-cut cell architecture, higher-capacity panels ranging from 500 to 750 Wp have become increasingly common. These panels contain 120 to 144 half-sized, rectangular solar cells and are divided into two electrically independent halves. This configuration ensures that even if one half is shaded, the other can continue to generate power efficiently. Additionally, by cutting the cells in half, the current flowing through each is reduced, thereby lowering resistive losses and enhancing overall performance and energy yield.

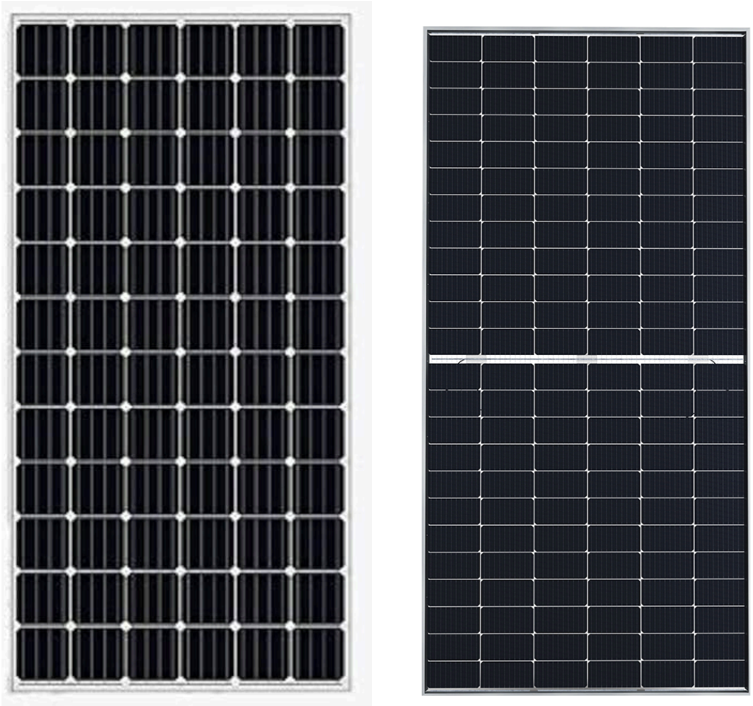

Fig 2.8 Traditional and Half cut cell Solar panels | VIKRAM SOLAR

2.11 Building Integrated Photovoltaics (BIPV)

BIPV panels are an innovative solar technology that combines energy generation with construction aesthetics. Unlike conventional solar panels mounted on rooftops or frames, BIPV panels are designed to replace traditional building elements such as roof tiles, facades, windows, and skylights. These systems integrate directly into the architecture, making them an ideal solution for urban buildings where space is limited or visual appeal is a priority. BIPV panels are available in various colors, textures, and levels of transparency, offering designers and architects the flexibility to match them with a building's overall appearance. In addition to their sleek look, BIPV panels serve a dual function: they generate electricity while also acting as structural components. Glass BIPV panels, for instance, can be used in place of conventional window panes contributing to the building's energy efficiency without compromising natural lighting. The advantages of BIPV panels go beyond aesthetics. They reduce on-site energy consumption, contribute to lower carbon footprints, and can enhance property value due to their modern, eco-friendly design. However, BIPV systems do come with higher costs, mainly due to customization, specialized materials, and the need for coordination between architects, engineers, and solar installers. Their efficiency may also be slightly lower than standard panels depending on placement, shading, and angle. Despite these challenges, BIPV remains a forward-thinking option for new buildings or renovations targeting sustainability and visual appeal.

Fig 2.9 BIPV panels | ASA

2.12 DCR vs Non DCR panels, ALMM

When purchasing solar panels especially under government subsidy schemes, it is essential to understand the difference between DCR (Domestic Content Requirement) and Non-DCR panels. DCR panels are made using key components like solar cells, encapsulants, backsheets, and the entire module within India, and they must be listed in the MNRE's Approved List of Models and Manufacturers (ALMM). These panels are mandatory for central government schemes like PM Surya Ghar Yojana making them the right choice for anyone seeking subsidies and policy compliance.

CONSUMER FOCUS

To avail the subsidy under PM Surya Ghar scheme, it is mandatory to use DCR solar panels

Non-DCR panels, in contrast, can include imported components or be fully assembled abroad. While they're often more affordable and widely available, they are not eligible for subsidies under most government programs. Consumers frequently face issues after unknowingly installing non-DCR panels, only to realize they can't claim financial benefits. To avoid this, buyers should confirm the DCR status with their installer or supplier and check for ALMM approval. In short, if applying for a subsidy, go with DCR. If not, non-DCR panels can still be a good option as long as they come from a trusted brand.

2.13 Understanding specifications of the typical solar panel

When choosing a solar panel, it's important to understand a few key specifications to ensure you get the best system for your needs. Some of the important technical parameters of the solar panel is briefed below :

1. ***Rated Power (W_p) :*** The rated power of a solar panel, usually shown in Watt peak (Wp), is the maximum amount of electricity the panel can produce under Standard Test Conditions (STC). These conditions include sunlight intensity of 1000 W/m², cell temperature of 25°C, and AM 1.5 sunlight spectrum. In real-world conditions, the panel's output will vary based on available sunlight and ambient temperature.
2. ***Electrical parameters :*** Solar panels come with several crucial electrical parameters: Voc (open circuit voltage), Isc (short circuit current), Vmp (voltage at maximum power), and Imp (current at maximum power). These are used to plan how many panels should be connected in series (a string) and how many strings can run in parallel to match your inverter's input.
3. ***Temperature coefficient of panel :*** Solar cells are made of semiconductor materials. When solar cells are operating it generates heat. This increases the cell temperature. The typical cell temperature while in operation (Nominal Operating Cell Temperature [NOCT]) is around 20 to 25℃ more than the ambient temperature. As the temperature rises, the efficiency of the solar panel drops. This drop is measured by the temperature coefficient, usually given as a percentage loss in power per degree Celsius increase. Advanced cell technologies like HIT and TOPCon have a lower temperature coefficient (around -0.3%/°C), meaning they maintain better performance even in hot conditions. In contrast, traditional monocrystalline and polycrystalline panels have higher coefficients (around -0.4 to -0.5%/°C), resulting in a more noticeable drop in output when temperatures rise. Choosing a panel with a lower temperature coefficient is especially beneficial in warm climates like India.

4. **Certification of solar panels :** Crystalline silicon solar panels must be tested and certified to meet safety and performance standards. In India, this includes:
   - IEC 61215 / IS 14286 – Verifies electrical performance and durability
   - IS / IEC 61730 – Ensures electrical safety and protection

   These certifications are tested by NABL accredited labs, and should always be confirmed before buying. There are also additional certifications applicable to solar modules based on specific operating conditions. For example, certain certifications are required for panels installed in corrosive environments (such as coastal areas), while others are relevant for large-scale solar parks or installations in extreme weather zones. These certifications help ensure that the modules perform reliably and safely under unique or challenging environmental conditions.
5. ***Warranty of solar panels :***

   Product warranty : Modules are typically warranted against manufacturing defects for a period of 5 to 10 years.

   Performance warranty : Performance warranty guarantees at least 90% of rated output for the first 10 years and 80% for up to 25 years. This means that a 200 Wp panel will generate as much power as a 180 Wp panel in 10 years time (90%) and 160 Wp panel in 25 years time (80%).

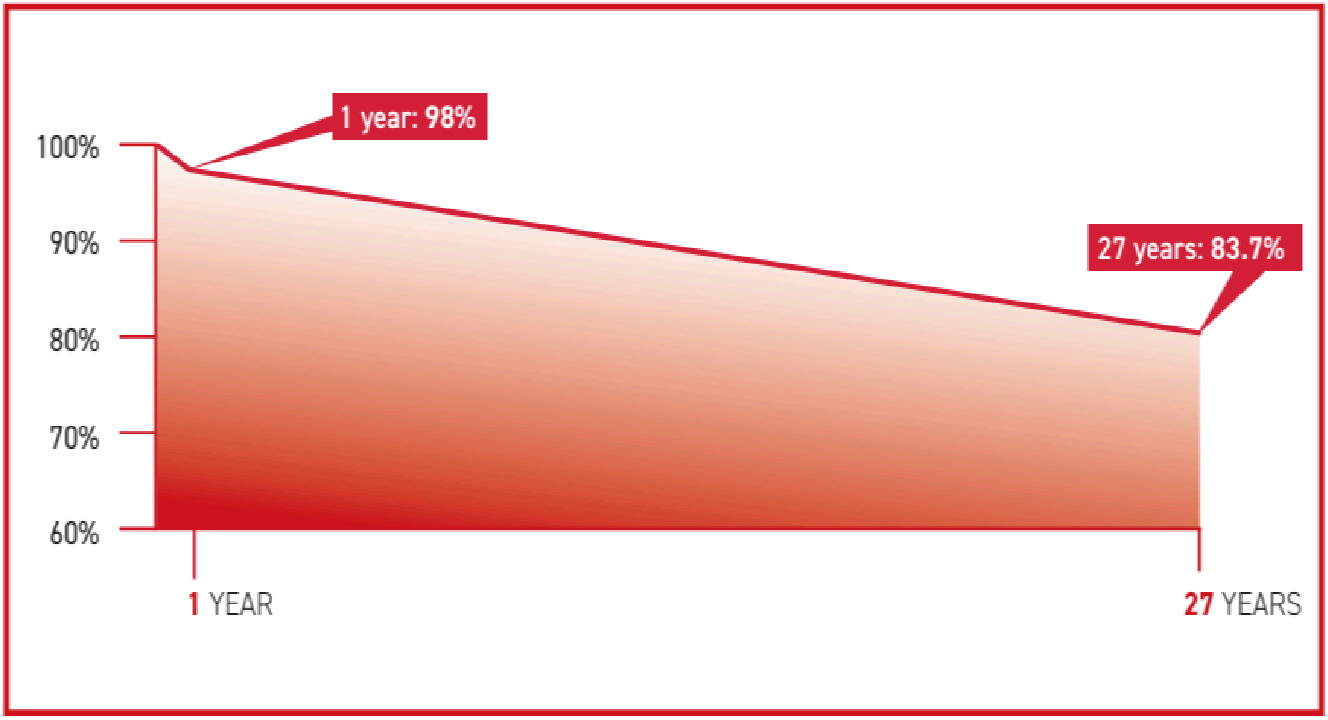

Fig 2.10 Performance warranty of Solar Panel | WAAREE

Solar PV module Technical specification sheet

Electrical Data[1,2] All data refers to STC (AM 1.5, 1000 W/m², 25°C)

Peak Power P_{max} (Wp)	380	385	390	395	400	405	410
Maximum Voltage V_{mpp} (V)	30.8	31	31.2	31.4	31.6	31.8	32
Maximum Current I_{mpp} (A)	12.34	12.42	12.5	12.58	12.66	12.74	12.82
Open Circuit Voltage V_{oc} (V)	37.1	37.2	37.3	37.4	37.5	37.6	37.7
Short Circuit Current I_{sc} (A)	12.9	13	13.1	13.2	13.3	13.4	13.5
Module Efficiency (%)	19.45	19.70	19.96	20.22	20.47	20.74	21

1) STC:1000 W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3. | 2) Power measurement uncertainty is within +/- 2%.

Temperature Coefficients (Tc) permissible operating conditions

Tc of Open Circuit Voltage (β)	-0.27%/°C
Tc of Short Circuit Current (α)	0.050%/°C
Tc of Power (γ)	-0.35%/°C
Maximum System Voltage	1500V
NOCT	45°C ± 2°C
Temperature Range	-40°C to + 85°C

Mechanical Data

Length × Width × Height	1722 X 1134 x 35 mm (67.80 X 44.65 X 1.38 inches)
Weight	21.3 Kg (46.96 lbs)
Junction Box	IP68, Split Junction Box with individual bypass diodes
Cable & Connectors#	200 mm (+ve terminal) & 300mm (-ve terminal) length cables,MC4 Compatible/MC4 Connectors
Application Class	Class A (Safety class II)
Superstrate##	3.2 mm (0.125 inches) high transmission low iron tempered glass, AR coated
Cells	54 Mono PERC (108 half-cells) P-Type Bifacial solar cells
Back Sheet	High Transmittance Composite film
Frame	Anodized aluminium frame with twin wall profile
Encapsulant	Polyolefin (POE)/ EPE
Mechanical Load Test	5400 Pa (Snow load), 2400 Pa (Wind load)
Maximum Series Fuse Rating	25 A

Warranty and Certifications

Product Warranty**	12 years
Performance Warranty**	Linear Power Warranty for 27 years with 2% for 1st year degradation and 0.55% from year 2 to year 27
Approvals and Certificates^	IEC 61215 : 2016, IEC 61730 : 2016, IEC 61701, IEC 62716, IEC 60068-2-68, IEC 62804, CE, CEC (California), UL 61215, UL 61730, CAN-CSA

