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Partnership to Advance Clean Energy – Deployment (PACE-D)
Technical Assistance Program

Solar PV Rooftop Training Program - Handbook for Utility Engineers

Learners Manual

May 2017

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List of Acronyms

Acronyms	Definition
AC	Alternate Current
BESCOM	Bangalore Electric Supply Company Limited
CEI	Chief Electrical Inspector
CSS	Cascading Style Sheets
CERC	Central Electricity Regulatory Commission
DC	Direct Current
DISCOMs	Distribution companies
EI	Electrical Inspector
EPC	Engineering, Procurement, and Construction
GW	Giga Watt
GSES	Global Sustainable Energy Solutions
HT	High Tension
IEC	International Electrotechnical Construction
IRR	Internal Rate of Return
KREDL	Karnataka Renewable Energy Development Limited
kWp	Kilowatt Peak
LT	Low Tension
MNRE	Ministry of New and Renewable Energy
NOC	No Objection Certificate
O&M	Operations and Maintenance
PACE-D	Partnership to Advance Clean Energy – Deployment
PPA	Power Purchase Agreement
PV	Photovoltaic
RECs	Renewable Energy Certificate
RESCO	Renewable Energy Services Company
RPO	Renewable Purchase Obligation
SERC	State Electricity Regulatory Commission
SPO	Solar Purchase Obligation
RTPV	Rooftop Photovoltaic
SPV	Solar Photovoltaic
TA	Technical Assistance

EXECUTIVE SUMMARY

The Government of India has adopted a very ambitious national target for solar capacity deployment by 2022. The Government of India aims to deploy 100 gigawatt (GW) of solar photovoltaic (PV) capacity by 2022, 40 percent of which (40 GW) will come from solar PV rooftop installations. In order to achieve this target of 40 GW of commissioned solar rooftop projects, concerted efforts would be required from a number of stakeholders. Above all, roles and responsibilities of utility engineers are considered to be critical for successful implementation of grid connected rooftop projects. These engineers will be the interface between utility and consumers and may be involved in certifying grid connectivity, safety and quality aspects of rooftop PV systems connected to grid.

The USAID PACE-D TA Program has developed a 1.5-day training program for utility engineers (middle and junior levels) on solar rooftop with an objective to build technical, procedural and administrative knowledge and skills of utility engineers for permitting and managing solar rooftop systems. This handbook will be provided to the participants of this training as a reference book for implementation of grid connected rooftop PV projects.

1 INTRODUCTION

Objective

To provide basic information and raise awareness amongst utility management and engineers on the following:

- Concept, design and components with specific focus on technical architecture of solar rooftop system/project.
- Policy and regulatory framework for solar rooftop at the national and state level.
- Different implementation/business models followed in the solar rooftop market and role of stakeholders.

To provide specific information to the utility management and engineers on the following:

- Solar PV Rooftop Interconnection Process: Design of the interconnection framework including forms, formats, systems and procedures
- Protocols for Solar PV Rooftop Development: Relevant configurations, standards, and safety requirements for interconnection
- Solar PV Rooftop Program Management: Customer interface and process management

Who Can Use This Manual?

Senior management and utility engineers across departments.

Main Features of the Manual

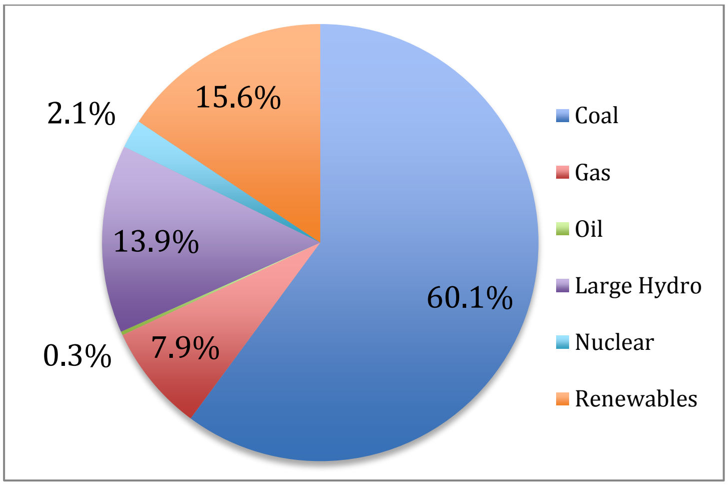
- Overview of solar rooftop power sector in India
- Solar PV rooftop technology overview
- Policy and regulatory framework in India
- Solar PV rooftop systems design and safety overview
- Grid connectivity and inspection procedure
- Administrative procedure for implementing solar rooftop projects
- Challenges in integration of solar PV rooftop with utility grid

2 OVERVIEW OF SOLAR ROOFTOP POWER SECTOR IN INDIA

Growth of Solar Power Installation in India

The impact of fossil fuel based energy system in creating and exacerbating climate change has been widely established and accepted. Governments and communities across the world, including India, are investing in renewable energy technologies to replace existing fossil fuel based energy generation systems with cleaner sources.

India is relatively a new entrant in the renewable energy industry, and reflects in its energy generation mix, where fossil fuel based sources account for almost 70 percent of total sources of generation. Renewable energy, excluding large hydropower is approximately 13 percent of the total mix. Of all the forms of renewable energy in India, Solar power has received a great level of interest from government and private sectors as one of the solutions to India's energy challenges.



Conventional Power (MW)	
Coal	192,163
Gas	25,329
Oil	838
Large Hydro	44,478
Nuclear	6,780
Renewable Energy	50,018

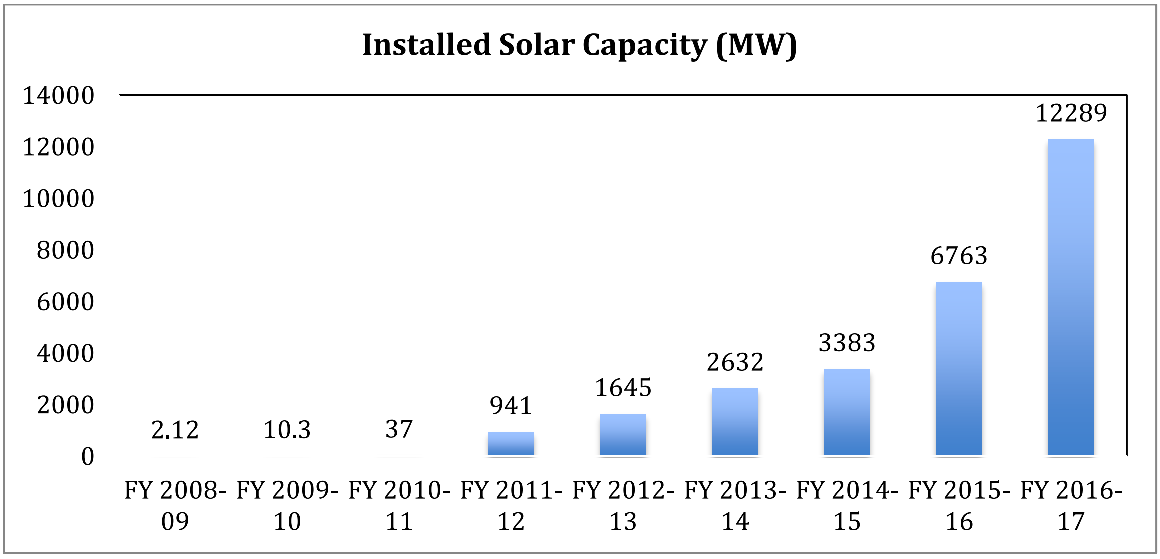
Source: Ministry of Power, Government of India

Figure 1: Share of Renewable Energy in Indian Power Sector

Use of solar power as a supplementary source to traditional grid based electricity is relatively recent in India. The Generation Based Incentive (GBI) scheme, announced in January 2008, was the first step by the government to promote installation of grid connected solar power plants.

Prior to this, the Indian Government regarded the Rural Electrification Program of 2006 as the first set of guidelines. This program focuses on promoting off-grid solar applications including solar lanterns, solar pumps, home lighting systems, street lighting systems, and solar home systems.

In 2008, the Indian Government announced National Action Plan for Climate Change (NAPCC), which also marked commencement of National Solar Mission (NSM). The NSM sets targets, provides policy guidelines, and financial incentives to support the growth of solar power in India. Under NSM, the installed capacity of solar power in India has propelled from just over 2 megawatt (MW) in 2009 to over 12,000 MW as on March 31' 2016, as illustrated in Figure 2.



Source: Wikipedia

Figure 2: Installed solar capacity (MW) in India

India's NSM

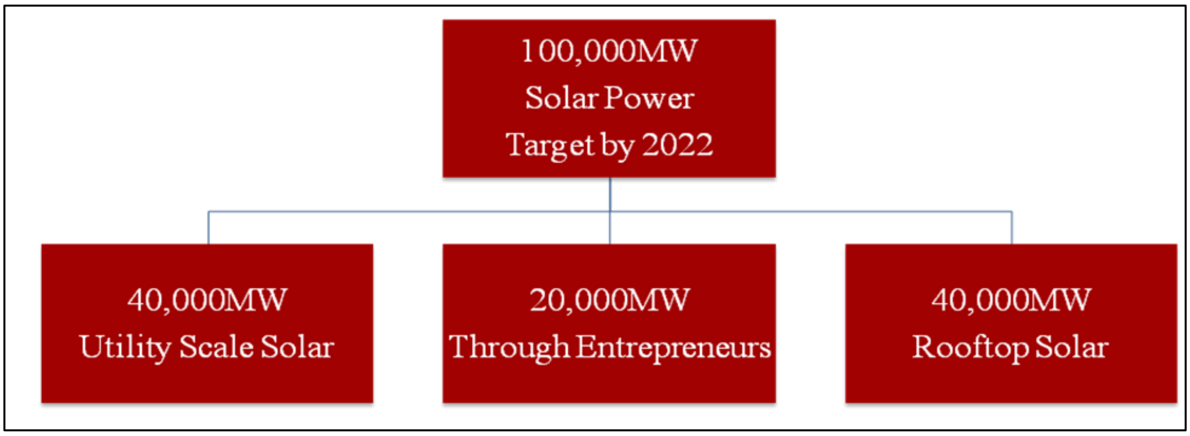
The NSM commenced in 2009 is an initiative of the Government of India and the State Governments to address India's energy security challenges while promoting ecologically sustainable growth. The NSM will be a major contribution to India's intended commitment to meet its share of climate change mitigation and adaptation activities agreed within the United Nations Framework Convention on Climate Change (UNFCCC).

The UNFCCC is an international treaty, established to coordinate international efforts in addressing the challenges of climate change.

The overall objective of the NSM is to make solar cost completive with fossil fuel based energy options by 2022 through the following actions:

1. Long term policy
2. Large scale deployment goals
3. Aggressive research and development
4. Domestic production of critical raw materials, components, and products

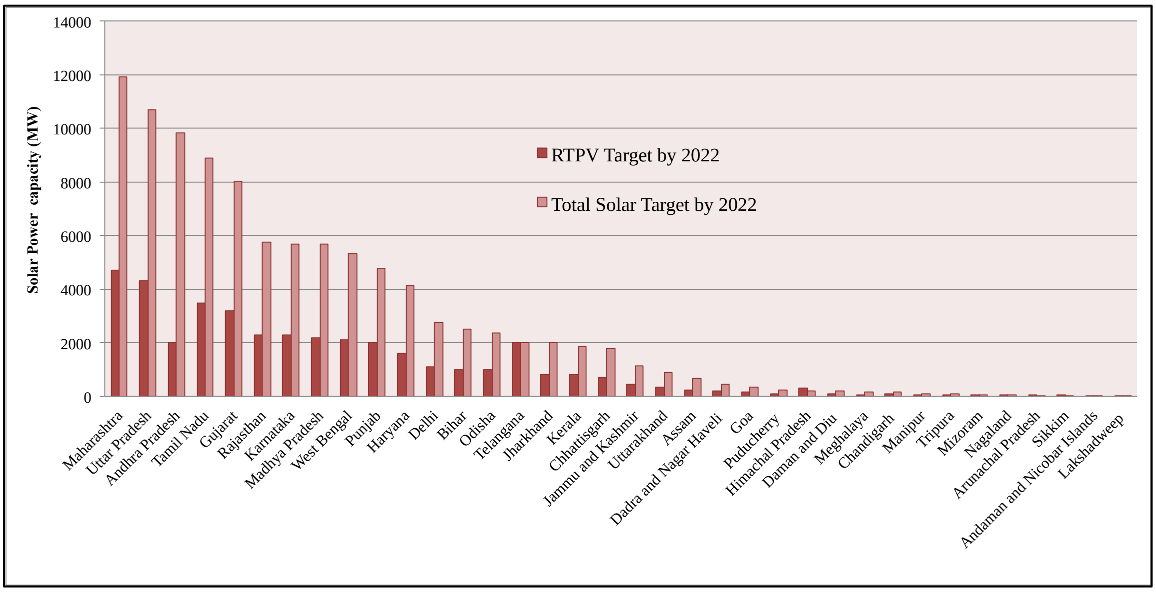
Following up on the objectives of the Mission, the Government of India announced ambitious targets for grid connected solar power. Under these targets, overall 100,000 MW of grid connected solar power is to be installed across India by 2022. Utility scale solar and solar rooftop will contribute 40 percent each towards this target, while entrepreneurs will get an opportunity to meet 20 percent of the targets, with a focus to promote local job creation and skill development. A detailed breakdown of this target is illustrated in Figure 3.



Source: Ministry of New and Renewable Energy, Government of India

Figure 3: Targets Under India's NSM

The States have been allocated their contribution towards the National targets by the Ministry of New and Renewable Energy. As illustrated in Figure 4, Indian states have been allocated overall solar targets for 100,000 MW and targets of 40,000 MW solar rooftop separately by 2022.



Source: Ministry of New and Renewable Energy, Government of India

Figure 4: Solar Targets Allocated to States

It is estimated that 40 GW solar rooftop power plants will contribute about 3 percent of India's total energy demand by 2022 (Figure 5).

The scale of integration of new electricity generation sources in national grid network will present both challenges and opportunities for utilities in India, and also lead to the creation of new business models as the worldwide trends suggest. An overview of the potential business models will be provided in the later sections.

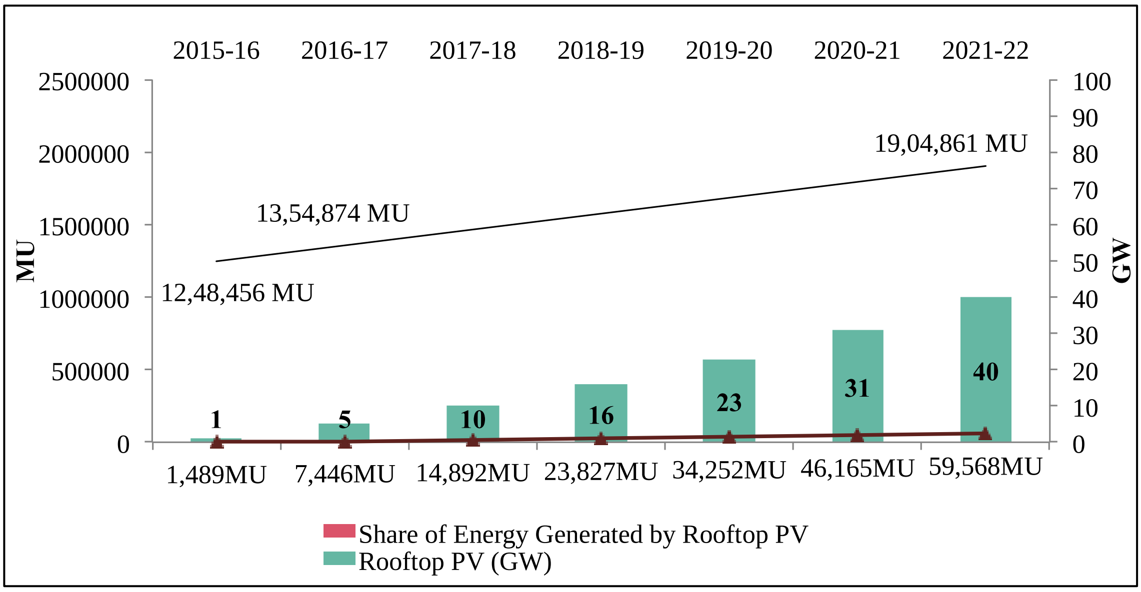


Figure 5: Estimated Contribution of Rooftop PV to India's Total Energy Demand

Advantages of Rooftop PV Over Utility Scale Power Projects

Grid connected solar power systems use sunlight as fuel to generate DC power. This DC power is converted to AC power via the inverter, which is then fed into the electricity grid. This is the fundamental working principle of all grid connected systems.

A large solar PV array is directly connected to the transmission and distribution system, which then carries the generated electricity through the distribution network to the end user. The size of a utility scale system can be as small as 50 kWp while systems as large as 250 MWp have been installed in recent years in the USA. In India, the state of Gujarat is host to world's second largest PV plant with nominal capacity of 214 MWp. Under the national solar mission of India is going to have ultra MW scale PV power parks in near the coming years.

In solar rooftop power projects, the solar array is placed on the shadow free and stable south facing (north facing in southern hemisphere) roof area of a residential, commercial or industrial establishment. The power generated by a rooftop PV system is typically consumed by the loads within the building and excess power is then fed into the grid. The quantity of exported power is subject to policies within the respective states, and metering restrictions.

The size of a rooftop PV project can be as small as 1 kWp to 5 kWp for a residential roof and as large as 10 kWp to 50 kWp and even MW capacity, subject to roof availability. At the time of writing, the largest solar rooftop scale project commissioned in India, and the world is 12 MWp commissioned in Amritsar (Punjab).

While both utility and rooftop PV projects serves at different generation scales and at a point of power delivery, they broadly achieve similar goals in the context of the overall energy supply system. The key advantages of using rooftop projects, where possible, over utility projects is that it removes the typical transmissions and distribution losses in the system, and also optimizes the use of available infrastructure. A summary of key advantages of rooftop PV over utility scale solar power projects is illustrated in Table 1.

Table 1: Benefits and Limitations of Utility Versus Solar Rooftop Power Projects

Solar Deployment Areas	Benefits and Limitations				
	Supply Gap Reduction	Energy Security	T&D Loss Reduction	Stimulate Investments	Optimal Utilization of Infrastructure
Utility scale solar projects	√	√	X	√	X
Large commercial solar rooftop projects	√	√	√	√	√
Small household based rooftops projects	√	√	√	√	√

Solar rooftop power projects are very popular across many countries. Germany has the highest solar rooftop installed capacity (~24 GW), while Australia has the highest percentage of solar rooftop installations (80 percent) as the share of total solar power installations, including utility scale. A list of countries leading in rooftop installations is provided in Table 2.

Table 2: List of Countries Leading in Solar Rooftop Installations

Country	Total PV Installed Capacity	Share of Rooftop PV (Percent)
China	50.3 GW (April 2016)	~20
Germany	40.1 GW (May 2016)	~60
US	29.3 GW (May 2016)	~40
Japan	34.4 GW (Dec 2015)	~35
Italy	18.9 GW (Dec 2015)	~70
UK	9.8 GW (April 2016)	~52
India	7.8 GW (June 2016)	~10
Spain	5.4 GW (Dec 2015)	~70
Australia	5.1 GW (Dec 2015)	~80

Source: REN21 Report 2015/Wikipedia

Key Policy Instruments to Promote Solar PV Rooftop

As aforementioned, the solar PV rooftop program is allocated 40 percent or 40,000 MW of the 100,000 MW solar installed capacity target by 2022. The Government of India is using the following policy instruments to achieve this objective:

1) Accelerated depreciation, available to industrial and commercial buildings.
2) Provision of bank loans as part of home improvement loan or home loan for solar rooftop systems.
3) Loans available for projects and individuals under priority sector lending.
4) Loans for system integrators from Indian renewable energy development agency at concessional interest rates.
5) Custom duty concessions and excise duty exemptions.
6) Government subsidy for residential, institutional, government and social sectors.
7) Viability gap funding through competitive bidding.

8) Solar specific renewable energy purchase obligation.

Key Challenges for Solar PV Rooftop Sector in India

While there appears to be, multiple levels of support from both central and state governments to promote the development of solar PV rooftop sector in India, there are many challenges which are potentially affecting the growth of this sector. The key challenges in the solar PV rooftop sector are discussed in this section.