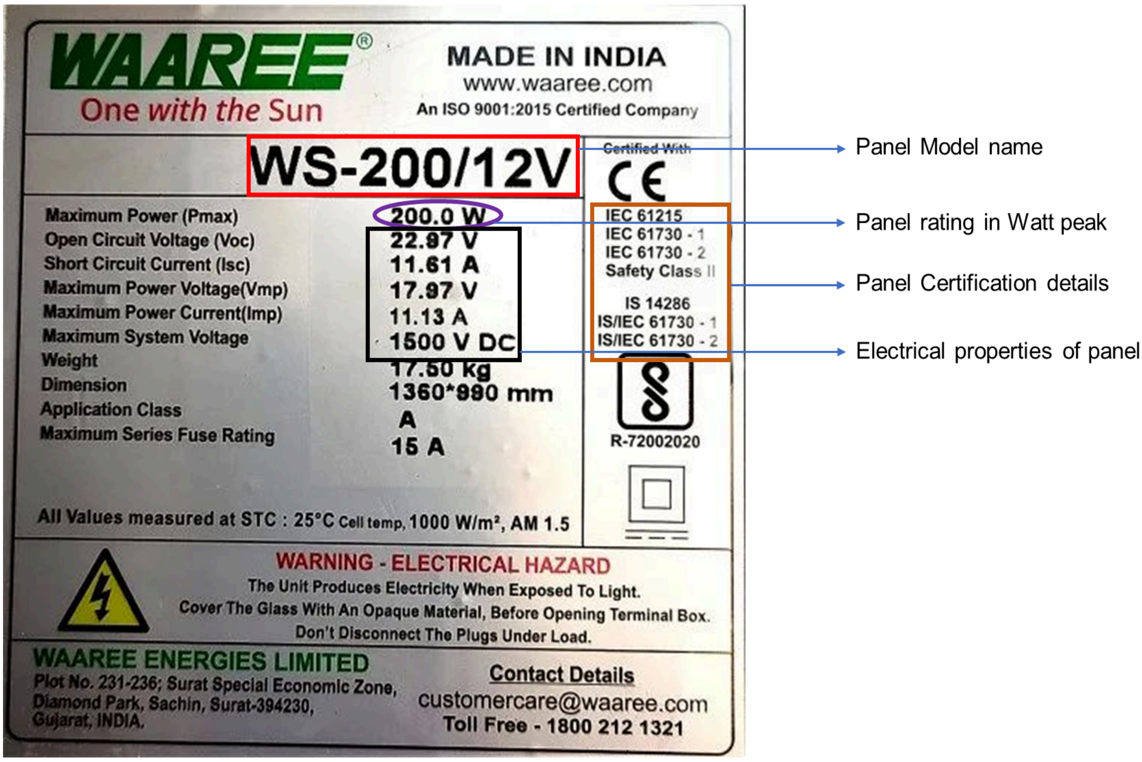

Fig 2.11 Nameplate details of a typical solar PV panel | WAAREE

2.14 Technical Specifications for Solar PV Modules under the "CFA for Residential Consumers" Component of PM Surya Ghar: Muft Bijli Yojana

1. Domestic Manufactured Solar PV modules using domestically manufactured Solar cells shall be used to avail benefits under the Scheme.
2. The PV modules used must qualify to the latest edition of IEC standards or equivalent BIS standards, i.e. IEC 61215 / IS 14286, IEC 61853-Part I or IS 16170-Part I, IS/IEC 61730 Part-1 & Part 2 and IS 17210 (part 1) or IEC 62804-1 (PID). For the PV modules to be used in a highly corrosive atmosphere throughout their lifetime, they must qualify to IEC 61701 / IS 61701. Thin - Film terrestrial photovoltaic (PV) modules must qualify to IS 16077: 2013 / IEC 61646: 2008
3. The rated power of the solar PV module shall have maximum tolerance up to +3%.
4. The peak-power point current of any supplied module string (series connected modules) shall not vary by +1% from the respective arithmetic means for all modules and/or for all module strings (connected to the same MPPT), as the case may be.
5. The peak-power point voltage of any supplied module string (series connected modules) shall not vary by + 2% from the respective arithmetic means for all modules and/or for all module strings (connected to the same MPPT), as the case may be.

6. The temperature co-efficient power of the PV module shall be equal to or better than -0.4%/°C for crystalline modules and -0.3 %/°C for thin film modules.
7. Solar PV modules capacity to be used should adhere to the Approved List of Models and Manufacturers (ALMM) of Solar Photovoltaic Modules (Requirement for Compulsory Registration) Order 2019 - Implementation issued vide OM NO. 283/54/2018-GRID SOLAR -Part (I) Dated 10th March 2021 and subsequent amendments.
8. Solar PV modules of minimum fill factor 75%, to be used.
9. All PV modules should have a nominal power output of >90% at STC during the first 10 years, and >80% during the next 15 years. Further, module shall have nominal power output of >97% during the first year of installation—degradation of the module below 0.5 % per annum
10. The manufacturer should warrant the Solar Module(s) to be free from the defects and/or failures specified below for a period not less than five (5) years from the date of commissioning.
    a. Defects and/or failures due to manufacturing.
    b. Defects and/or failures due to quality of materials.
    c. Nonconformity to specifications due to faulty manufacturing and/or inspection processes. If a solar module does not meet the specified standards due to manufacturing defects or inspection errors, the manufacturer will either repair or replace the faulty module, based on the owner's choice. The PV modules shall be replaced by manufacturers, without charging any cost to the end consumer during the specified period of warranty.
11. Modules deployed must use a Radio Frequency Identification (RFID) tag laminated inside the glass. The following information must be mentioned in the RFID used on each module:
    a. Name of the manufacturer of the PV module
    b. Name of the manufacturer of Solar Cells.
    c. Month & year of the manufacture (separate for solar cells and modules)
    d. Country of origin (separately for solar cells and module)
    e. I-V curve for the module Wattage, Im, Vm and FF for the module
    f. Unique Serial No and Model No of the module
    g. Date and year of obtaining IEC PV module qualification certificate.
    h. Name of the test lab issuing IEC certificate.
    i. Other relevant information on traceability of solar cells and modules as per ISO 9001 and ISO 14001.
    j. Nominal wattage +3%.

        k. Name, if applicable.

12. Other details as per IS/IEC 61730-1 clause 11 should be provided at appropriate places. In addition to the above, the following information should also be provided:
    a. The actual Power Output Pmax shall be mentioned on the label pasted on the back side of PV Module.
    b. The Maximum system voltage for which the module is suitable to be provided on the back sheet of the module.
    c. Polarity of terminals or leads (colour coding is permissible) on junction Box housing near cable entry or cable and connector.
13. Unique Serial No, Model No, Name of Manufacturer, Manufacturing year, Make in India logo and module wattage details should be displayed inside the laminated glass.

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3 SOLAR INVERTERS

3.1 Solar Inverters

A solar inverter is the essential bridge between solar panels (which generate direct current, or DC) and our home's electrical system (which runs on alternating current, or AC). It converts the DC power from the solar panels into usable AC power and to adjust this to the frequency and voltage level of the grid or building's electrical system.

But the inverter does more than just convert power, it also acts as the heart and brain of the solar PV system. Modern solar inverters come with smart features such as:

- Maximum Power Point Tracking (MPPT): To ensure maximum energy is harvested from the panels under varying sunlight conditions.
- Grid Synchronization: Matches your output with the voltage, frequency, and phase of the utility grid.
- Safety Functions: Automatically shuts down during a grid failure (anti-islanding), protecting utility workers and grid equipment, preventing accidents.
- System Protection: Detects and protects from issues like reverse polarity, overvoltage, or overcurrent on the DC side, and grid faults on the AC side.
- Monitoring & Communication: Logs and provides data on system performance, including energy production, voltage, current, and efficiency, and shares it via displays or remote platforms for performance tracking.

Inverter efficiency is a crucial factor, indicating how much of the DC power from the panels is successfully converted to AC power. High-quality inverters typically have efficiencies ranging from 95% to 98%. Efficiency can vary depending on the load and operating conditions.

Choosing the best type of solar inverter for a particular installation depends on several factors, including:

- System size
- Budget
- Shading conditions
- Roof layout and orientation
- Whether battery storage is planned
- Monitoring requirements

Solar inverters typically last around 10 to 15 years, which is often less than the lifespan of solar panels (25+ years). Most manufacturers offer warranties ranging from 5 to 10 years, with extended warranties available for some models, especially microinverters.

3.2 Components of a solar inverter

Built with complex electronic components like filters, switching devices, transformers, and control circuits, solar inverters are a critical Balance of System (BoS) component that ensures smooth, safe, and efficient energy conversion. The specific design and complexity can vary depending on the type and size of the solar inverter.

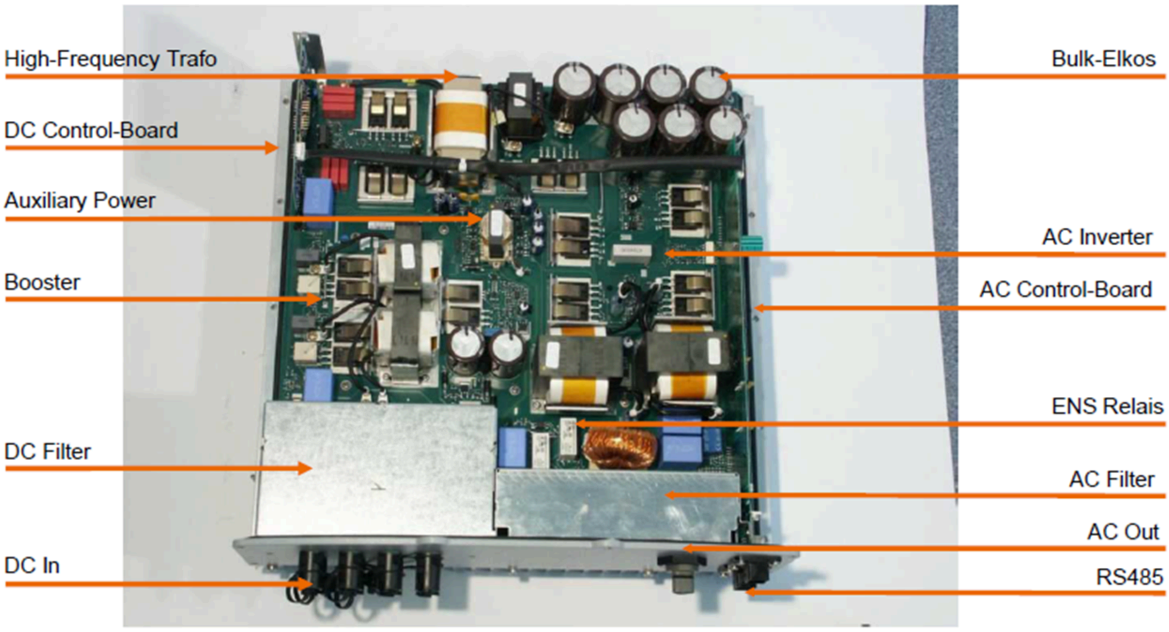

Fig 3.1 Components in an Inverter | Enphase

The main components in an inverter are as follows :

1. Input Stage:

- DC Input Terminals: These are the connection points where the DC electricity from the solar panels enters the inverter.
- Fuses or DC Disconnect Switch: These safety devices protect the inverter from overcurrent or provide a way to safely disconnect the solar panels for maintenance.
- Capacitors (DC Bus): These components filter the DC voltage from the solar panels, smoothing out any ripples and providing a stable DC input for the conversion stage.

2. DC to AC Conversion Stage:

- Switching Devices (Transistors - IGBTs or MOSFETs): These are the core components responsible for rapidly switching the direction of the DC current on and off. This high-speed switching creates a stepped AC waveform.
- Control Circuitry (PWM - Pulse Width Modulation): This circuitry precisely controls the switching of the transistors to create an AC waveform with the desired voltage and frequency (e.g., 230V, 50Hz in India).
- Transformer (in some designs): Transformers can be used for voltage step-up or step-down and to provide galvanic isolation between the DC and AC sides for safety. Transformerless inverters are also common for higher efficiency and lighter weight.
- Inductors and Capacitors (Output Filter): These passive components filter the stepped AC waveform, smoothing it out to create a clean sine wave that is compatible with household appliances and the grid.

3. Control and Monitoring System:

- Microcontroller/Digital Signal Processor (DSP): This is the "brain" of the inverter, responsible for managing all its functions, including MPPT, DC-to-AC conversion, safety features, and communication.
- Software/Firmware: The embedded software controls the inverter's operation, implements algorithms like MPPT, and manages communication with monitoring systems.
- Sensors: Various sensors monitor voltage, current, temperature, and other parameters to ensure safe and efficient operation.
- Communication Interface: Many modern inverters have interfaces like Wi-Fi, Ethernet, or RS485 to connect to monitoring platforms, allowing users to track system performance remotely.
- Display Interface: A local display (LCD or LEDs) often provides real-time information about the system's status and energy production.

4. Maximum Power Point Tracking (MPPT):

MPPT Controller: This electronic circuit continuously tracks the maximum power point of the solar array. Solar panels produce varying voltage and current depending on sunlight intensity and temperature. The MPPT optimizes the operating point to extract the maximum possible power from the panels at any given time. This is often implemented within the microcontroller.

5. Protection Systems:

- Overcurrent Protection (Fuses, Circuit Breakers): These protect the inverter and the connected systems from damage due to excessive current.
- Overvoltage Protection: Prevents damage from voltage surges on either the DC or AC side.
- Ground Fault Detection: Detects and protects against faults where current might leak to the ground, ensuring safety.
- Anti-Islanding Protection (for grid-tie inverters): This crucial safety feature automatically shuts down the inverter if the utility grid fails, preventing it from feeding power into a potentially dangerous "islanded" grid.
- Reverse Polarity Protection: Prevents damage if the solar panels are accidentally connected with the wrong polarity.

6. Cooling System:

- Heat Sinks: These passive components dissipate heat generated by the power electronic components (transistors, diodes) to prevent overheating.
- Fans: Some inverters use fans to actively cool internal components, especially in high-power units or hot environments, ensuring longevity and reliable operation.

7. Output Stage:

- AC Output Terminals: These are the connection points where the converted AC electricity leaves the inverter to power your home or feed into the grid.
- Output Circuit Breaker: Provides protection on the AC side against overcurrent.
- Relays: Used for grid connection and disconnection, especially for anti-islanding protection.

3.3 Types of solar inverters

Sn	Inverter type	Description
1	Grid tied inverters	Converts DC to AC for use in your home and exports excess power to the grid. Requires a live grid connection to operate.
2	Off Grid inverters	Converts DC to AC for use in your home and stores excess energy in the battery for later use. Common in remote or standalone systems.
	Types of grid tied inverters	

1	Single phase inverters	Used in small residential systems (typically <5 kW). Suitable for homes with single-phase power supply.
2	Three phase inverters	Common in larger homes or buildings with higher energy demands (>5 kW systems). Matches three-phase utility supply.
3	String inverter	Most widely used for residential rooftops. Multiple panels are connected in series (a string), and the string is connected to a single inverter. Easy to install and cost-effective, but suffers if one panel is shaded or damaged.
4	Multiple MPPT String inverters	Each group of similarly oriented panels is connected to a separate MPPT. Ideal for rooftops with multiple tilts or shading. Helps reduce energy loss and improves yield.
5	Central inverters	Generally used in large utility scale solar power plants. DC strings are combined into arrays and fed into the inverter through a string combiner box. Typical ratings range between 100 kW to 5+ MW.
6	Hybrid inverters	Hybrid solar systems generate power in the same way as a common grid tied solar system. They use batteries to store energy for later use. They can operate as a backup power supply during a blackout, similar to a UPS system
7	MLPE - Micro inverter	These are installed on each panel individually. Converts DC to AC at the module level. Offers excellent performance in shaded conditions and enables per-panel monitoring. Downsides: higher upfront cost and maintenance complexity.
8	Power Optimizer	Installed at the panel level like microinverters, but instead of converting to AC, they optimize and condition DC before sending it to a central inverter. Offers many of the benefits of microinverters with lower cost.

a b c

Fig 3.2 a) Central inverter b) String inverter c) Micro inverter | [O&M manual, GERMI]

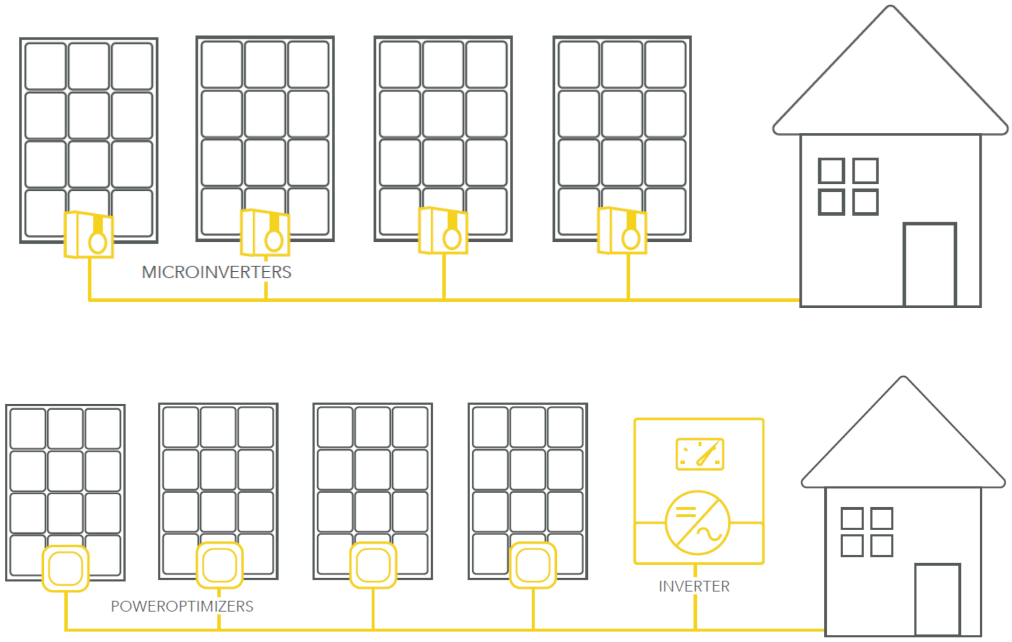

Fig 3.3 Difference between Micro inverters and Power optimizers | [O&M manual, GERMI]

Grid-tied solar inverters shut off instantly during a power outage, even if the sun is shining. This safety feature, called *anti-islanding*, prevents your system from sending power to the grid, protecting utility workers fixing the lines. To use solar power during outages, consider a hybrid inverter with battery storage.

Isolation transformers for inverters

Isolation transformers are used in some solar systems to protect inverters from grid surges and prevent DC injection into the grid. While many modern inverters already include built-in protection and don't require separate transformers as it adds costs and reduces overall efficiency, these devices can still be useful in specific scenarios.They are particularly helpful in areas with unstable grid voltage—like low voltages at the far end of a distribution line or high voltages near substations. In such cases, a transformer with adjustable taps can slightly tweak the voltage to keep the inverter operating smoothly.

Each inverter type has its place based on system size, shading, complexity, and budget. Choosing the right inverter is key to ensuring your rooftop solar system runs safely, efficiently, and reliably for years to come.

3.4 Specification sheet of the solar inverter

Model	**XYZ**
Input (DC)	
Rated DC Power	20 kWp
Max. DC Power	25 kWp
Max. input voltage	1000 V
DC voltage range	200 - 1000 V
MPP voltage range, Full Power	470 - 820 V
Nominal DC voltage	635 V
Max. input current per MPPT	22 A
Total input current	44 A
No. of independent MPP Trackers	2
Unbalanced input (%)	33 / 67
Input connection type	4 pair MC4
DC disconnection switch	Yes (inbuilt)
Output (AC)	
Rated output power	20 kVA
Maximum output power	21 kVA
Rated output current	29 A
Max. output current	32 A
Nominal AC voltage	3 Ph, 400 V
AC voltage range	400 V ± 20 % (320~480)
Nominal Frequency	50 Hz

Frequency range	45 Hz - 55 Hz
Power factor at rated power	Unity
Reactive power (adjustable)	0.8 Lagging ~ 0.8 Leading
Harmonics	<3% at Rated Power
No. of conductors (user settable)	4/5 Wire (L1,L2,L3,N,PE)
Efficiency	
Maximum Efficiency	**98.40%**
Euro Efficiency	98.10%
Communication	
Communication Port	MODBUS RTU over RS 485 Physical Layer
Graphical Display	5" Graphical LCD
Built-in Energy data logger	Yes
Emergency Power Off (EPO)	Yes, External Switch to be Connected
General Data	
Dimension (H/W/D)	625 mm x 612 mm x 278 mm
Weight (kg)	43
Operating temperature range	-25℃ to + 60℃
Self consumption at night	< 2 Watts

3.5 Technical specifications for Solar Inverters under the "CFA for Residential Consumers" Component of PM Surya Ghar : Muft Bijli Yojana

1. The Solar Photovoltaic Inverters must comply with the Quality Control Order dated 30.08.2017 for Solar Photovoltaic Inverters and its amendments thereof.
2. Inverters/PCU should comply with applicable IEC/equivalent BIS standard for efficiency measurements and environmental tests as per standard codes IEC

61683/IS 61683, IS 16221 (Part 2), IS 16169 and IEC 60068-2(1,2,14,30) / Equivalent BIS Std.

3. Maximum Power Point Tracker (MPPT) shall be integrated in the inverter/PCU to maximize energy drawn from the array. Charge controller (if any) / MPPT units environmental testing should qualify IEC 60068-2(1, 2, 14, 30)/Equivalent BIS standard. The junction boxes/enclosures should be IP 65 or better (for outdoor)/ IP 54 or better (indoor) and as per IEC 529 Specifications.
4. All inverters/PCUs shall be IEC 61000 compliant for electromagnetic compatibility, harmonics, Surge, etc.
5. The PCU/ inverter shall have an overloading capacity of minimum 20%.
6. Typical technical features of the inverter shall be as follows-
    a. Nominal AC output voltage and frequency: as per CEA/State regulations
    b. Output frequency: 50 Hz
    c. Grid Frequency Synchronization range: as per CEA/State Regulations
    d. Ambient temperature considered: -20°C to 60°C
    e. Protection of Enclosure: IP-54 (Minimum) for indoor and IP-65 (Minimum) for outdoor.
    f. Grid Frequency Tolerance range: as per CEA/State regulations
    g. Grid Voltage tolerance: as per CEA/State Regulations
    h. No-load losses: Less than 1% of rated power
    i. Inverter efficiency (Min.): >90% (In case of 10 kW or below with in-built galvanic isolation)
    j. The Minimum Overall Efficiency (ηt) as per IS 17980 for Solar Inverters should adhere to the following:
    k. THD: < 3%
    l. PF: > 0.9 (lag or lead)
    m. Should not inject DC power more than 0.5% of full rated output at the interconnection point and comply with IEEE 519.
    n. The inverter should have the inbuilt facility to communicate system related data through SIM/dongle. The inverter may also be enabled for Wi-Fi based communication.
7. All the Inverters should contain the following clear and indelible Marking Label & Warning Label as per IS16221 Part II, clause 5. The equipment shall, as a minimum, be permanently marked with:
    a. The name or trademark of the manufacturer or supplier;
    b. A model number, name or other means to identify the equipment;

c. A serial number, code or other marking allowing identification of manufacturing location and the manufacturing batch or date within a twelve-month time period;
d. Input voltage, type of voltage (AC or DC), frequency, and maximum continuous current for each input;
e. The Ingress Protection (IP) rating

8. In case the consumer is having a 3-ϕ connection, 1-ϕ/3-ϕ inverter shall be provided by the vendor as per the consumer's requirement and regulations of the State.
9. Inverter/PCU shall be capable of complete automatic operation including wake-up, synchronization & shutdown.
10. Integration of PV Power with Grid & Grid Islanding: In the event of a power failure on the electric grid, it is required that any independent power-producing inverters attached to the grid turn off in a short period of time. This prevents the DC-to-AC inverters from continuing to feed power into small sections of the grid, known as "islands." Powered islands present a risk to workers who may expect the area to be unpowered, and they may also damage grid-tied equipment. The Rooftop PV system shall be equipped with islanding protection. In addition to disconnection from the grid (due to islanding protection) disconnection due to under and over voltage conditions shall also be provided, if not available in the inverter.

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4 DISTRIBUTION BOX

4.1 Introduction

In a rooftop solar PV system, two key electrical boxes are used to manage and protect the flow of electricity: the DC Distribution Box (DCDB) and the AC Distribution Box (ACDB). These boxes are vital for ensuring safe operation, isolating parts of the system when needed, and protecting the equipment from electrical faults or surges.

4.2 DCDB

The DCDB, also known as the String Junction Box (SJB) or combiner box, is installed between the solar PV array (the solar panels) and the inverter. Its main role is to combine the outputs of multiple solar panel strings and safely feed them into the inverter. Inside the DCDB, you'll typically find string fuses, surge protection devices (SPDs), DC isolators, and sometimes string diodes.

- String Fuses protect each panel string from overcurrent and are rated for DC applications usually 1.25 to 1.5 times the expected current of the string. For instance, if a string produces 8 amps, a fuse rated between 10 A and 12 A is typically used.
- String Diodes are optional but useful in preventing reverse current if one string is shaded or damaged.
- DC SPDs protect the system from voltage spikes (like lightning) and are chosen based on system voltage - Type 2 SPD rated for at least 1000 VDC is common for residential systems.
- The DC Isolator allows for safe manual shutdown of the DC power during maintenance or emergency.

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The DC Distribution Box (DCDB) safely combines outputs from multiple solar panel strings and house protection devices like fuses, surge protection devices (SPD), and MCBs, to safeguard the system.

A good DCDB is weatherproof (IP54 or higher), UV-resistant, and clearly separates the positive and negative terminals. It should follow Protection Class II, ensuring double insulation for extra safety.

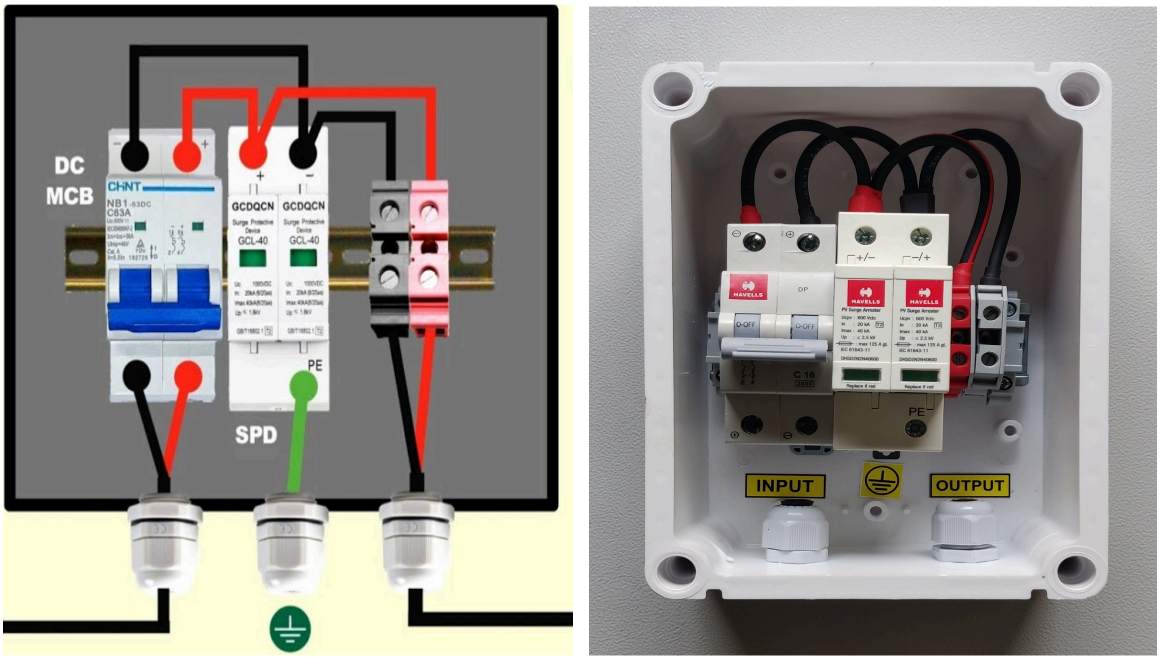

Fig 4.1 Layout of a simple DC Distribution Box | [Havells]()

4.3 ACDB

On the AC side, the ACDB is installed between the inverter output and main electrical panel of the house. Its primary function is to protect homes from faults originating in the solar system and to safely disconnect the inverter from the grid when necessary.