Policy and Regulation Challenges:

- There are multiple incentive structures available through both Centre and State governments. These are not always aligned, thus, creating gaps in implementation of NSM. An example is the Renewable Purchase Obligation (RPO) scheme, where the Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commission (SERC) are required to purchase a purchase certain percentage of grid-based power from renewable sources. The RPO targets are conservative and are not aligned with the aggressive 2022 policy targets.

- Participation and engagement of utilities in solar rooftop power scheme is still regarded to be at a very early stage. There is lack of consistent and established policy and procedures, which leads to complexity in operation of the grid connection process.

- It is interesting to note that the challenges were similar for utility scale power projects initially. Over the time, as these challenges were resolved, the utility scale installations in India began to soar, as illustrated earlier in Figure 2.

Distribution Utility Preparedness:

- As aforementioned, the grid connected solar rooftop scheme is a new experience for utilities in India. While some states like Gujarat and Rajasthan are doing well than others in establishing procedures for solar rooftop schemes, the rest are on steep learning curve to create a standardized interconnection process.

- The other challenge facing the utilities is limited knowledge and capacity of the staff to handle this shift in business operation. Agencies such as USAID are working with Indian Government and training institutions to build the capacity and skills of utilities needed to be successful in this area.

Financing:

- The Indian financing community's exposure to solar rooftop financing has been almost non-existent due to limited understanding of how to evaluate the solar rooftop projects and determine their credit worthiness. The perceived technical and commercial risks of solar rooftop plant have been cited as a barrier in other countries as well, at the initial stage solar rooftop market. Countries such as the United States, where solar rooftop is a relatively mature market, are successful in obtaining loan for financial institutions and investors.

- In India, programs are underway to build the capacity of banks and financial institutions (FIs) to identify the key parameters that drive the viability and sustainability of rooftop commercial and industrial solar rooftop projects.

Market and Awareness:

- As previously mentioned, the solar PV rooftop market is in early stages in India. Most of the installations are user owned and operated. There is still a lack of consumer education on product quality and relevant standards and certifications important for a reliable long lasting system.

- As the markets mature, and consumer confidence in the service increases with better contract structures, it is envisaged that solar rooftop systems will become further mainstream product in the mix of India's energy ecosystem.

A summary of these challenges has been illustrated below in Figure 6.

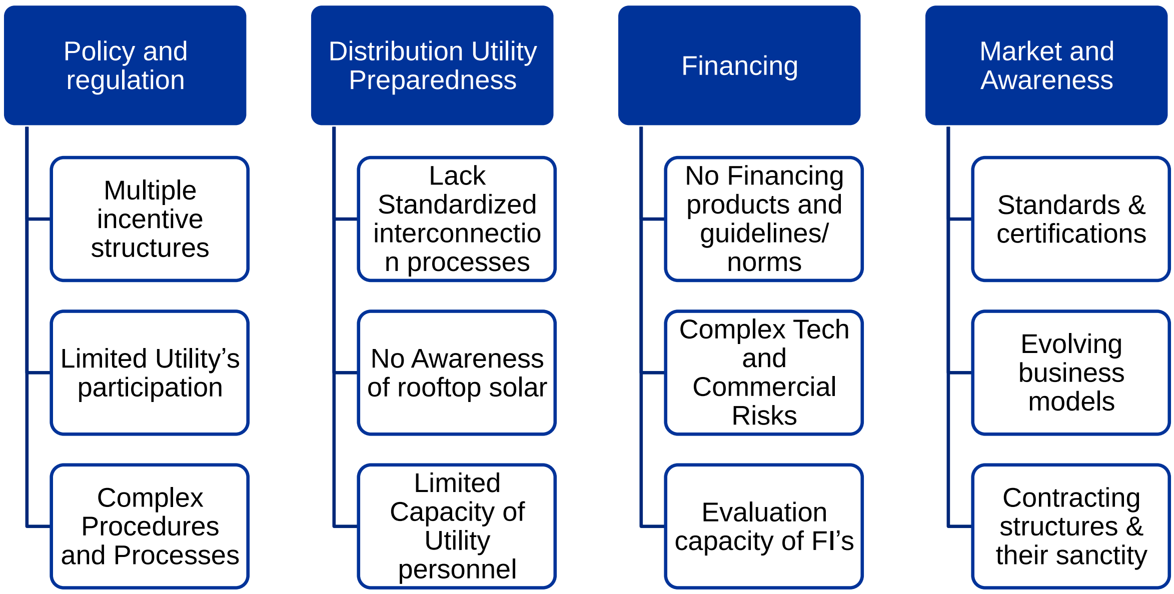


Figure 6: Key Challenges for Solar PV Rooftop Sector in India

3 OVERVIEW OF SOLAR PV ROOFTOP TECHNOLOGY

Introduction to Grid Connected Solar PV Rooftop System

As the name suggests, a grid-connected solar PV rooftop system is located on the roof of a home, factory, shed or any other building. The installation is secured with the help of frames and structures. The technology works in the same manner as described in the earlier chapter — solar array converts photon particles in sunrays to direct current (DC) current, which is changed over to alternate current (AC) current using inverter. Subject to the metering arrangement, the electricity generated the PV array is consumed by the loads first and the excess power generated is exported to the grid.

Sizing of the PV array is depends on the following variables: load demand, demand profile, availability of structurally sound shadow free south facing roof area and availability of grid interconnection facilities.

Photo Credit: Global Sustainable Energy Solutions (GSES)

Figure 7: Typical Grid Connected Rooftop PV System

Components of Grid Connected Solar PV Rooftop System

The major components of grid connected solar PV rooftop system include:

1. PV array (series parallel combination of solar PV modules).
2. Grid connected inverter.
3. Array mounting structure.
4. Balance of system components, including DC cables, AC cables, junction box, cables, fuses, isolators etc.

For grid-connected PV system with battery storage, following components are added:

- Multimode inverter.
- Storage battery.

The components are further detailed in the following section.

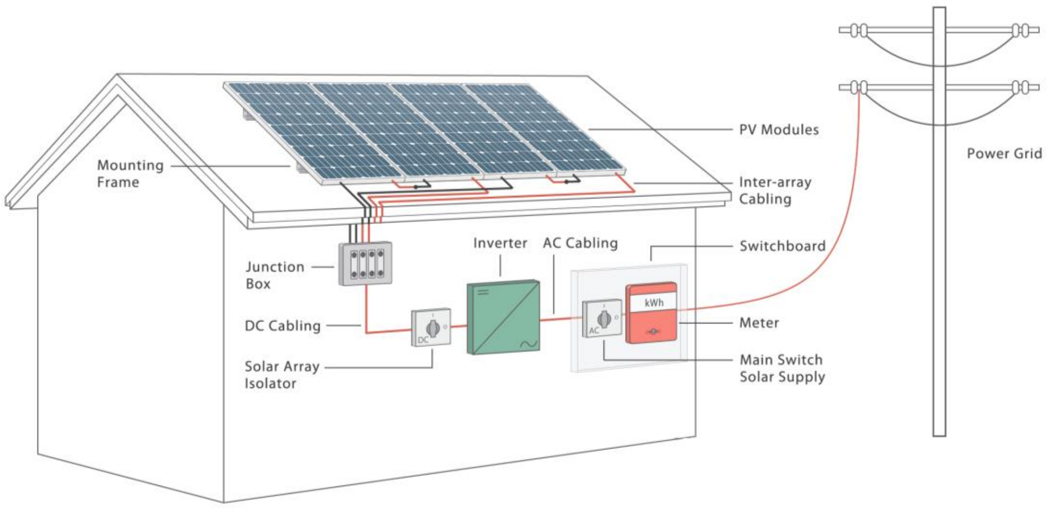


Illustration Credit: GSES

Figure 8: Grid Connected Rooftop PV System

1. PV Array

PV array is a series of parallel combination of multiple PV modules. The solar PV technology is evolving and different technologies have been emerged in recent years. There are two major types of solar modules crystalline and thin film modules. Crystalline modules are classified as mono-crystalline and poly-crystalline based on the process of growth of silicon crystal. Thin film modules are classified based on the compounds used in making the modules.

In selecting modules for an application, attention must be paid on their test and compliance certificates evidencing meeting of relevant codes and standards. Some of the commonly used PV modules which are available in the market are summarized in Table 3.

Table 3: Key Parameters for Different Types of PV Technologies

Type	Technology	Efficiency (Percent)	Area (m^2/kWp)
Mono-crystalline	Cells manufactured from wafers cut from an ingot of a single silicon crystal	15-22	6.5–4.6
Polycrystalline modules	Cells manufactured from wafers cut from an ingot of a several silicon crystals	14–16.7	7.0–6.0
Amorphous thin film	Silicon deposited by gaseous deposition	5-10	20-10
Micro-morph thin film	Silicon deposited by gaseous deposition method in several layers, creating multi-junction cells	10-12	10–8
CdTe thin film	Use CdTe layer designed to absorb and convert sunlight into electricity	12–13	8–7.5
CIGS thin film	Made by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing	10–13	10–7.5

2. Grid Connected Inverter

Inverter changes the DC electricity produced from the arrays into AC sine wave that matches the AC supply in voltage and frequency to which it is connected. The resulting power can then be used by the AC loads, and also exported to the grid.

In a grid-connected PV system, the PV array is directly connected to the grid-connected inverter. These inverters cannot produce a grid equivalent AC sine wave independently, as the inverter must detect and reference the grid to operate. If the AC grid is not present, the inverter will simply not function.