- The ACDB typically includes Miniature Circuit Breakers (MCBs) for input and output connections. These are selected based on the inverter's output current usually rated at 1.25 to 1.5 times the inverter's maximum AC output current.
- Residual Current Circuit Breakers (RCCBs) are used to detect leakage currents and prevent electrical shock. A 30 mA rating is common in residential systems for personal protection.
- AC SPDs (Type 2) are installed to handle surges on the AC side, again rated for grid voltage typically 275 V or 320 V for single-phase systems and higher for three-phase.

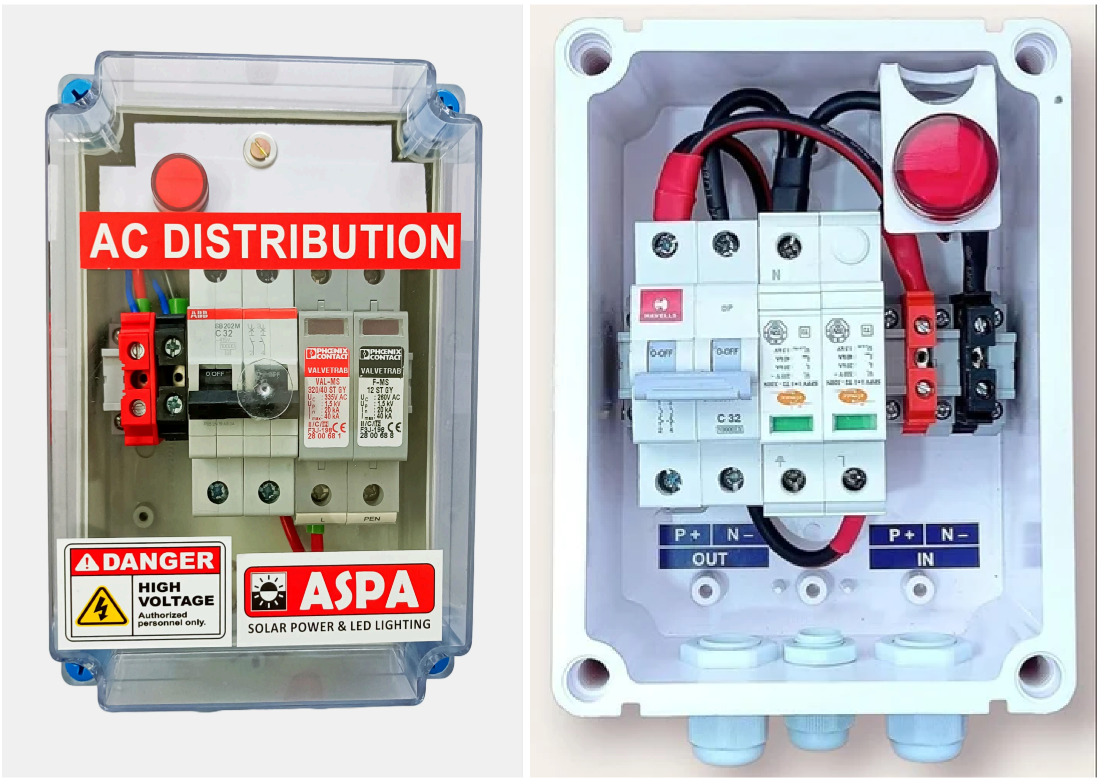

Fig 4.2 Layout of AC Distribution Box | ASPA Solar & Kenbrook Solar

In some systems, inverters already include internal protection components, such as MCBs, SPDs, and RCCBs. In that case, the external ACDB and DCDB may be simplified, but still required for inspection and safety compliance.

4.4 Technical specifications for Distribution box under the "CFA for Residential Consumers" Component of PM Surya Ghar : Muft Bijli Yojana

1. Array Junction Boxes

i. The junction boxes are to be provided in the PV array for termination of connecting cables. The Junction Boxes (JBs) shall be made of GRP/FRP/Powder Coated aluminum /cast aluminum alloy with full dust, water & vermin proof arrangement. All wires/cables must be terminated through cable lugs. The JBs shall be such that input & output termination can be made through suitable cable glands. Suitable markings shall be provided on the bus-bars for easy identification and cable ferrules will be fitted at the cable termination points for identification.

ii. Copper bus bars/terminal blocks housed in the junction box with suitable termination threads, conforming to IP 65 or better standard, and IEC 62208 hinged door, with EPDM rubber gasket, to prevent water entry, single /double compression cable glands should be provided.

iii. Polyamide glands and MC4 Connectors may also be provided. The rating of the junction box shall be suitable with adequate safety factor to interconnect the Solar PV array.
iv. Suitable markings shall be provided on the bus bar for easy identification and the cable ferrules must be fitted at the cable termination points for identification.
v. Junction boxes shall be mounted on the MMS such that they are easily accessible and are protected from direct sunlight and harsh weather.

2. DC Distribution Box (DCDB)

i. May not be required for small plants, if suitable arrangement is available in the inverter.
ii. DC Distribution Box are to be provided to receive the DC output from the PV array field.
iii. DCDBs shall be dust & vermin proof and conform to having IP 65 or better protection, as per site conditions.
iv. The bus bars are made of EC grade copper of required size. Suitable capacity MCBs/MCCB shall be provided for controlling the DC power output to the inverter along with necessary surge arresters. MCB shall be used for currents up to 63 Amperes, and MCCB shall be used for currents greater than 63 Amperes.

3. AC Distribution Box (ACDB)

i. AC Distribution Panel Board (DPB) shall control the AC power from inverter, and should have necessary surge arresters, if required. There is interconnection from ACDB to mains at LT Bus bar while in grid tied mode.
ii. All switches and the circuit breakers, connectors should conform to IEC 60947:2019, part I, II and III/ IS 60947 part I, II and III.
iii. The isolators, cabling work should be undertaken as part of the project.
iv. All the Panels shall be metal clad, totally enclosed, rigid, floor mounted, air -insulated, cubical type suitable for operation on 1-ϕ/3-ϕ, 415 or 230 volts, 50 Hz (or voltage levels as per CEA/State regulations).
v. The panels shall be designed for minimum expected ambient temperature of 45 degree Celsius, 80 percent humidity and dusty weather.
vi. All indoor panels will have protection of IP 54 or better, as per site conditions. All outdoor panels will have protection of IP 65 or better, as per site conditions.
vii. Should conform to Indian Electricity Act and CEA safety regulations (till last amendment).

viii. All the 415 or 230 volts (or voltage levels as per CEA/State regulations) AC devices / equipment like bus support insulators, circuit breakers, SPDs, Voltage Transformers (VTs) etc., mounted inside the switchgear shall be suitable for continuous operation and satisfactory performance under the following supply conditions.

   a. Variation in supply voltage: as per CEA/State regulations
   b. Variation in supply frequency: as per CEA/State regulations

ix. The inverter output shall have the necessary rated AC surge arresters, if required and MCB/ MCCB. RCCB shall be used for successful operation of the PV system, if the inverter does not have required earth fault/residual current protection.

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5 CABLING AND WIRING

5.1 Introduction

The electrical cables and wiring play a very important role in system designing and array layout configurations of a solar power plant. They are crucial for safely and efficiently transmitting the electricity generated from the solar panels to the inverter and then to the home's electrical system or the grid. Choosing the right cables and proper wiring practices is essential for the system's performance, longevity, and safety. Cables should be planned in such a way so that they can last for 25 years.

Types of Cables in a Solar PV System:

- ***DC Cables:*** These cables connect the solar panels to each other (in strings) and then to the solar inverter. They carry direct current (DC) electricity.
  - String Cables: Connect individual solar panels in series.
  - Module Cables: Often short cables attached to the panels themselves, used for initial connection.
  - Array Cables: Connect the strings of panels to the DCDB or directly to the inverter.
- ***AC Cables:*** These cables connect the solar inverter to the AC distribution board and then to the home's electrical panel or the grid connection point. They carry alternating current (AC) electricity after the DC has been converted by the inverter.
- ***Earthing / Grounding Cables :*** These are vital for safety and connect the non-current-carrying metallic parts of the system (panel frames, mounting structures, inverter chassis, junction boxes) to the earth grounding system.

5.2 Key considerations

The following is to be considered for Cable and Wiring :

- Voltage and Current Ratings: Cables must be rated for the maximum DC voltage and current produced by the solar array and the AC voltage and current handled by the inverter. Using undersized cables can lead to overheating, voltage drops, and potential fire hazards. Always choose cables with a slightly higher rating than the maximum expected.

- Environmental Conditions: Solar cables are exposed to harsh outdoor conditions, including UV radiation, extreme temperatures, rain, and humidity. Use cables specifically designed for solar PV applications that are UV-resistant, weatherproof, and have a wide operating temperature range. Common insulation materials include cross-linked polyethylene (XLPE).
- Cable Size (Gauge): The correct cable size is crucial to minimize voltage drop and energy loss over the length of the cable. Longer cable runs require thicker cables. Factors influencing cable sizing include:
    - Maximum current
    - Cable length
    - Allowable voltage drop (typically a maximum of 1-3%)
    - Ambient temperature
    - Installation method

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Selecting the correct gauge size for both AC and DC cables is crucial. The cable size should be chosen in such a way that the voltage drop remains below 2%.

- Material: Copper is the most common conductor material due to its excellent conductivity and flexibility. Aluminum cables can be used in some larger applications but require careful installation and termination. Solar cables often have tinned copper conductors to prevent corrosion.
- Insulation and Sheathing: The insulation must be robust and rated for the expected voltage and environmental conditions. The outer sheath provides mechanical protection. Look for cables with double insulation for added safety. Low Smoke Zero Halogen (LSZH) cables are preferred in some installations for enhanced fire safety.
- Color Coding: Follow standard color coding conventions for DC (red for positive, black for negative) and AC (as per local electrical codes) wiring to ensure correct connections and aid in troubleshooting. Green or green with a yellow stripe is used for earthing.

- Connectors: Use appropriate connectors designed for solar PV applications (e.g., MC4 connectors) to ensure secure and weatherproof connections between panels and other components. Ensure proper crimping of connectors using the correct tools. Avoid mixing connectors from different manufacturers unless specifically allowed.
- Few common installation practices to follow:
    - Support cables properly to prevent strain and damage.
    - Avoid sharp bends that can damage the cable.
    - Protect cables from physical damage, moisture ingress, and exposure to chemicals. Use conduits or cable trays where necessary.
    - Ensure proper termination and tightening of all connections.
    - Maintain separation between DC and AC wiring runs to minimize electromagnetic interference.

DC cables are used to carry DC current from the PV modules right up to the inverter. The DC cable should be sized to carry the required current (along with necessary safety margins) and also limit the voltage drop (i.e. resistance losses). Typically, single-core multi-stranded copper cables with cross section 4 or 6 mm^2 rated for a maximum voltage of 1.8 kVDC are used for string connections of PV modules up to the string junction box. It is a common practice to use red-colored sheath for the positive terminal of the string and black-colored sheath for the negative terminal of the string. These cables have a single-core structure with a copper conductor, insulated with a flame-retardant material, and sheathed with a UV-resistant, durable jacket.

1. Conductor:

- The conductor is usually made of flexible, tinned copper strands.
- Tinned copper helps prevent corrosion and improves soldering.
- The cross-sectional area (e.g., $4mm^2$, $6mm^2$, $10mm^2$) is a key factor in cable selection, influencing resistance and voltage drop.

2. Insulation:

- Insulation materials are chosen for their flame retardancy and ability to withstand high temperatures and environmental conditions.
- Common insulation materials include cross-linked polyethylene (XLPE) and PVC.

3. Sheath:

- The outer sheath protects the cable from UV radiation, moisture, and mechanical damage.

- Materials like cross-linked polyethylene (XLPE) or PVC, with UV stabilizers, are used for the sheath.

Fig 5.1 DC Cable cross section | Clare solar

DC Cables from string junction box to inverter are typically longer. They are sized to carry the required current and also limit the voltage drop. As a general practice, the DC wiring should not cause more than 2 percent power loss in the PV system.

The DC cables used in solar strings use specialized connectors known as MC4 connectors. MC4 stands for Multi-Contact, 4 millimetre. The MC4 connector is used to connect cables, panels and other components in a solar PV system, such as junction boxes and inverters. As these connectors are usually installed outdoors, they should be IP67-rated, UV and fire-resistant with a typical operating temperature of - 40°C to +85°C. The contact resistance at the DC connectors should be minimal (typically less than 0.5 mΩ rated for at least 30 ADC (but not less than the short-circuit current expected through that connector with necessary safety factors) and 1,000 VDC.

Fig 5.2 MC 4 Connectors + ve and - ve terminals | Pronounce Solar

AC Cables carry the AC power of the PV system to the metering point, which is typically at the lower floors and hence has to be carefully chosen critically to ensure safety as well as minimize power loss. While copper or aluminum cables can be used, it is highly recommended to use armored cables. AC cabling practices are common in India, and suitable standards and certifications should be adhered to. As a common practice, AC wiring loss of a PV system should not exceed 2 percent.

5.3 Technical specifications for cables under the component of “CFA to residential consumers” of PM - Surya Ghar: Muft Bijli Yojana

1. All cables should conform to the latest edition of IEC/equivalent BIS Standards along with IEC 60227/IS 694, IEC 60502/IS 1554 standards.
2. Cables should be flexible and should have good resistance to heat, cold, water, oil, abrasion etc.
3. Armored cable should be used and overall PVC type ‘A’ pressure extruded insulation or XLPE insulation should be there for UV protection.
4. Cables should have Multi Strand, annealed high conductivity copper conductor on the DC side and copper / FRLS type Aluminum conductor on the AC side. For DC cabling, multi- core cables shall not be used.
5. Cables should have an operating temperature range of -10°C to +80°C and voltage rating of 660/1000 V.
6. Sizes of cables between array interconnections, array to junction boxes, junction boxes to Inverter etc. shall be so selected to keep the voltage drop less than 2% (DC Cable losses).
7. The size of each type of AC cable selected shall be based on minimum voltage drop. However; the maximum drop shall be limited to 2%.
8. The electric cables for DC systems for rated voltage of 1500 V shall conform to IS 17293:2020.
9. All cable/wires are to be routed in a RPVC pipe/ GI cable tray and suitably tagged and marked in a proper manner by good quality ferrule or by other means so that the cable is easily identified.
10. All cable trays, including covers, to be provided.
11. Thermo-plastic clamps to be used to clamp the cables and conduits, at intervals not exceeding 50 cm.
12. Size of neutral wire shall be equal to the size of phase wires, in a three phase system.

13. The cable should be so selected that it should be compatible up to the life of the solar PV panels i.e. 25 years.

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6 EARTHING AND LIGHTNING PROTECTION

6.1 Introduction

Earthing is the process of creating a low-resistance path for stray electrical currents to flow safely into the ground. The earth has a neutral electrical potential, so any unwanted charges can be safely dissipated into it without causing harm. Earthing (or grounding) in a rooftop solar PV system is critical for safety, system protection, and compliance with electrical standards. It ensures any fault current or lightning surge is safely directed to the ground, reducing the risk of electric shock, fire, or equipment damage.

Purpose of Earthing in Solar PV Systems:

- Safety of People : Prevents electric shock from leakage currents or faults.
- Protection of Equipment : Helps avoid damage from faults, surges, and lightning.
- Lightning Protection : Routes high voltage from lightning away from sensitive components.
- Electromagnetic Interference (EMI) Reduction :Stabilizes voltage levels and improves performance.

6.2 Earthing in rooftop PV system

In rooftop solar PV systems Earthing is required for the following :

1. ***DC Side Earthing :*** This specifically focuses on grounding the metallic frames and mounting structures of the solar panel array. It ensures that these large conductive surfaces are at earth potential, providing protection against faults and lightning strikes that might directly hit the array. The purpose is to ensure that if a fault occurs and these metallic parts become energized, they are safely brought to earth potential, preventing electric shock hazards.
2. ***AC Side Earthing :*** Earthing on the AC side ensures that any fault currents or surges on the AC wiring are safely conducted to the ground, protecting both people and equipment. It involves Earthing of inverter AC output, usually through the main distribution board (MDB). Components to be Earthed on the AC Side includes metal enclosures, conduits, and inverter casing.
3. ***Lightning and Surge Protection Earthing :*** Rooftop solar PV systems are exposed to lightning strikes and power surges. This type of earthing involves implementing

measures to safely dissipate these high-energy transients into the ground, protecting sensitive equipment like inverters and the solar panels themselves. This often includes:

- ***Lightning arresters (Lightning Rods)*** : These are installed to intercept lightning strikes and provide a preferred path to the ground. They have their own dedicated grounding conductors and earth electrodes. A separate earth pit connected to a lightning arrester is installed on the rooftop protecting against direct lightning strikes.
- ***Surge Protection Devices (SPDs)*** *:* These devices are installed on the AC and DC sides of the system to divert voltage spikes caused by lightning or other surges to the ground. Proper grounding of SPDs is crucial for their effective operation.

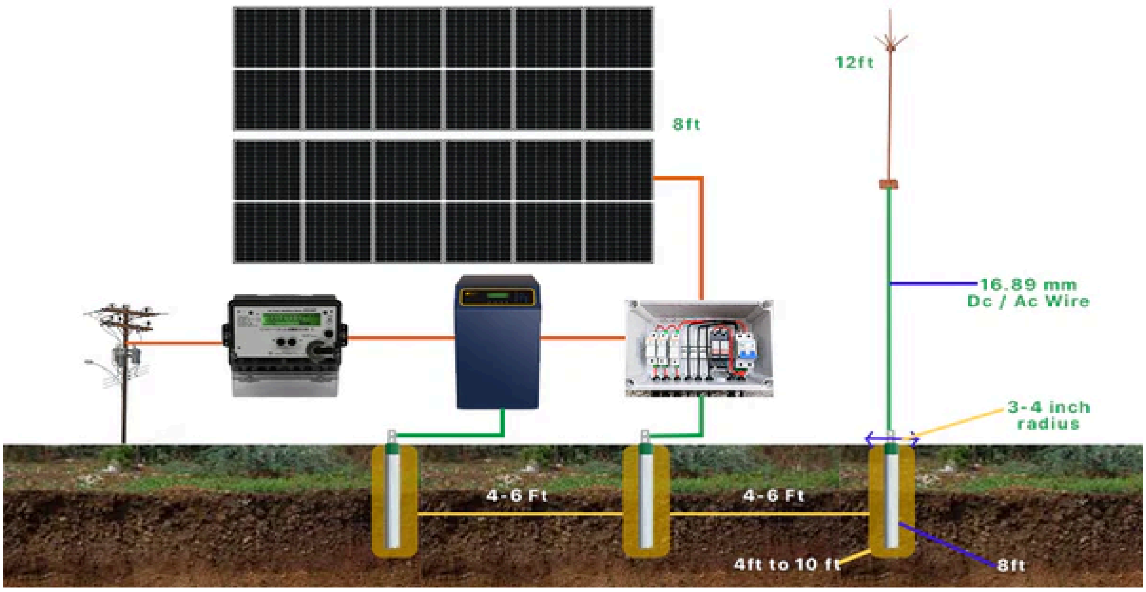

Fig 6.1 Earthing in Solar PV system | Loom Solar

The specific requirements and implementation details depend on local electrical codes, the type and size of the system, and site-specific conditions like soil resistivity and lightning exposure.

Components Used in Earthing:

- Earth electrodes (copper or GI rods)
- Earth pits (filled with salt, charcoal, or chemical compound for better conductivity)
- Earthing wires or strips (copper or galvanized iron)
- Earth bus bar in the system's combiner box or LT panel

For a rooftop solar PV system, three separate earthing pits are required:

- One for **DC Earthing** (solar panels, mounting structures, and DCDB
- One for **AC Earthing** (inverter and ACDB)
- One for the **Lightning Arrester**

6.3 Technical specifications for rooftop solar plants installed under the component of "CFA to residential consumers" of PM - Surya Ghar: Muft Bijli Yojana

The system should be provided with all necessary protections like earthing, lightning, and surge protection, as described below:

i) Earthing Protection

1. The earthing shall be done in accordance with latest Standards.
2. Each array structure of the PV yard, Low Tension (LT) power system, earthing grid for switchyard, all electrical equipment, inverter, all junction boxes, etc. shall be grounded properly as per IS 3043-2018.
3. All metal casing/ shielding of the plant shall be thoroughly grounded in accordance with CEA Safety Regulation 2010. In addition, the lightning arrester/masts should also be earthed inside the array field.
4. Earth resistance should be as low as possible and shall never be higher than 5 ohms.
5. For 10 KW and above systems, separate three earth pits shall be provided for individual three earthing viz.: DC side earthing, AC side earthing and lightning arrester earthing.

ii) Lightning Protection

1. The SPV power plants shall be provided with lightning & over voltage protection, if required. The main aim in this protection shall be to reduce the overvoltage to a tolerable value before it reaches the PV or other sub system components. The source of over voltage can be lightning, atmosphere disturbances etc. Lightning arresters shall not be installed on the mounting structure.

2. The entire space occupying the SPV array shall be suitably protected against lightning by deploying the required number of Lightning arresters (LAs). Lightning protection should be provided as per NFC17-102:2011/IEC 62305 standard.
3. The protection against induced high-voltages shall be provided by the use of Metal Oxide Varistors (MOVs)/Franklin Rod type LA/Early streamer type LA.
4. The current carrying cable from lightning arrester to the earth pit should have sufficient current carrying capacity according to IEC 62305. According to standard, the minimum requirement for a lightning protection system designed for class of LPS III is a 6 mm2 copper/ 16 mm2 aluminum or GI strip bearing size 25*3 mm thick). Separate pipe for running earth wires of Lightning arrester shall be used.

iii) Surge Protection : Internal surge protection, wherever required, shall be provided. It will consist of three SPD type-II/MOV type surge arresters connected from +ve and –ve terminals to earth.

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7 MODULE MOUNTING STRUCTURE

7.1 Rooftop Solar Module Mounting Structure (MMS)

For a solar PV system to produce the most electricity, it must be properly installed. The solar array must be installed in a shade free location and should be oriented so that it points directly to the true south (in the northern hemisphere). The panels should also be tilted at an angle that matches the latitude of project location for maximum energy production. Since the solar PV modules are built to last for 25 years, it is very important to choose the solar PV module mounting structure. MMS are designed keeping several structural considerations such as :

- Load (weight) of the PV system, load bearing capacity of the terrace, rooftop or the structure on which the PV system is mounted.
- Typical and maximum wind loads at that particular location factoring the height of the installation.
- Seismic zone safety factors and other considerations such as saline or corrosive environments.

7.2 Materials used for MMS

The MMS is typically made from one of the three materials, each with its own benefits.

(i) Galvanized iron :

The galvanized iron is the most commonly used mounting structure in the rooftop solar PV system. To protect rooftop solar mounting structures from rusting, a zinc coating is applied to the iron or steel frames through a process called galvanization. The most common method used is **hot-dip galvanization**, where the metal is dipped into molten zinc at around 449°C. This zinc layer forms a strong, dull grey surface when it reacts with the air, creating a protective shield called zinc carbonate. This shield prevents rust and ensures that the structure stays strong and durable for many years.

Hot Dip Galvanized iron is the most commonly used material for MMS in rooftop Solar PV systems.

(ii) Mild Steel

Mild Steel has very low carbon content ranging between 0.5% to 0.25% in weight. Mild steel is not used very often in case of solar PV module mounting. It is usually used in case of not so strong roofs, when there is a need for lightweight structures, or particularly elevated structures. It is very flexible and can be made into several shapes as it is machinable.

(iii) Aluminium

Aluminum is a lightweight, silvery-white metal that naturally resists rust and corrosion. It's softer and more flexible than steel, making it easier to install. Aluminum is cost-effective and a great option for areas with salty air (like near the coast) because it doesn't corrode easily. Its lightweight also makes it easier to install on roofs with limited load-bearing capacity.

7.3 Types of MMS

Based on the type of roof the MMS are broadly classified into two categories,

(i) Flat roof MMS

In a roof-mounted system on flat roofs, modules are mounted with the help of module mounting structure on top of the roofs. Modules are kept at a tilt angle using support structure. Method for securing mounts requires considerable attention as PV modules have a large area and wind forces must be taken into account. The ability of roof to handle the loads determines whether the system can be ballast mounted or must be fixed with respect to the roof (anchoring)

a) Ballast mounted : In ballast-mounted systems, the MMS is held in place using heavy weights (like concrete blocks or slabs) instead of drilling into the roof. This method avoids damaging the roof's waterproofing. The concrete weights are placed on the roof, and the MMS is attached to them with screws. To protect the roof from sharp edges, a soft mat is often placed under the weights. This system is simple and works well for strong roofs. Alternatively, the concrete weights can be inserted in channels on the support frame.

b) Anchored systems : If the roof can't support a ballast system, the MMS is anchored directly to the roof or its walls. This involves drilling holes and securing the MMS with bolts. To prevent leaks, the holes are carefully sealed. Engineers try to use as few holes as possible to minimize damage. Anchored systems are common when renovating flat roofs, as the sealing can be done during the renovation process.

Fig 7.1 Rooftop Solar MMS for RCC roof : Ballast mounted and Anchored system | GRENGY SOLAR

Fig 7.2 Elevated Mounting structures | RK Solar Energy

(ii) Sloped roof MMS

The modules are fitted above the existing roof covering using a metal substructure. The metal structure to support the module consists of three main components : Roof mounts, mounting rails and module fixings. Using the roof mounts, a rail system is anchored to the roof structure beneath the roof covering or is fixed directly to the roof cover itself (but only if the roof covering is structurally strong enough). The modules are fixed to the rails with system specific fixing elements. The MMS is designed to keep the panels slightly above the roof to allow air circulation, which helps cool the panels and improve their efficiency.

Fig 7.3 Rooftop solar MMS for sloped roof structures | Maysun solar

7.4 Technical specifications for Module Mounting Structure (MMS) installed under PM - Surya Ghar: Muft Bijli Yojana

1. Supply, installation, erection and acceptance of module mounting structure (MMS) with all necessary accessories, auxiliaries and spare parts shall be in the scope of the work.
2. Module mounting structures can be made from three types of materials. They are Hot Dip Galvanized Iron, Aluminium and Hot Dip Galvanized Mild Steel (MS). However, MS will be preferred for raised structure.
3. MMS Steel shall be as per latest IS 2062:2011 and galvanization of the mounting structure shall be in compliance with latest IS 4759. MMS Aluminium shall be as per AA6063 T6. For Aluminium structures, necessary protection towards rusting needs to be provided either by coating or anodization.
4. All bolts, nuts, fasteners shall be of stainless steel of grade SS 304 or hot dip galvanized, panel mounting clamps shall be of aluminium and must sustain the adverse climatic conditions. Structural material shall be corrosion resistant and electrolytically compatible with the materials used in the module frame, its fasteners, nuts and bolts.
5. The module mounting structures should have angle of inclination as per the site conditions to take maximum insolation and complete shadow-free operation during generation hours. However, to accommodate more capacity the angle of inclination may be reduced until the plant meets the specified performance ratio requirements.
6. The mounting structure shall be so designed to withstand the speed for the wind zone of the location where a PV system is proposed to be installed. The PV array structure design shall be appropriate with a factor of safety of minimum 1.5.