Grid converted inverters can be classified based on the following criteria:

- Isolated or non-isolated
- Interfacing set-up with respect to PV array

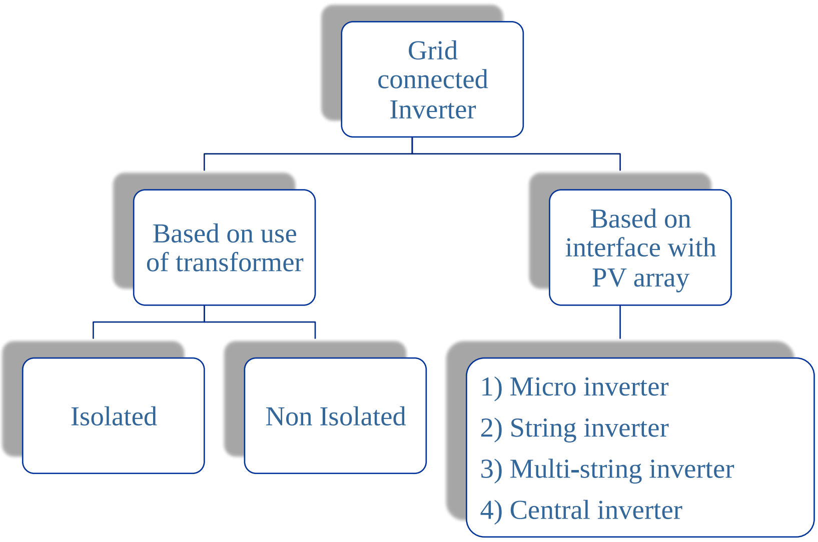


Figure 9: Classification of Grid-Connected Inverter

Isolated Inverter: According to IEC 62548 standard, an Isolated Inverter is an "inverter where there is at least a simple separation between input and output circuits (e.g., by means of a transformer with separate windings)".

Non-Isolated Inverter: According to IEC 62548 standard, a non-isolated inverter is an "inverter that does not have at least a simple separation between input and output circuits". These inverters are known as transformer-less inverters.

Inverters that are classified based on their interfacing features are listed below.

Micro inverters or modular inverters are small isolated inverters (some can also have an isolating transformer) that are designed to be mounted on the back of the solar module.

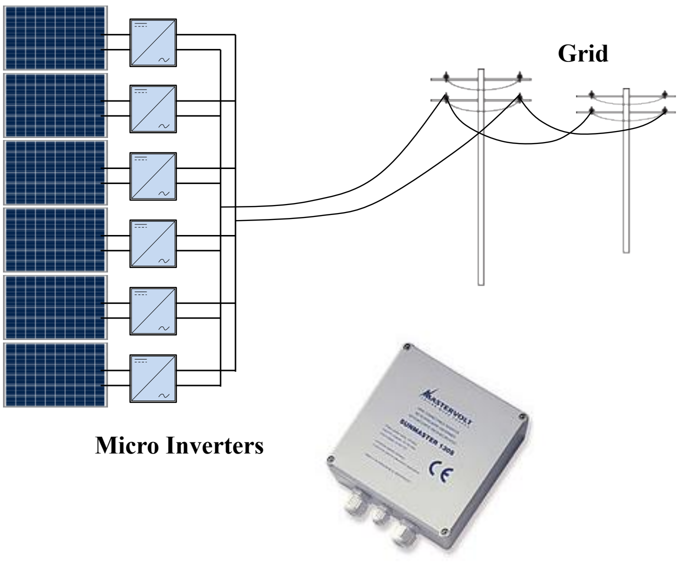


Figure 10: Micro Inverters (Also Known as Modular Inverters)

String Inverters range from 1 kW_p up to approximately 20 kW_p, and are connected to a string of PV array. A “string” is made of PV modules connected in series. An example of a string inverter is shown in Figure 11. Multiple inverters can be used to spread the generated power over more than one phase. Multiple inverters may also be used for extra redundancy, or when a larger inverter is either not available or more expensive than two smaller inverters.

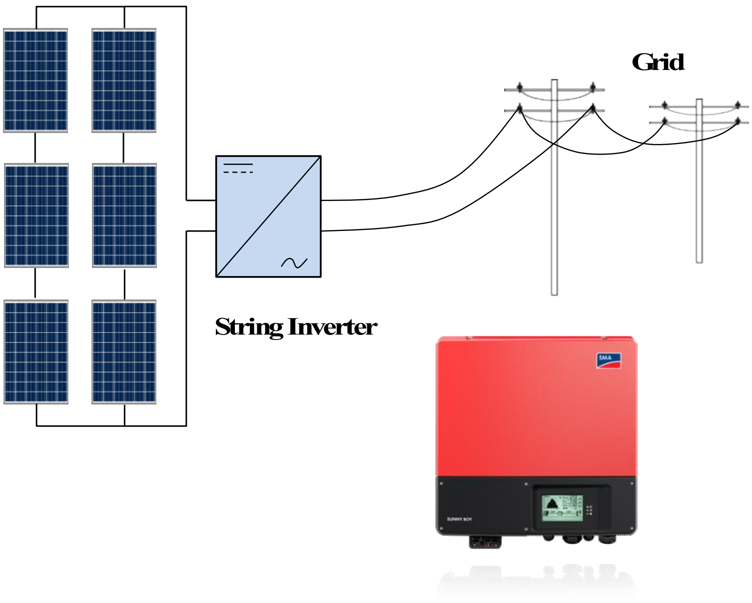


Figure 11: Grid Connected String Inverter

Multi Sting Inverter has a number of Maximum Power Point Tracker ([MPPT] inputs). This feature allows a solar array to be divided into multiple strings; and connect each string individually to the inverter as shown in Figure 12.

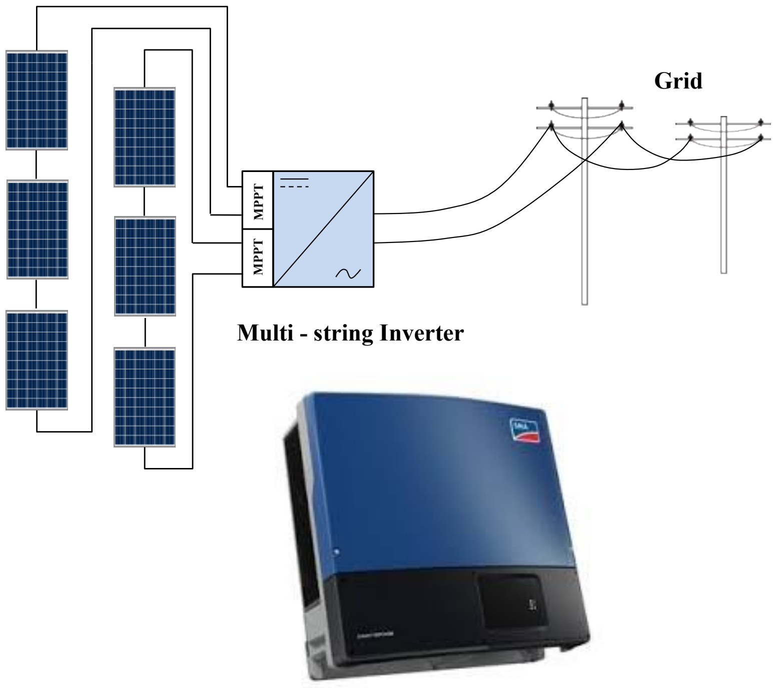


Figure 12: Grid Connected Multi-String Inverter

Central Inverters are used for large grid connected solar systems. A central inverter is similar to a string inverter with multiple strings – the difference is that central inverters can have PV arrays divided into a number of sub-arrays each comprising of a number of strings. Central inverters are decided based on their operating voltage window of that specific inverter. An illustrative diagram of a central inverter is shown in Figure 13.

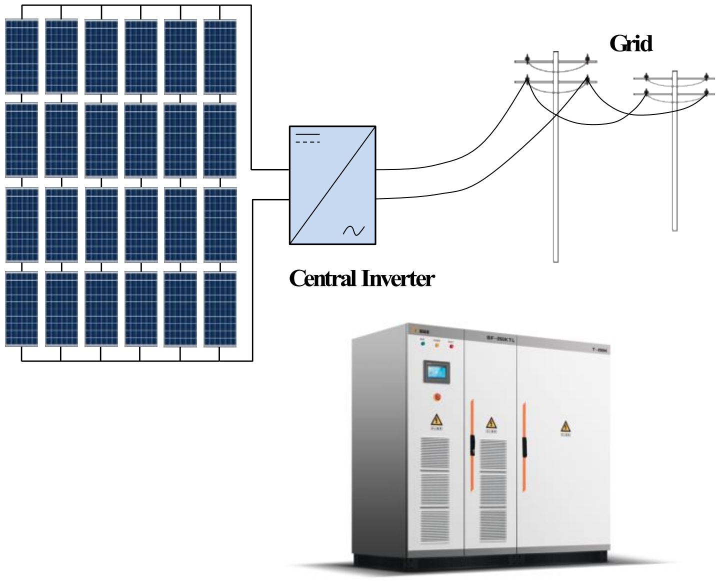


Figure 13: Grid Connected Central Inverter

Multi-Mode Inverters also called as hybrid inverters are used with grid connected PV systems with storage battery bank. This type of inverter works as a standalone inverter when there is no grid and grid connected inverter stops feeding to the grid. They are generally more expensive than a normal grid connected inverter.

Photo Credit: GSES

Figure 14: Grid Connected Multimode Inverter and Storage Battery

The types of batteries vary from manufacturer to manufacturer and they all have their unique operating principles. Currently, lead acid batteries are most affordable and common for solar storage applications. Developments in advanced battery chemistries such as the lithium ion and ferrous derivatives will provide affordable and more reliable storage solutions in the near future.

3. Array Mounting Structure

Support structures and module mounting arrangements should comply with –

- Applicable building codes regulations.
- Standards and module manufacturer's mounting requirements.

The following aspects are to be considered in designing array mounting structure:

- **Thermal aspects —** To allow expansion/contraction of modules/structure.
- **Mechanical loads on PV structures —** To comply with related standards
- **Wind —** shall be rated for the maximum expected wind speeds.
- **Material accumulation on PV array —** Snow, ice, or other material.
- **Corrosion —** Mounting shall be made from corrosion resistant materials suitable for the lifetime and duty of the system.

Figure 15: Different Rooftop Array Mounting Structures

4. Balance of System Components (BoS)

The balance of system equipment must be selected and installed correctly. If appropriate, design procedures are not followed through; the system could have performance and reliability problems, premature faults and even failures.

The key balance of system components include:

- DC cables and AC cables
- Array junction box/DC combiner box
- Over current protection device/circuit breakers
- Disconnection devices
- Plugs, sockets, and connectors

- Lightning protection system (LPS)
- Earthing and bonding arrangement
- Energy meters
- System monitoring
- Marking and signage

DC cables are used to connect the modules to the array junction box, the array junction box to the DC isolator and the DC isolator to the inverter. It is important to select a cable that meets the requirements *of Draft IEC 62548: Design Requirement for PV arrays* (in terms of voltage and current specifications) and minimises voltage drop.