7. The upper edge of the module must be covered with a windshield so as to avoid build air ingress below the module. Slight clearance must be provided on both edges (upper & lower) to allow air for cooling.
8. Suitable fastening arrangements such as grouting and calming should be provided to secure the installation against the specific wind speed. The Empanelled Agency shall be fully responsible for any damages to SPV System caused due to high wind velocity within the guarantee period as per technical specification.
9. The structures shall be designed to allow easy replacement, repairing and cleaning of any module. The array structure shall be so designed that it will occupy minimum space without sacrificing the output from the SPV panels. Necessary testing provision for MMS to be made available at site.
10. Adequate spacing shall be provided between two panel frames and rows of panels to facilitate personnel protection, ease of installation, replacement, cleaning of panels and electrical maintenance.
11. The structure shall be designed to withstand operating environmental conditions for a period of minimum 25 years.
12. The rooftop structures may be classified in three broad categories as follows:

i. Ballast structure

a. The mounting structure must be non-invasive ballast type and any sort of penetration of the roof to be avoided.
b. The minimum clearance of the structure from the roof level should be in between 70-150 mm to allow ventilation for cooling, also ease of cleaning and maintenance of panels as well as cleaning of terrace.
c. The structures should be suitably loaded with reinforced concrete blocks of appropriate weight made out of M25 concrete mixture.

ii. Tin shed

a. The structure design should be as per the slope of the tin shed.
b. The inclination angle of structure can be done in two ways-
    i. Parallel to the tin shed (flat keeping zero-degree tiling angle), if the slope of shed is in proper south direction
    ii. With the same tilt angle based on the slope of tin shed to get the maximum output.
c. The minimum clearance of the lowest point from the tin shade should be more than 100mm.

d. The base of the structure should be connected on the purlin of the tin shed with the proper riveting.
e. All structure member should be of minimum 2 mm thickness.

iii. RCC Elevated structure: It can be divided into further three categories:

- ***Minimum clearance from roof (upto 1000 mm) (for reference only)***
  a. The structure shall be designed to allow easy replacement of any module and shall be in line with site requirement. The gap between module should be minimum of 30mm.
  b. Base Plate – Base plate thickness of the structure should be 5mm for this segment.
  c. Column – Structure of the column should be a minimum 2mm in the lip section / 3mm in C-Channel section. The minimum section should be 70mm in web side and 40 mm in flange side in lip section.
  d. Rafter - Structure rafter should be a minimum 2mm in lip section / 3mm in C-Channel section. The minimum section should be 70mm in Web side (y- axis) and 40 mm in flange side (x-axis).
  e. Purlin - Structure purlin should be a minimum 2mm in the lip section. The minimum section should be 60mm in Web side and 40mm in flange side in lip section.
  f. Front/back bracing – The section for bracing part should be minimum 2mm thickness.
  g. Connection – The structure connection should be bolted completely. Leg to rafter should be connected with a minimum 12 diameter bolt. Rafter and purlin should be connected with a minimum 10 diameter bolt. Module mounting fasteners should be SS-304 only and remaining fasteners either SS-304 or HDG 8.8 Grade.
  h. For single portrait structure the minimum ground clearance should be 500mm.

- ***Medium clearance from roof (1000mm – 2000 mm) (for reference only)***
  a. Base Plate – Base plate thickness of the structure should be Minimum 6mm for this segment.
  b. Column – Structure of column should be a minimum 2mm in the lip section / 3mm in C-Channel section. The minimum section should be 80mm in Web side and 50mm in flange side in lip section.
  c. Rafter - Structure rafter should be minimum 2mm in Lip section / 3mm in C-Channel section. The minimum section should be 70mm in Web side and 40mm in flange side in lip section.
  d. Purlin - Structure purlin should be minimum 2mm in the Lip section. The minimum section should be 70mm in Web side and 40mm in flange side in Lip section.
  e. Front/back bracing – The section for bracing part should be minimum 2mm thickness.

f. Connection – The structure connection should be bolted completely. Leg to rafter should be connected with a minimum 12 diameter bolt. Rafter and purlin should be connected with a minimum 10 diameter bolt. Module mounting fasteners should be SS-304 only and remaining fasteners either SS-304 or HDG 8.8 Grade.

- ***Maximum clearance from roof (2000mm – 3000 mm) (for reference only)***

a. Base Plate – Base plate thickness of the structure should be minimum 8 mm for this segment.
b. Column – Structure column thickness should be minimum 2.6mm in square hollow section (minimum 50x50) or rectangular hollow section (minimum 60x40) or 3mm in C-Channel section.
c. Rafter - Structure rafter should be minimum 2mm in Lip section / 3mm in Channel section. The minimum section should be 80mm in Web side and 50mm in flange side in Lip section.
d. Purlin - Structure purlin should be minimum 2mm in lip section. The minimum section should be 80 mm in web side and 50mm in flange side in lip section.
e. Front/back bracing – The section for bracing part should be minimum 3mm thickness.
f. Connection – The structure connection should be bolted completely. Leg to rafter should be connected with a minimum 12 diameter bolt. Rafter and purlin should be connected with a minimum 10 diameter bolt. Module mounting fasteners should be SS-304 only and remaining fasteners either SS-304 or HDG 8.8 Grade.

- ***Super elevated structure (More than 3000 mm clearance from roof) (for reference only)***

A. Base structure
   a. Base Plate – Base plate thickness of the structure should be 10mm for this segment.
   b. Column – Structure column minimum thickness should be minimum 2.9mm in square hollow section (minimum 60x60) or rectangular hollow section (minimum 80x40).
   c. Rafter - Rafter’s minimum thickness should be minimum 2.9mm in square hollow section (minimum 60x60) or rectangular hollow section (minimum 80x40).
   d. Cross bracing – Bracing for the connection of rafter and column should be of minimum thickness of 4mm L-angle with the help of minimum bolt diameter of 10mm.

B. Upper structure of super elevated structure

a. Base Plate – Base plate thickness of the Structure should be minimum 5mm for this segment.
b. Column – Structure Column should be minimum 2mm in Lip section / 3mm in Channel section. The minimum section should be 70mm in Web side and 40mm in flange side in Lip section.
c. Rafter - Structure rafter should be minimum 2mm in Lip section / 3mm in Channel section. The minimum section should be 70mm in Web side and 40mm in flange side in Lip section.
d. Purlin - Structure purlin should be minimum 2mm in Lip section. The minimum section should be 60mm in Web side and 40mm in flange side in Lip section.
e. Front/back bracing – The section for bracing part should be minimum 2mm thickness.
f. Connection – The structure connection should be bolted completely. Leg to rafter should be connected with minimum 12 diameter bolt. Rafter and
g. Purlin should be connected with minimum 10 diameter bolt. Module mounting fasteners should be SS-304 only and remaining fasteners either SS-304 or HDG 8.8 Grade.

C. If distance between two legs in X-Direction is more than 3M than sag angle/Bar should be provide for purlin to avoid deflection failure. The sag angle should be minimum 2mm thick, and bar should be minimum 12 Dia.
D. Degree - The Module alignment and tilt angle shell be calculated to provide the maximum annual energy output. This shall be decided on the location of array installation.
E. Foundation – Foundation should be as per the roof condition; two types of the foundation can be done- either penetrating the roof or without penetrating the roof.
    a. If penetration on the roof is allowed (based on the client requirement) then minimum 12mm diameter anchor fasteners with minimum length 100mm can be used with proper chipping. The minimum RCC size should be 400x400x300 cubic mm. Material grade of foundation should be minimum M20.
    b. If penetration on roof is not allowed, then foundation can be done with the help of ‘J Bolt’ (refer IS 5624 for foundation hardware). Proper Neto bond solution should be used to adhere the foundation block with the RCC roof. Foundation J - bolt length should be minimum 12mm diameter and length should be minimum 300mm.
F. Material standards:

a. Design of foundation for mounting the structure should be as per defined standards which clearly states the Load Bearing Capacity & other relevant parameters for foundation design (As per IS 6403 / 456 / 4091 / 875).
b. Grade of raw material to be used for mounting the structures so that it complies the defined wind loading conditions (As per IS 875 - III) should be referred as follows (IS 2062 – for angles and channels, IS 1079 – for sheet, IS 1161 & 1239 for round pipes, IS 4923 for rectangular and square hollow section)
c. Test reports for the raw material should be as per IS 1852 / 808 / 2062 / 1079 / 811.
d. In process inspection report as per approved drawing & tolerance should be as per IS 7215.
e. For ascertaining proper welding of structure part following should be referred:
f. D.P. Test (Pin Hole / Crack) (IS 822)
g. Weld wire grade should be of grade (ER 70 S - 6)
h. For ascertaining hot dip galvanizing of fabricated structure following should be referred:-
i. Min coating required should be as per IS 4759 & EN 1461.
j. Testing of galvanized material
    - Pierce Test (IS 2633)
    - Mass of Zinc (IS 6745)
    - Adhesion Test (IS 2629)
    - CuSO4 Test (IS 2633)
    - Superior High-Grade Zinc Ingot should be of 99.999% purity (IS 209) (Preferably Hindustan Zinc Limited or Equivalent).
k. Foundation Hardware – If using foundation bolt in foundation then it should be as per IS 5624.

References :

1. Ulaginoli Energy Solutions. (April 10, 2019). An introduction to solar PV module mounting structures. https://www.ulaginoli.com/solar-energy/an-introduction-to-solar-pv-module-mounting-structures/ (Accessed on 8th May, 2025).
2. Government of India. (2024). Guidelines for PM-Surya Ghar: Muft Bijli Yojana. https://pmsuryaghar.gov.in/assets/files/1.%20CFA%20to%20Residential%20Consumers.pdf (Accessed on 8th May, 2025).

8 METERS FOR SOLAR PV SYSTEM

8.1 Introduction

- In a grid-connected rooftop solar PV system, electricity flows in two directions:
    - During daylight hours, surplus solar energy is exported to the utility grid.
    - During night time or cloudy periods, electricity is imported from the grid.
- Traditional residential energy meters are unidirectional, capable of recording only the energy imported from the grid. To enable rooftop solar systems to function properly within a grid-connected framework, specialized bidirectional meters commonly known as net meters are required. These meters can record both imported and exported energy, allowing for accurate billing based on net usage.
- Additionally, a solar energy generation meter is installed to monitor the total electricity produced by the solar PV system, which assists consumers in tracking system performance.
- Proper metering is not just important for billing; it is mandatory to avail government subsidies such as those offered under the PM Surya Ghar: Muft Bijli Yojana.
- In many newly constructed homes, DISCOMs are now installing bidirectional meters by default, even without a solar PV system. In such cases, consumers may simply need to have their existing meters reconfigured and calibrated, without requiring a new meter installation.

If your home already has a bidirectional meter installed by DISCOM, check if simple reconfiguration is enough. You may not need to purchase a new meter.

8.2 Types of Meters in a Solar PV System

- **Net (Bidirectional) Meter:**
  Measures both electricity imported from the grid and exported to the grid. Net consumption is used for billing.

- **Solar Energy Generation Meter:**
  Tracks the total energy produced by the solar PV system, regardless of how much is consumed or exported. It helps consumers monitor system performance over time.

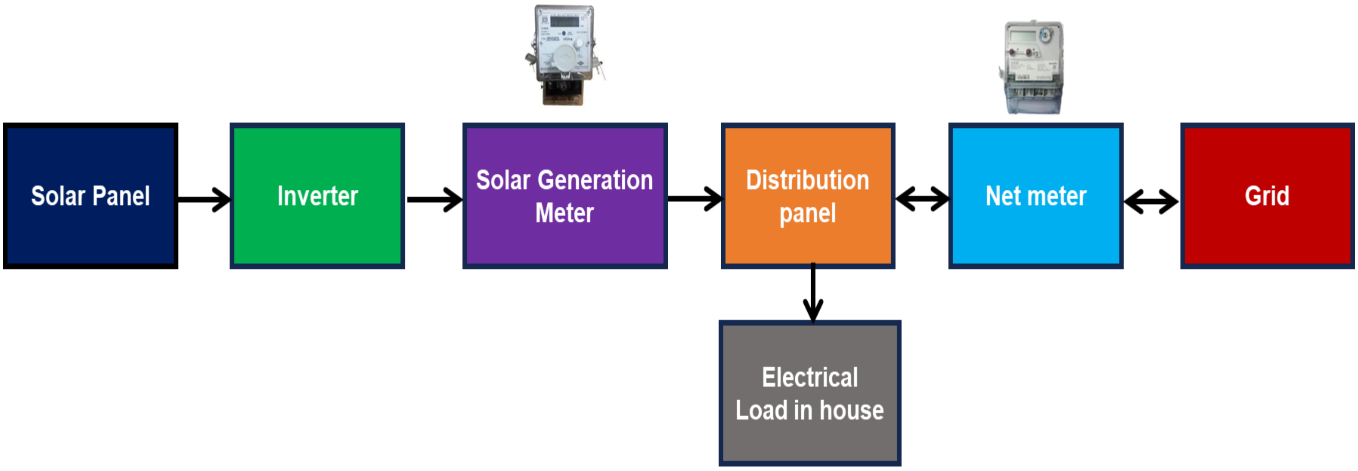

Fig 8.1 Meters used in Solar PV system | CAG

8.3 Net Metering Mechanism

Net metering is a billing mechanism that allows owners of solar photovoltaic (PV) systems (and sometimes other small-scale renewable energy systems like wind) to receive credit for the excess electricity sent back to the utility grid. The basic principle behind working of net metering mechanism is -

- Electricity Generation: Solar panels generate electricity during daylight hours.
- Self-Consumption: This electricity is used to power home or business.
- Excess Generation: If the solar PV system produces more electricity than needed, the surplus is automatically fed back into the utility grid.
- Bi-directional Meter: A special meter, called a bi-directional meter or net meter, tracks the flow of electricity in both directions: electricity consumed from the grid, electricity sent back to the grid.
- Crediting: For the excess electricity sent to the grid, credits on the electricity bill is received. These credits can then offset the cost of electricity drawn from the grid at times when solar panels are not producing enough (e.g., at night or during cloudy days).
- Net Billing: At the end of the billing cycle, the utility calculates "net" energy usage. This is the difference between the electricity consumed and the electricity exported. The customer is then billed (or credited) for this net amount.