AC cables connect the inverter to distribution board and AC loads. The voltage from the inverter is typically 230 V AC single phase and the cables required are the same cables used in electrical installations for general household/building cabling. In larger systems, the inverters may be 400 V AC three phase.

Array junction box/DC combiner box are used when the array is comprised of a number of parallel strings. Cables from the array strings are interconnected in an array junction box.

If there are multiple parallel strings, the array junction box will house the connection of positive and negative cables and fuses from the different PV strings to identified links (or similar). There will be only one DC positive and negative array cable from the junction box interconnecting with the inverter (via the PV array DC isolator).

The PV array and string combiner boxes shall at least be IP 54 compliant in accordance with International Electrotechnical Construction (IEC) 60529, and shall be UV resistant.

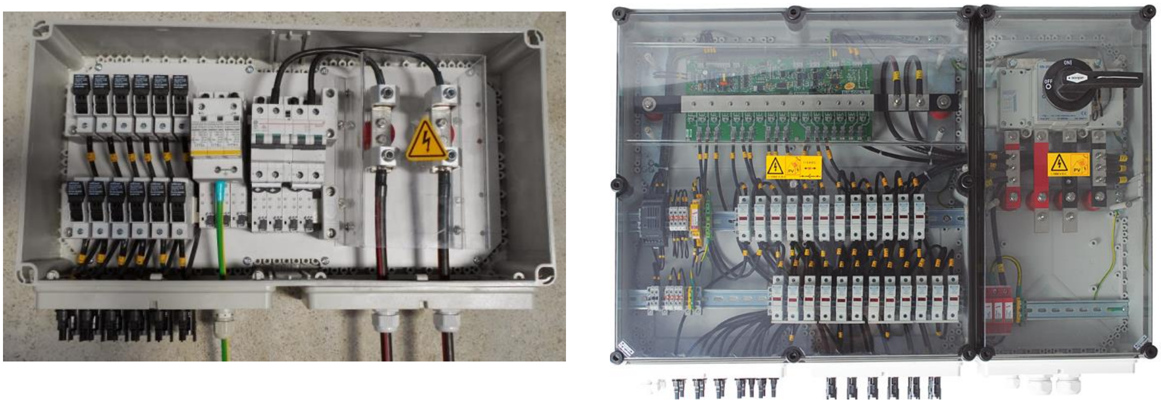


Figure 16: Array Junction Box

Overcurrent protection device/circuit breakers

PV modules are current limited sources; however, can be subjected to over currents. The over current can originate from multiple parallel strings or inflows from external sources. Overcurrent within a PV array can also result from earth faults in array wiring or from fault currents due to short circuits in modules, in junction boxes, combiner boxes or in module wiring.

Disconnection devices such as fuses and isolators are used to protect the system during the time of maintenance.

Plugs, sockets and connectors for use at the array level connections should be rated for DC use. They should be also rated for outdoor use with the appropriate UV resistant and IP rating. The plugs and sockets used for household equipment should not be used in PV arrays.

LPS are installed in areas where there is high occurrence of thunderstorms. Most buildings are already equipped LPS and in such cases, proper integration with the RTPV system as per IEC 62305 – 3.

Earthing and bonding arrangement for earthing exposed conductive parts of a PV array arises for the following reasons:

- Bonding to avoid uneven potentials across an installation.
- Protective earthing so that there is fault current path.
- To provide lightning protection.

In order to perform these operations, an earthing conductor must be used as per the guidelines described in IEC 62548.

Energy meters record the electrical energy consumed by the loads in kWh within the building where the meter is connected. The electricity consumer is then billed for this consumption on the tariff set for that consumer. Electricity distributors will often have different rates for residential houses compared with industrial and/or commercial consumer.

There are two categories of energy meters in the context of solar PV installation -

Bi-directional analog meter for net metering

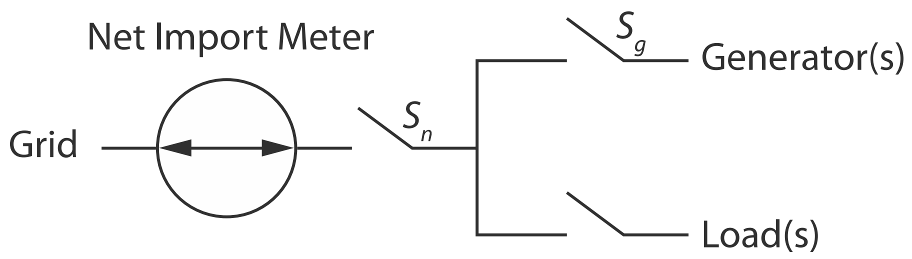


Illustration Credit: GSES

Figure 17: Schematic of Net Import Meter

Two directional analog meters for net metering

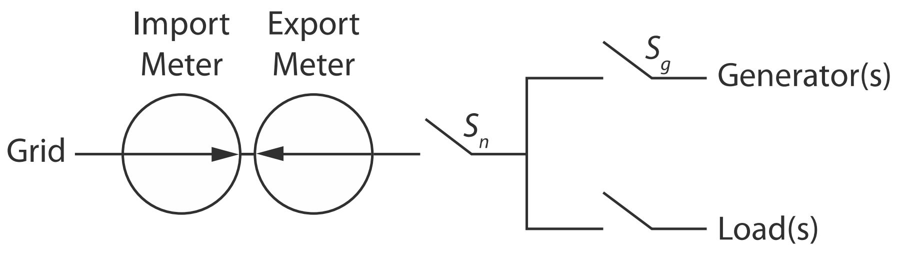


Illustration Credit: GSES

Figure 18: Schematic of Separate Import and Export Meters

System monitoring plays an important role as it gives an overview of the entire system based on how many units of kWh is generated per annum.

Most inverters are equipped with a data module and communication system that constantly updates the amount of power generated on a timely basis (hourly, daily, monthly) and sends it to its respective online portal on which the customer can monitor his/her system.

For commercial plants, system monitoring is more relevant as the investment is at a larger scale.

Figure 19: System Monitoring Application

Marking and signage is required to make the installation and operation as safe as possible for everyone involved. All electrical equipment shall be marked according to the requirements for marking in IEC 62548 or to local standards and regulations when applicable. Markings should be in the local language or use appropriate local warning symbols.

For reasons of safety of the various operators (maintenance, personnel, inspectors, public distribution network operators, emergency aid services, etc.), it is essential to indicate the presence of a photovoltaic installation on a building.

A sign shall be fixed:

- At the origin of the electrical installation.
- At the metering position, if remote from the origin.
- At the consumer unit or distribution board to which the supply from the inverter is connected.
- At all points of isolation of all sources of supply.

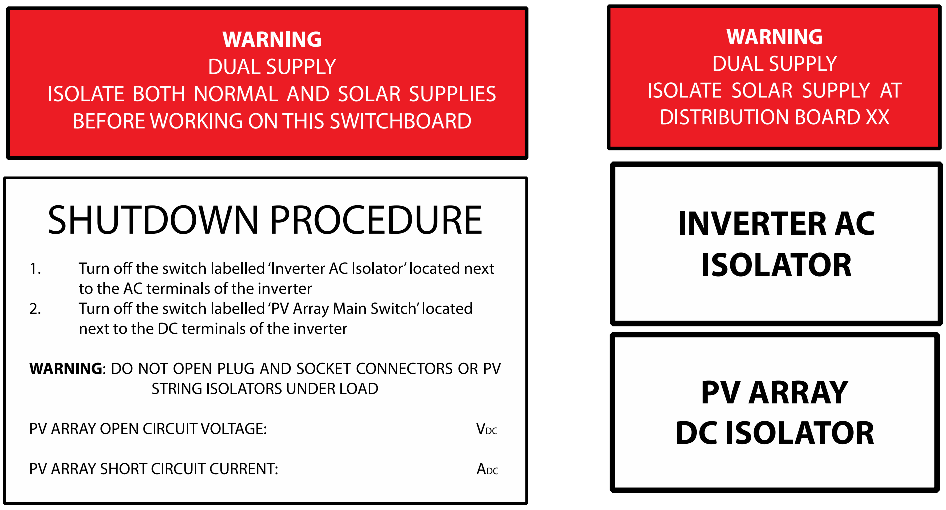
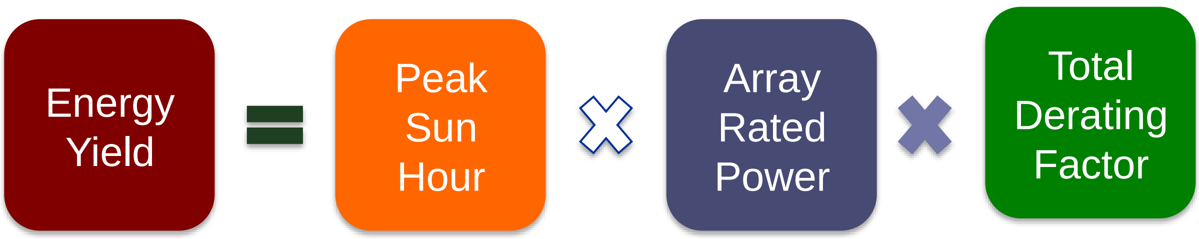


Illustration Credit: GSES

Figure 20: Examples of Marking and Signage

Energy Generation Estimation From PV System

The amount of electrical energy delivered by the PV system is calculated using the following equation.



The inputs of this equation are explained below:

- **Amount of Solar Irradiation Falling on the Modules (Expressed as Peak Sun Hours [PSH]):**

Solar energy available in a given location is expressed as kWh/m^2/day. This is commonly referred as PSH. For example, if solar radiation for a particular location is 5.2kWh/m^2/day then PSH for that location will be 5.2 hours.

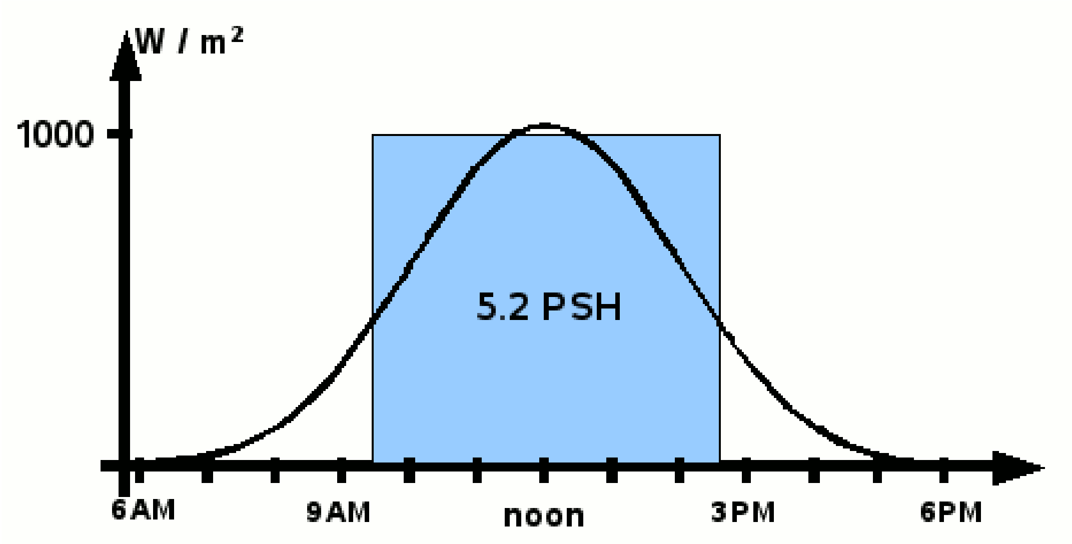


Figure 21: Illustration of PSH

- **Array Rated Power (Peak Watt [W_p])**

This is the rated nameplate capacity of the system, derived from the rated power of modules. The W_p of a solar module is the number of watts it will produce under the Standard Test Conditions (STC), i.e., 1000W/m^2 of solar irradiance, cell temperature of 25º C and air mass of 1.5. However, a PV array never work in these standard test conditions at field and array power will be always derated from the rated power at STC.

- **Total Derating Factor**

The factors directly affecting the power generation are temperature, shadow, dust over PV array, manufacturer's tolerance, orientation, tilt angle, and loss due to irradiance level. PV array will also degrade over its period of life cycle. Apart from derating of module power, there will also be losses due to inverter efficiency, voltage drop, and loss in transformer, if used.

Total efficiency of the system after considering all the losses are expressed as Total Derating Factor

Losses in solar PV system arises from weather factors, site constraints, and voltage drops. A summary of typical losses are provided in Table 4.

Table 4: Typical Losses in PV System

Cause of Loss	*Estimated Loss (Percent)	De-Rating Factor
Temperature	10	0.90
Dirt	3	0.97
Manufacturer's tolerance	3	0.97
Shading	2	0.98

Cause of Loss	*Estimated Loss (Percent)	De-Rating Factor
Orientation	0	1.00
Tilt angle	1	0.99
Voltage drop	2	0.98
Inverter	3	0.97
Loss due to irradiance level	3	0.97
Transformer and AC transmission	1	0.99
Total de-rating factor (multiplying all de-rating factors)		0.72

** Typical losses in PV systems. Actual loss will be as per site conditions*

In the above example, there are 27 percent losses in the system. It simply means that an array rated 1 kW will produce power equivalent to 0.73 kW.

- **Performance Degradation Over Life Cycle**

The performance of a PV module will decrease over time. The degradation rate is typically higher in the first year upon initial exposure to light and then stabilizes. Factors affecting the degree of degradation include the quality of materials used in manufacture, the manufacturing process, the quality of assembly and packaging of the cells into the module, as well as maintenance levels employed at the site. Generally, degradation of a good quality module is considered to be about 20% during the module life of 25 years @ 0.7 percent to 1 percent per year.

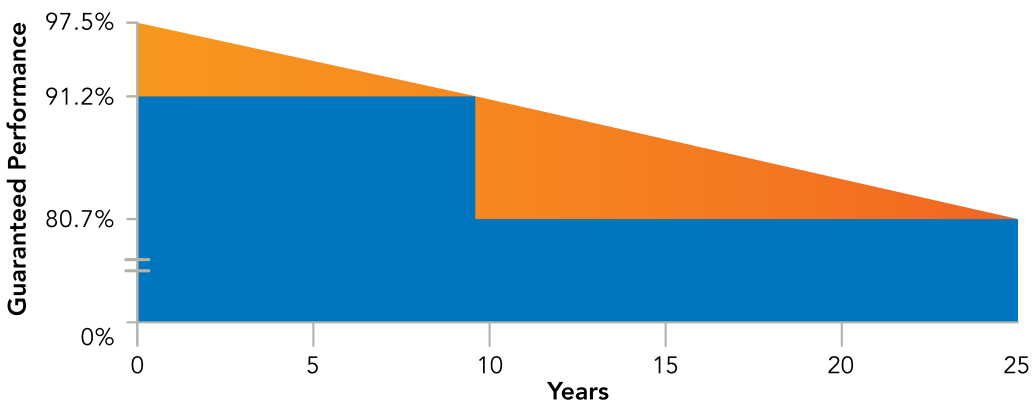


Figure 22: Example of PV Module Degradation

Working Example of Energy Generation Estimation

On a clear and sunny day, a 10 kWp PV array received 5 PSH (hours). Total loss (de-rating factor) in the system is estimated as 0.73 (73 percent)

Expected output can be determined as follows:

Expected Output = PSH x Peak Power Output x Total De-rating Factor

= 10 kWp x 5 hour/day x 0.73

= 36.50 kWh per day (1st year)

= 32.85 kWh per day (on 10th year)

= 29.56 kWh per day (on 25th year)

Different Configurations of Rooftop PV System

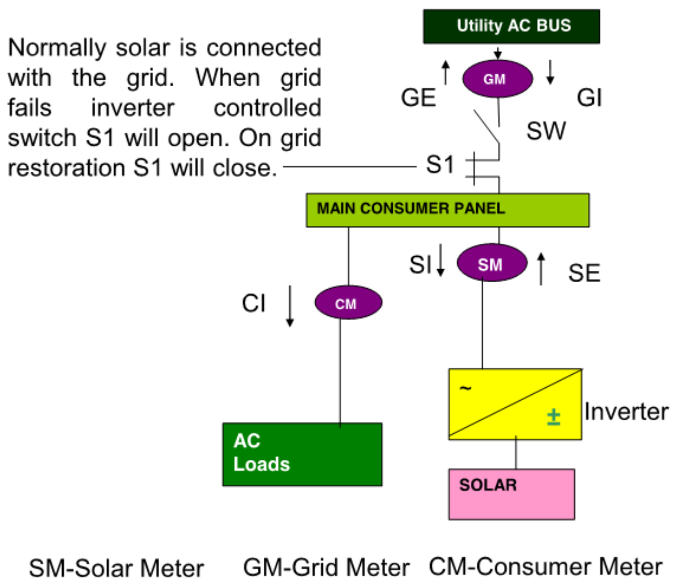
Rooftop PV systems can be configured in different ways based on how it is connected to the grid and whether it is connected to any other energy supply or storage system. Four different types of configurations are illustrated below.

Grid Connected Solar PV Rooftop System With No Battery or DG Backup

In this setup, the solar PV array is connected to the grid with the help of an inverter. Excess power, which is not drawn by the load, is sent to the grid.

The inverter acts as a first line of defense in this system. In the event of grid failure, the inverter senses the over voltage or under voltage and disconnect the system from the grid.

The drawback of such a system however, is that since it is directly connected to the grid, during a grid fault, the PV system will not supply any energy.



Source: Central Electrical Authority

Figure 23: Grid Connected System

Grid Connected Solar PV Rooftop System With Charger cum Inverter as Load

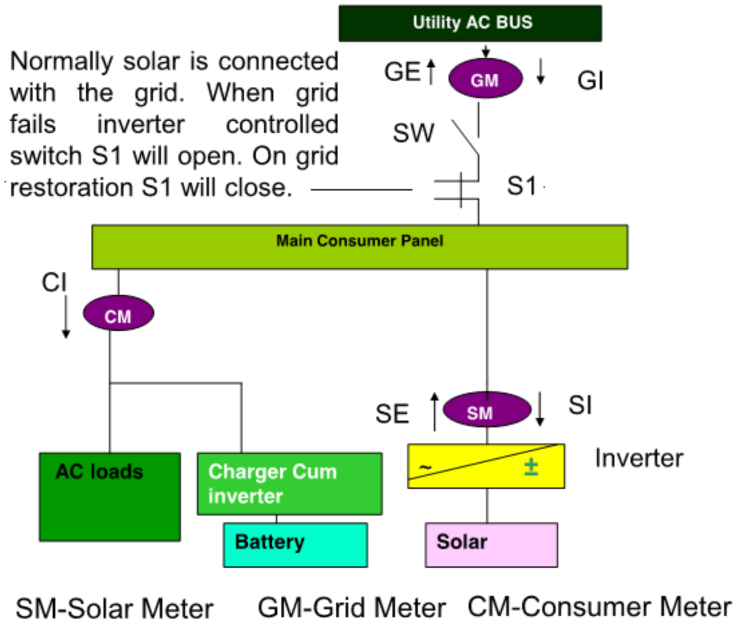
This configuration is similar to the simple grid connected system in the manner it connects with the grid. The feature, which differentiates it, is the presence of battery and charger cum inverter in the load circuit,

A proportion of power is sourced from the load circuit, which can arise either from solar PV or from grid electricity, to charge a battery bank. This charger is a converter to change AC current to DC.

This battery bank can be either sized to power of the critical loads in the circuit, or the entire load within the meter boundary. A battery inverter is also present in the circuit to change the DC electricity to AC.

In the event of a grid outage or a cloudy day, energy stored in the battery is used to provide electricity to the loads.

The presence of an additional power source adds flexibility and contingency to the system, however, a drawback of such a system is that it adds complexity and cost to the system, and requires regular maintenance schedules for batteries.