For example,

- A house has installed a 1 kW rooftop solar PV system.
- It is generating 300 units of electricity from solar in 2 months.
- The house consumes 200 units out of the 300 units generated and sends 100 units to the grid.
- The house is consuming 300 units of electricity from the grid bi-monthly during non sunshine hours.
- Consumers pay only for 200 units [Import (300) – export (100)] off setting their electricity bill.

Billing Scenarios:

- **Net Importer:** If the imported units exceed the exported units during a billing cycle, the consumer is billed for the net balance of energy consumed.
- **Net Exporter:** If the exported units exceed the imported units during a billing cycle, the surplus units are typically carried forward to offset consumption in subsequent billing cycles. However, any unused surplus remaining at the end of the financial year (March 31st) will lapse and cannot be carried over further.

8.4 Key Benefits of Net Metering

- Grid as a Virtual Battery: Net metering essentially allows the use of the public grid as a virtual storage system for excess solar energy, eliminating or reducing the need for expensive batteries.
- Bill Reduction: The primary benefit for solar owners is a significant reduction in their electricity bills. In some cases, if generated energy is more than the electricity consumed over a billing period, excess energy will be carried over to future bills.
- Encourages Renewable Energy: Net metering is a key policy that incentivizes the adoption of solar energy by making it more financially attractive.
- Grid Stability: By allowing distributed generation of electricity, net metering can help reduce strain on the central grid, especially during peak demand periods.

8.5 Net Metering Policies and State Regulations

Net metering policies and regulations can vary significantly across different states and utility companies in India. Each state electricity regulatory commission defines specific eligibility criteria, technical standards, billing and settlement procedures for excess generation and application procedures for connecting rooftop solar PV systems to the grid under a net metering program. A bidirectional (net) meter is mandatory for participation in net metering programs, and there are usually associated costs for procurement, installation, configuration, and certification of these meters. Additionally, some states impose limits on the maximum capacity of rooftop solar systems eligible for net metering, and the treatment of surplus energy at the end of billing cycles or financial years can also differ.

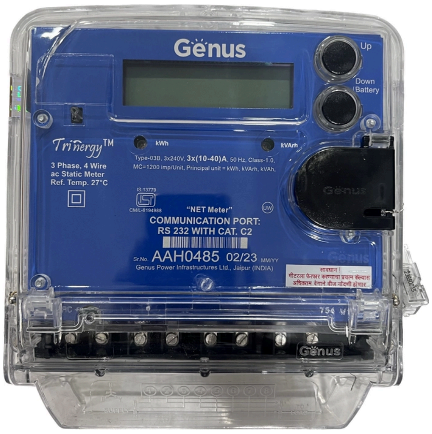

Fig 8.2 Net meter | [Genus power]

Net metering in Tamil Nadu

- In Tamil Nadu, the **Tamil Nadu Electricity Regulatory Commission (TNERC)** governs net metering policies. TNERC has defined net metering as:

  "A mechanism whereby solar energy exported to the grid from a grid-interactive rooftop solar photovoltaic (PV) system of a prosumer is deducted from the energy imported from the grid (in units, kWh) to calculate the net imported or exported energy. This net energy is either billed, credited, or carried over by the distribution licensee based on the applicable retail tariff, using a single bidirectional energy meter installed at the point of supply."

- In Tamil Nadu Net metering is available exclusively only to the following consumer categories:
  - **LA1A:** Domestic residential consumers.
  - **LA1D:** Common service connections in apartment complexes and gated housing societies.
- For all other consumer categories, **net metering is not applicable**. Instead, a different model called the **Net Feed-in Billing Mechanism** is followed, where exported energy is compensated separately at a predefined feed-in tariff.

- Consumers planning to install rooftop solar systems should refer to the latest TNERC regulations and tariff orders to understand detailed eligibility criteria, compensation structures, and procedural requirements before proceeding with installation.

In Tamil Nadu, Net Metering solar energy billing mechanism is applicable only for LA1A (Domestic) and LA1D (Common Service connection) consumer categories

8.6 Technical Specifications for Net meters under the "CFA for Residential Consumers" Component of PM Surya Ghar: Muft Bijli Yojana

1. The specifications net meter/smart meter shall be as per the latest technical specifications issued by the Central Electricity Authority (CEA) and its amendment thereof.

2. A Roof Top Solar (RTS) Photo Voltaic (PV) system shall consist of following energy meters:

    a) Net meter/ smart meter: To record import and export units.

    b) Generation meter (if required as per the state regulations: To keep record for total generation of the plant.

3. The installation of meters including CTs (Current Transformers) & PTs (Potential transformers), wherever applicable, shall be carried out by the respective DisComs as per the terms, conditions and procedures laid down by the concerned SERCs / DISCOMs.

References

1. Tamil Nadu Electricity Regulatory Commission. (2021). Generic Tariff Order for Grid Interactive PV Solar Energy Generating System (GISS). https://www.tnerc.tn.gov.in/Orders/files/TO-Order%20No%20251020211341.pdf (Accessed on 8th May, 2025).
2. Government of India. (2024). Guidelines for PM-Surya Ghar: Muft Bijli Yojana. https://pmsuryaghar.gov.in/assets/files/1.%20CFA%20to%20Residential%20Consumers.pdf (Accessed on 8th May, 2025).

9 MAINTENANCE OF SOLAR PV SYSTEM

9.1 PV module maintenance

Performance of a PV system is highly affected when solar modules are not kept clean. Energy generation of a PV system can go up by 20% or more if modules are cleaned regularly. It is recommended that the modules are inspected on a weekly basis and as and when required should be cleaned from dust and bird dropping etc. Areas that are generally dusty and polluted would require more frequent inspections and cleaning.

9.1.1 How to clean PV modules?

- Inspect the site prior cleaning work is performed. Note for any hazardous conditions and danger.
- Cover all electrical equipment, i.e. inverters and combiner boxes, beneath the area to be cleaned with covers prior to cleaning.
- Inspect the surface of solar modules prior to cleaning. All accumulated dirt is to be removed from the module surface.
- Use ladder whenever required to reach surface of solar modules to be cleaned
- Use a wiper with a sponge or brush to clean modules. Use clean water at minimal pressure. No chemicals or abrasive cleaning shall be applied to clean solar modules.
- Use of hard water for a long time will damage the modules by forming a coating on the modules. Avoid using water with hardness more than 200 ppm.
- It is advisable to condition the module cleaning water through water softener prior to application. This will minimize mineral deposit on the module.
- If dirt like bird droppings cannot be removed easily, use a brush with soft bristle to remove such dirt.
- Perform cleaning in the early morning or wait until evening, to avoid thermal shock to glass.
- Perform washing only when modules are not in direct sunlight, when the sun is positioned below the horizon.
- Inspect arrays for broken modules at least once in a year.

For cleaning solar panels it is recommended not to use chemicals and hard water with hardness more than 200 ppm

- Conduit and connections must all be tight and undamaged. Look for loose, broken, corroded, vandalised and otherwise damaged components. Check close to the ground for animal damage.

9.2 Maintenance of Inverter

- Remove dust or dirt. Check all inverter wiring for loose, broken, corroded or burnt connections or wires.
- Look for potential accidental short circuits or ground faults.
- Check if any object blocks inverter room ventilation and restricts free airflow for natural cooling of inverter. Remove such obstruction or objects.

9.3 Maintenance of Cables, Connectors and Switches

- Visually check all conduits and wire insulation for damage.
- Make sure all wiring is secured, by gently but firmly pulling on all connections.
- Check for working conditions of fuse, surge protection device, MCB switches, circuit breakers.

Table 9.1 Sample Maintenance schedule for Rooftop Solar PV system

Sl	Maintenance work	Frequency
1	Ensure security of the power plant	Daily
2	Inspect and clean the PV modules from dust and other dirt like bird's dropping etc., as and when required	Weekly
3	Monitor power generation and export	Daily (Remotely)
4	Keep the inverters clean to minimize the possibility of dust ingress	Quarterly
5	Ensuring all electrical connections are kept clean and tight	Half-yearly
6	Check mechanical integrity of the array structure	Annually
7	Check all cabling for mechanical damage	Annually
8	Check output voltage and current of each string of the array and compare to the expected output under the existing conditions	Annually
9	Check the operation of the PV array DC isolator	Annually

Reference

1. Solar PV Installer (Suryamithra) Participant Handbook.
https://pmsuryaghar.gov.in/assets/files/5_NISE_Solar_PV_Installer_Suryamitra_English.pdf
(Accessed on 8th May, 2025).

10 ELECTRICAL SAFETY IN SOLAR PV SYSTEMS

Electrical safety is paramount in solar PV systems due to high voltage direct current electricity generated by the solar PV systems. Adhering to electrical safety practices ensures operational safety and the longevity of the PV system. Here are key considerations and practices to ensure electrical safety in solar installations :

10.1 Design and Planning

- Permits and Codes : Design the PV system in compliance with local electrical codes, National Electrical Code (NEC) and other relevant standards.
- Regulatory Compliance : Obtain necessary approvals for solar installations.
- Clearance : Ensure adequate clearance around electrical equipment to facilitate safe operation and maintenance.
- Labeling : Clearly label all electrical components, including inverters, disconnect switches and circuit breakers to facilitate safe identification and operation.

10.2 Installation Practices

- Qualified Personnel : Ensure that vendors employ and train qualified personnel for the installation and wiring of the solar PV system.
- Safe work : Ensure that vendors have implemented safe work practices, including proper use of personal protective equipment (PPE) such as gloves, safety glasses and arc flash protection.

10.3 Electrical Components

- Inverters : Ensure inverters are installed in well-ventilated areas and are accessible for maintenance and troubleshooting. Follow manufacturer’s instructions for installation.
- Disconnection Switches : Ensure whether the vendor installs disconnect switches that can isolate both AC and DC sides of the PV system to safely de-energize during maintenance or emergencies.
- Grounding and Bonding : Implement proper grounding and bonding techniques to prevent electrical faults and ensure equipment safety. This includes grounding of metal frames and mounting systems.

- Protection Devices : Proper rated protection devices viz, fuse, surge protection device, MCB switches are used in the installations.

10.4 DC wiring and conduit

- Conduit use : Use conduit to protect and route DC wiring safely, especially when running wires through walls or exposed areas.
- Voltage Ratings : Use cables, connectors and junction boxes rated for DC voltages present in the PV system to prevent overheating and potential fire hazards.
- Cable Management : Securely fasten and manage cables to prevent damage or accidental contact with sharp objects or moving parts.

10.5 Maintenance and Inspection

- Regular Inspections : Conduct regular inspections of the PV system, including electrical components and connections, to detect signs of wear, corrosion or damage.
- Cleaning : Safely clean solar panels and electrical components using appropriate methods and materials to maintain optimal performance and safety.
- Testing : Perform periodic testing of electrical systems and components to ensure proper functioning and adherence to perform standards.

10.6 Documentation

Records : Maintain detailed records of system design, installation, maintenance, inspections, and training sessions for compliance and reference purposes.

Reference

1. National Institute for Entrepreneurship & Small Business Development (NIESBUD). PM Surya Ghar Muft Bijili Yojna Handbook https://www.niesbud.nic.in/docs/2024-25/Reports/ESDP-on-Solar-Entrepreneurship-PM-Surya-Ghar-Muft-Bijli-Yojana.pdf (Accessed on 8th May, 2025).

11 MONITORING OF SOLAR PV SYSTEM

11.1. Importance of Rooftop SPV Monitoring System

Regular monitoring of a rooftop solar photovoltaic (PV) system is essential to ensure its sustained performance and reliability. Monitoring allows consumers to track the system's energy output, detect performance anomalies, and take timely corrective actions in case of faults. It also provides transparency on energy savings, helping users evaluate the return on their investment. For systems designed to operate for 25 years or more, consistent monitoring plays a critical role in ensuring long-term efficiency.

11.2. Monitoring Technologies and Tools

- Modern solar inverters, both single-phase and three-phase, are typically equipped with built-in communication features that enable real-time monitoring. These inverters can be connected to the internet through Wi-Fi, Ethernet, or SIM-based modules. Once connected, system data is transmitted to a cloud-based platform, which can be accessed through mobile applications or web portals.
- Reputed inverter manufacturers offer user-friendly apps that allow consumers to monitor key performance metrics such as daily energy generation, cumulative production, grid interaction, and inverter status. Additionally, the inverter itself often includes an LCD or LED display showing basic operational parameters such as voltage, current, and real-time power output.
- The most commonly monitored indicators in a rooftop PV system include daily, monthly, and lifetime energy generation (in kWh), instantaneous AC power output (in kW), inverter status (on, standby, or fault), grid voltage and frequency, and energy exported to the grid where applicable. Some systems also provide environmental indicators such as carbon dioxide (CO_2) offset and temperature data.

11.3. Monitoring Best Practices

- It is recommended that users monitor their system at least once daily through the mobile application or inverter display to confirm normal operation. A 1 kW rooftop system typically generates 4 to 5 units of electricity on a clear sunny day. Any significant deviation from this expected output, especially during favorable conditions, may indicate a fault in the system or an issue with the grid connection. In such cases, users are advised to contact their installer or service provider immediately for inspection and corrective action.

11.4. Performance Tracking and Troubleshooting

- For grid-connected PV systems, it is important to understand that the inverter is designed to shut down automatically in the event of a grid outage, a function known as anti-islanding protection. This means that even on a bright sunny day, the system will not operate if the grid is unavailable.
- In the case of three-phase inverters, an additional factor must be considered. If any one of the three phases in the grid supply fails, the inverter will cease operation entirely, even if the remaining two phases are functioning. Furthermore, if the grid voltage exceeds or falls below the inverter's operational limits, the system may temporarily shut down to prevent damage. These are standard safety features and should not be mistaken for system faults.
- Monitoring systems are designed to flag abnormal conditions such as low generation, inverter shutdowns, or communication failures. In advanced systems, automatic alerts via email or push notifications inform the user about such issues. If the mobile application fails to display data, it may be due to communication issues rather than inverter faults. Consumers are encouraged to verify Wi-Fi connectivity or SIM signal strength in such cases.
- By reviewing weekly and monthly trends, consumers can assess seasonal variations and identify gradual declines in performance, which may suggest soiling, shading, or component degradation. Keeping a record of energy production also facilitates more accurate forecasting and system planning, especially in systems equipped with net metering or net feed-in mechanisms.