Source: Central Electrical Authority

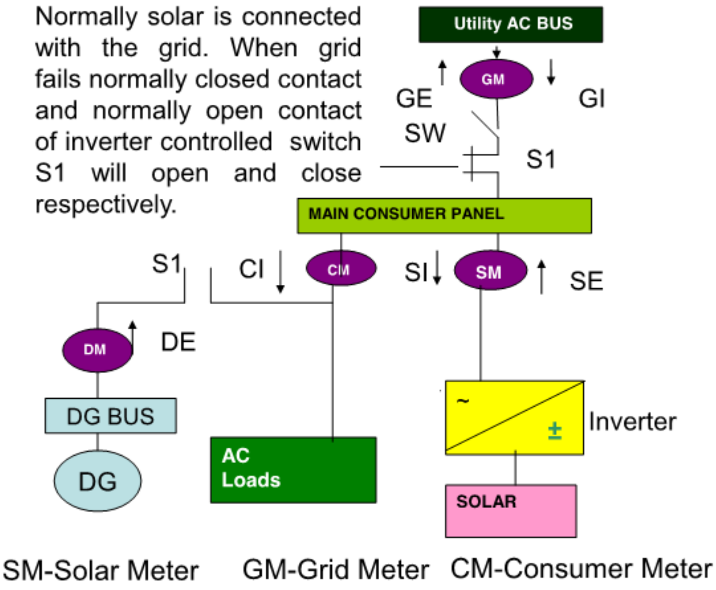
Figure 24: Grid Connected System With Charger cum Inverter as Load

Grid Connected Solar PV Rooftop With DG Set as Backup

The operational fundamentals of this system are similar to the earlier configuration of grid-connected system with charger cum inverter. The only difference is that the battery in this system is replaced with a diesel generator.

The generator is started when no power supply is available in the system. As generator provides AC electricity, no additional inverter is required in the system. An Uninterrupted Power Supply (UPS) is typically added to critical loads, to manage the gap times between power outage and generator startup.

Similar to the battery configuration, the presence of an additional power source adds flexibility and contingency to the system, however, a drawback of such a system is that it adds complexity and cost to the system, and requires regular maintenance schedules for generator.



Source: Central Electrical Authority

Figure 25: Grid Connected System With DG Set

Grid Connected Solar PV Rooftop With Multimode Inverter and Battery Storage

In this configuration, PV array, battery storage, and specified AC loads are all connected to the multi-mode inverter. When the grid is available, the specified and non-specified loads are powered by the grid as well as the PV system. Excess power from the PV system can be used to charge the battery, or be exported to the grid. When the grid is unavailable, the PV system charges the batteries, which supplies power to the loads.

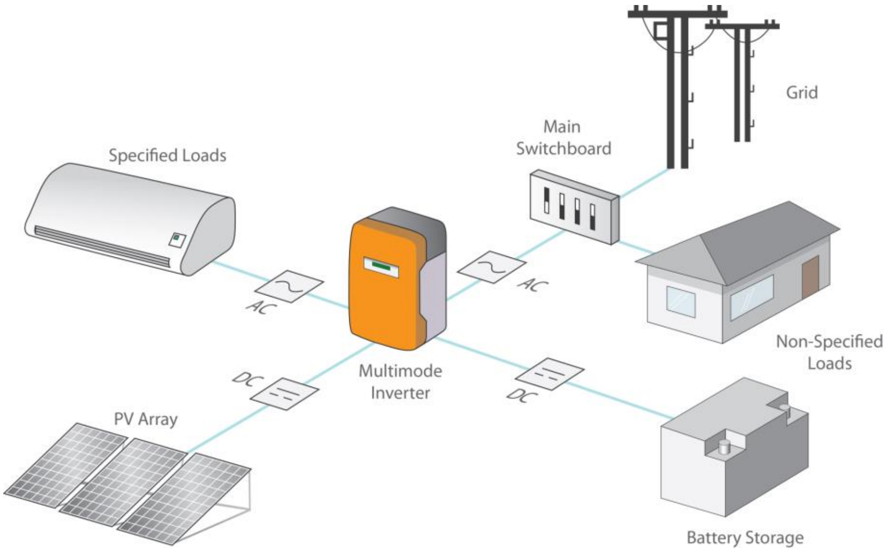


Illustration Credit: GSES Handbook on Grid Connected PV Systems With Battery Storage

Figure 26: Grid Connected System With Multimode Inverter and Battery Storage

4 POLICY AND REGULATORY FRAMEWORK IN INDIA

Role of Policy and Regulation in Solar Rooftop PV Development

Solar PV has emerged as the fastest-growing energy generation technology globally over the past decade. Some of the key drivers for this growth are listed as follows:

- Increased awareness of climate change risks and role of clean energy in mitigation effort.
- Energy access and security considerations.
- Rapid decline in price of solar PV modules and energy generation costs.
- Emergence of new and innovative business models achieving economies of scale and hence reduced cost for end consumer.
- Improved reliability of the technology due to advances in system design, engineering and monitoring.

While relatively a global success, the solar rooftop energy system in India is still an evolving industry. In the current phase, limited exposure and lack of knowledge about the technology creates a perceived risk within the consumers and investor community about the reliability and performance of technology. Lack of standardized industry practices and trained workforce also contributes to this perception.

Solar PV rooftop, unlike its other similar alternatives, for example diesel generator, has a high upfront cost, longer system life, and a very low operations and maintenance (O&M) costs. At the price point end, without knowledge of total cost of ownership, the customer chooses lower cost known alternative over solar rooftop. There are other variables also influencing this decision such as energy demand of the site and available roof space to cater for this demand.

Lastly, in the case of grid connected solar PV rooftop, the rate of electricity purchased from the grid is much cheaper than the electricity produced from solar PV rooftop (levelized cost of energy) for a majority of consumers.

To address the above challenges, governments at all levels across the world have used policy and regulations to incentivize the use of solar PV rooftop plants. Some of the most used policy and regulations are listed below:

- **Gross Metering –** Metering framework where all the energy generated from solar PV rooftop system is exported to the grid with no internal consumption at the rooftop owner's property. Energy for self-consumption is imported from the grid. The user gets two items on their bills, one of energy consumption and another for exported energy.

- **Feed in Tariff (FIT) –** Electricity tariff scheme designed for rooftop PV plant users. The user is billed for electricity consumption coming from grid through the mains meter, while credited for the amount solar PV generated electricity exported through export meter. The export component of this energy transaction is termed as 'Feed-in-Tariff', and its value can be higher, equal or lower than the price paid for grid electricity, depending on the state or country's legislation.

- **Net Metering –** Metering framework where energy generated by the rooftop system is first used internally within the metered premises and the electricity, which is not used and regarded as excess, is exported to the grid through a bi-directional meter. The bill received by consumer is net of electricity imported from the grid minus electricity exported to the grid. This policy is used to increase self-consumption.

- **Solar Tariff –** Electricity tariff scheme where consumers under net metering framework are paid for excess power exported to the grid.

Other key policy and regulation instruments being used specifically in India by Central Government is summarized below:

- Subsidy on project cost for residential, institutional, government and social sectors.
- Accelerated depreciation, available to industrial and commercial buildings.
- Provision of loans from banks and financial institutions at concessional rates.
- Custom duty concessions and excise duty exemptions.

Table 5: The Problem, the Responses and the Solution

The Problem — What, Who And How Questions	The Responses	The Solutions
What are the drivers for solar PV rooftop? Why do we need this?	Respond to India's climate change mitigation goals, improve energy security, use existing roof space to provide energy directly to load, reduce load on the utilities to generate more electricity and avoid line losses	Deployment of solar rooftop systems
How many installations are desired to be undertaken?	High-level estimation of the potential, set targets accordingly.	Rooftop policy and regulations
What level and form of support is required from policy and regulations?	Incentives, subsidies, grants, excise and custom duty exemptions	
Who are going be the stakeholders and what roles will they perform in implementing this program?	Define roles for Central and State Ministries, regulators, utilities, grievance settlement bodies, set standards for market.	
How would the policies be implemented? How to account for solar energy units generated by the rooftop plants?	Gross metering, net metering, feed in tariff, solar tariff, renewable purchase obligations (RPOs) and renewable energy certificates (RECs)	Implementation models
What would the ownership possibilities for a solar PV rooftop plant?	Self-owned, third party ESCO, open access	Implementation framework
How would the program be administered at individual state and central grid level?	Guidelines, standards, procedures, customer interface for utilities	Implementation guidelines for state utilities

Solar PV Rooftop Development Framework

For successful implementation of solar PV rooftop programs, the following policy and development framework are required:

(1) A favorable policy and regulation
(2) Robust implementation models/framework
(3) Well defined and simple implementation guidelines for distribution companies

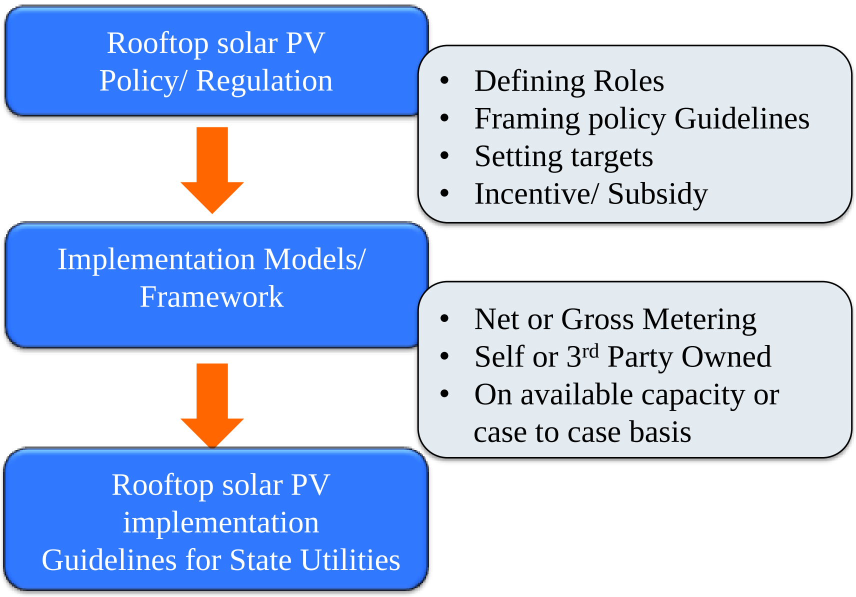


Figure 27: Solar PV Rooftop Development Framework

Conducive government policy availing financial incentives are critical for generating revenues for service providers and customers, which in turn make solar PV a viable business opportunity and investment. Similarly, mandatory RPO and more specifically solar purchase obligation can bring a boom to development of solar rooftop market.