CONSUMER FOCUS

On a normal sunny day **1 kW** solar PV system can produce **4 to 5 units** of electricity per day.

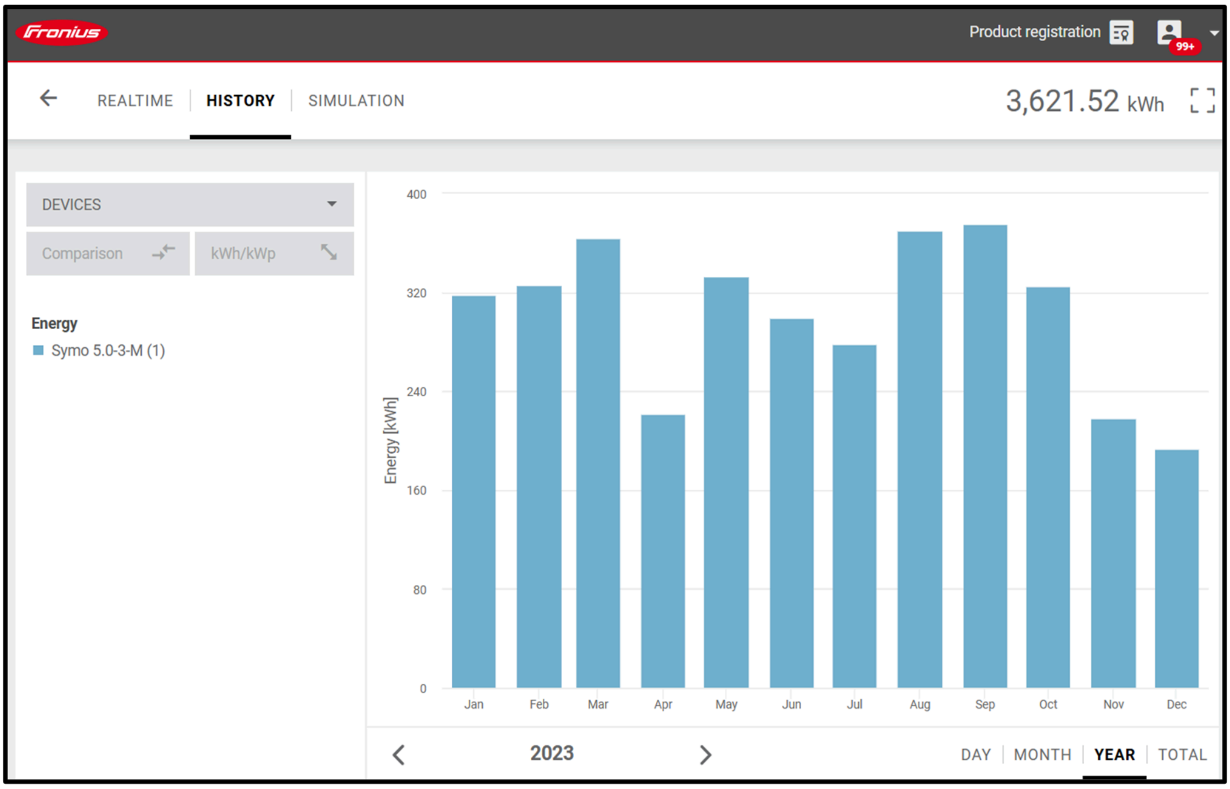

Fig 11.1 Monitoring system showing annual yield of solar PV system | Fronius

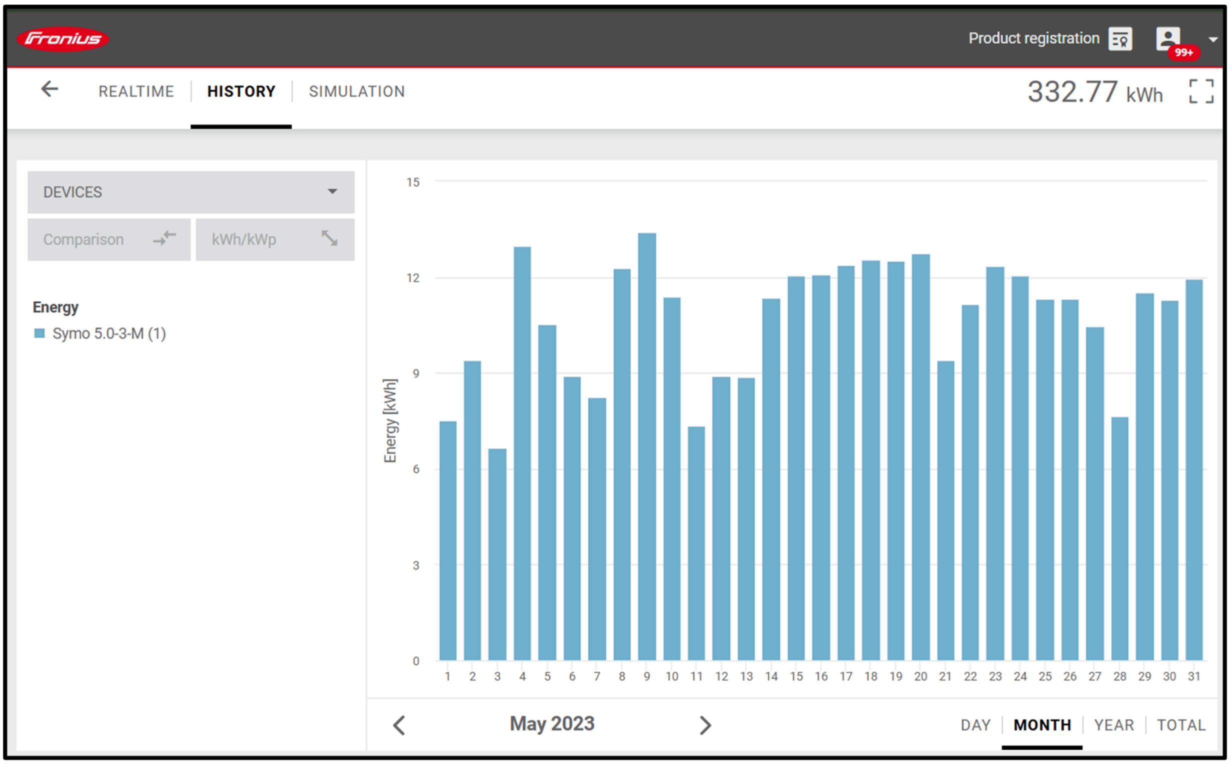

Fig 11.2 Monitoring system showing monthly yield of a rooftop solar PV system | Fronius

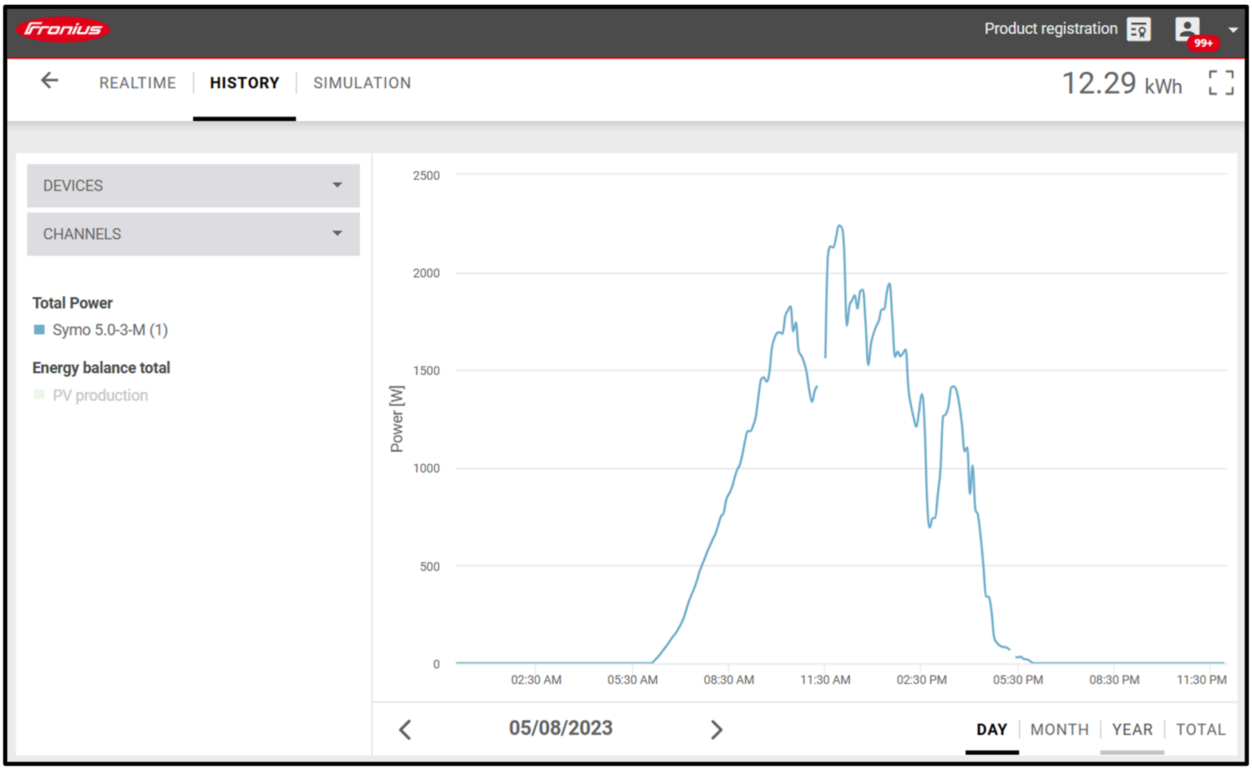

Fig 11.3 Monitoring system showing hourly yield of a solar PV system | Fronius

11.5 Understanding Performance Losses

Even when a rooftop solar PV system is installed correctly and appears to be functioning well, several environmental and technical factors can impact energy output. By understanding these potential sources of performance loss, consumers can better interpret monitoring data and take informed steps in maintenance or servicing.

Table 11.1: Loss factors that can reduce energy generation in rooftop solar PV systems

Sn	Loss	Description
1	Air pollution	The solar resource can be reduced significantly in some locations due to air pollution from industry and agriculture.
2	Shading	Due to mountains or buildings on the far horizon, mutual shading between rows of modules and near shading due to trees, buildings or overhead cabling
3	Incident angle	The incidence angle loss accounts for radiation reflected from the front glass when the light striking it is not perpendicular. For tilted PV modules, these losses may be expected to be larger than the losses experienced with dual axis tracking systems.
4	Low irradiance	The conversion efficiency of a PV module generally reduces at low light intensities. This causes a loss in the output of a module

		compared with the standard conditions at which the modules are tested (1000 W/m^2). This 'low irradiance loss' depends on the characteristics of the module and the intensity of the incident radiation.
5	Module temperature	The characteristics of a PV module are determined at standard temperature conditions of 25°C. For every degree rise in temperature above this standard, crystalline silicon modules reduce in efficiency, generally by around 0.5%. In high ambient temperatures under strong irradiance, module temperatures can rise appreciably. Wind can provide some cooling effect which can be also be modelled.
6	Soiling	Losses due to soiling (dust and bird droppings) depend on the environmental conditions, rainfall frequency and on the cleaning strategy as defined in the O&M contract. This loss can be relatively large compared to other loss factors but is usually less than 4%, unless there is unusually high soiling for long periods of time. The soiling loss may be expected to be lower for modules at a high tilt angle as inclined modules will benefit more from the natural cleaning effect of rainwater.
7	Module quality	Most PV modules do not match exactly the manufacturers nominal specifications. Modules are sold with a nominal peak power and a guarantee of actual power within a given tolerance range. The model quality loss quantifies the impact on the energy yield due to divergences in actual module characteristics from the specifications.
8	Module mismatch	Losses due to "mismatch" are related to the fact that the modules in a string do not all present exactly the same current / voltage profiles; there is a statistical variation between them which gives rise to a power loss.
9	DC cable resistance	Electrical resistance in the cable between the modules and the input terminals of the inverter give rise to ohmic loss (FR). This loss increases with temperature. If the cable is correctly sized this loss should be less than 3% annually.
10	Inverter performance	Inverters convert from DC into AC with an efficiency that varies with inverter load
11	AC losses	This include transformer performance and ohmic losses in the cable leading to the substation
12	Downtime	Downtime is a period when the plant does not generate due to failure. The downtime periods will depend on the quality of the plant components, design, environmental conditions, diagnostic response time and the repair response time.
13	Grid availability and disruptions	The ability of a PV power plant to export power is dependent on the availability of the distribution or transmission network. Typically, the owner of the PV power plant will not own the distribution network. He therefore relies on the distribution network operator to maintain service at high levels of availability. Unless detailed information is available, this loss is typically based on an assumption that the local

		grid will not be operational for a given number of hours / days in any one year and that it will occur during periods of average production.
14	Degradation	The performance of a PV module decreases with time. If no independent testing has been conducted on the modules being used, then a generic degradation rate depending on the module technology may be assumed. Alternatively, a maximum degradation rate that conforms to the module performance warranty may be considered.

References

1. International Finance Corporation. (Feb 2012). Utility Scale Solar Power Plants - A Guide For Developers and Investors. https://documents1.worldbank.org/curated/en/868031468161086726/pdf/667620WP00PUBL005B0SOLAR0GUIDE0BOOK.pdf (Accessed on 8th May, 2025).

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