Metering Requirement

Some financial incentives, such as capital subsidy and accelerated depreciation are provided to the consumers at the point of sale or tax return on assets. Others such as FIT, RECs and Generation Based Incentives are applied to the amount of solar power, which is produced. This requires establishing of mechanisms to account for energy generation from solar PV. **Gross metering and net metering** are the two popular metering schemes used across the world. Energy storage technology is an emerging trend, which will influence the future of metering schemes.

Interconnection Requirements

To enable effective commissioning of a grid connected rooftop system, complete execution of grid interconnection process is required. This involves meeting needs of all the stakeholders active within the interconnection process.

For Utilities, technical factors such as rated capacity of installed solar PV system, rated capacity of local transformer, connecting voltage levels, standards and certificates of inverters, anti-islanding protection are the key concerns for making a decision on allowing or disallowing integration to the grid.

For solar PV system providers and customers, commercial factors such as system performance guarantees, maintenance schedules, power purchase or system lease agreements (if applicable), and currency of these agreements are key concerns for making a decision on installation of a rooftop system.

For customers or renewable energy service providers (RESCOs), and the utility provides, billing factors such as cross subsidies charges, wheeling and banking charges, open access charges or change in minimum billing charges are key concerns for making a decision on choosing the size and configuration of a rooftop system.

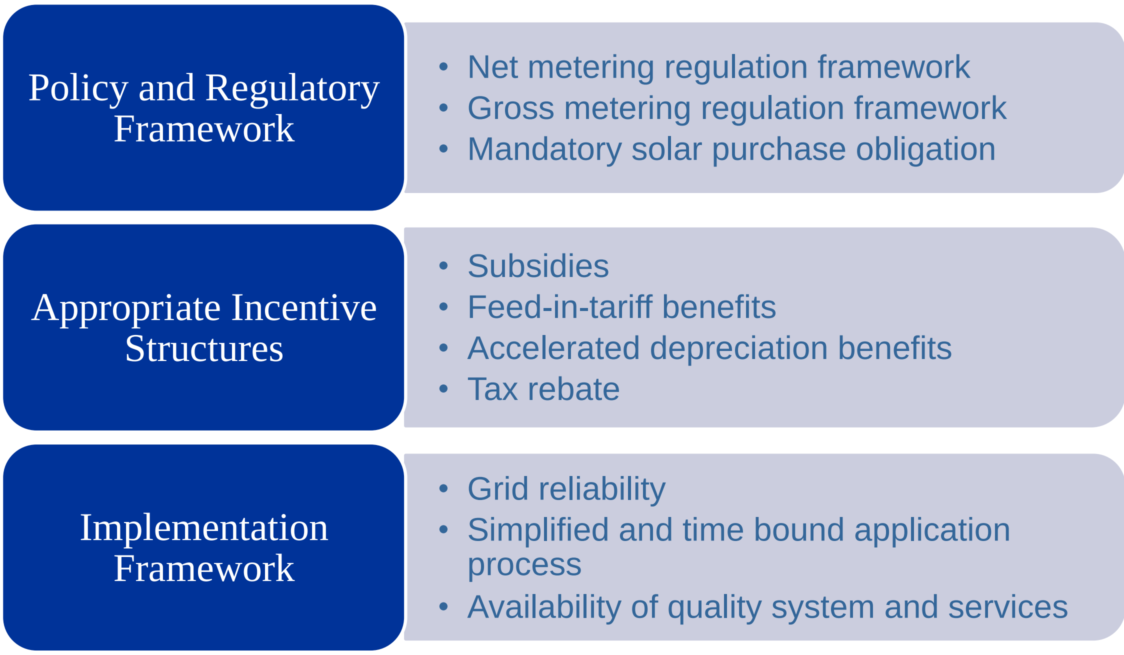


Figure 28: Key Requirements for Successful Rooftop PV Program

Solar Power Program Implementation

The renewable energy sector in India is open to private market investment. This has created a huge interest from private investors and companies, thus opening the solar PV sector to a range of options through which the rooftop plant program can be implemented. Currently, the following implementation pathways exist in India:

Utility Based Large-Scale Solar Power Projects: These projects are typically large scale. These projects are generally implemented through following models:

(1) IPP owned projects under FIT mechanism.
(2) Utility owned projects to meet RPO obligation.
(3) Other obligated entity owned projects to meet RPO obligation.
(4) IPP owned project for third party sale/captive use and avail benefit under REC mechanism .

Distributed Solar PV Rooftop Power Projects: These projects are of the range of few kW to few hundred kW. In limited cases, there are few MW scale rooftop projects as well. These projects are generally implemented through following models:

(1) Self-owned RTPV projects under net metering.
(2) Third party owned RTPV under FIT policy.
(3) ESCO owned RTPV for roof owners captive use.
(4) Utility owned projects to meet RPO obligation.
(5) Other obligated entity owned projects to meet RPO obligation.

A summary of solar power program implementation models is illustrated in Figure 29.

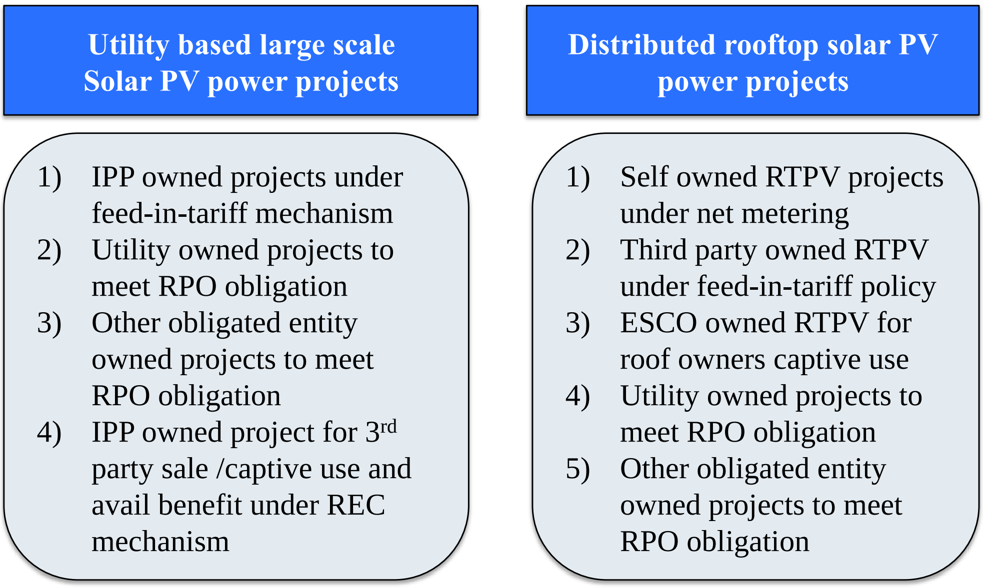


Figure 29: Solar Rooftop Power Program Implementation Model

Policy Instruments Adopted Globally to Implement Rooftop PV Program

Net metering, gross metering, FIT, and solar tariff has been used widely in many countries across the world to facilitate integration of solar PV rooftop system within electricity supply system. Germany is credited as one of the policy pioneers in the solar PV rooftop space.

Table 6: Policy and Regulatory Instruments Used Across the World

Country	Quantity	Pricing	Financial Incentives
Germany	FIT linked capacity cap (MW)- introduced recently	• FIT	• Capital subsidy • Low interest loans
Italy	FIT linked capacity cap (MW)- introduced recently	• FIT	• None
France	FIT linked capacity cap	• FIT	• Tax abatement on equipments
Spain	Annual capacity cap (MW)	• FIT	• Investment subsidies (prior to 2004)

Country	Quantity	Pricing	Financial Incentives
US	Energy purchase (RPS)	• Net metering	• Tax abatement on equipments • Capital subsidy • Tax rebates
Japan	Energy purchase (RPO)	• Now moved to FIT	• Capital subsidy

Key Stakeholders – Solar PV Rooftop Deployment

The key stakeholder groups required to effectively implement the rooftop PV projects are:

1. State Electricity Regulatory Commission (SERCs)
2. Distribution Utility (DISCOMs)
3. Eligible consumers
4. System installer

The roles and responsibilities of these stakeholders are listed in Table 7.

Table 7: Roles and Responsibilities of Stakeholders

Key Stakeholders	Responsibilities
SERCs	• To notify regulations for implementation of solar rooftops under gross/net metering arrangement • To determine benchmark capital cost and tariff for export of energy from rooftop systems under Net/gross metering arrangement • To approve power purchase agreement and Interconnection agreement • To determine charges for third party transaction (wheeling, banking, cascading style sheets [CSS] etc.)
DISCOMs	• Developing Information manual for interested parties • Established multiple communication channels for consumers • Drafting forms, formats, guidelines etc. for implementation of RTPV projects • Invite/Shortlist/Accept/Reject applications received from consumers • System up gradation/augmentation, system study, load flow analysis • Inspection, monitoring of utility grid and installed RTPV systems • Metering and billing of solar energy • Compliance to safety and protection measures
Eligible consumers	• Accessing Information from available communication channels (phone, email, in person etc.) • Evaluating potential opportunities for available roof/vacant ground space • Cost benefits analysis for installing solar rooftop system (net/gross etc.) • Meeting utility authorized personal (if required) • Arranging finance for the RTPV system (if required) • Engaging system provider/technical expert for installing RTPV system • Filling application forms and formats in utility prescribed format • Preparing relevant documents for submission of application
System installer	• Preparation of Detailed Project Report (DPR) and project feasibility • Installation of solar rooftop system • Ensuring safety standards and operational standards • Educating consumer for periodic O&M costs

Metering Arrangement

The Net Metering Concept
NetmMetering is the concept, which enables the eligible consumer, generates electricity using solar rooftop or other forms of renewable energy installed at its own premises for self-consumption and bank the excess electricity with the grid.

Excess energy that may be in the form of energy credits can be used to offset the electricity consumed by the consumer in next month energy consumption form the grid. In some cases (like Karnataka), the excess energy is bought by the utility at a Regulator defined FIT.

This whole process is made possible using a bi-directional meter, which records the net import and export of energy. Based on the net consumption shown in the meter, the consumer pays the bill as per the pre-determined tariff.

The gross and net metering arrangements are illustrated in Figure 30 and 31 respectively.

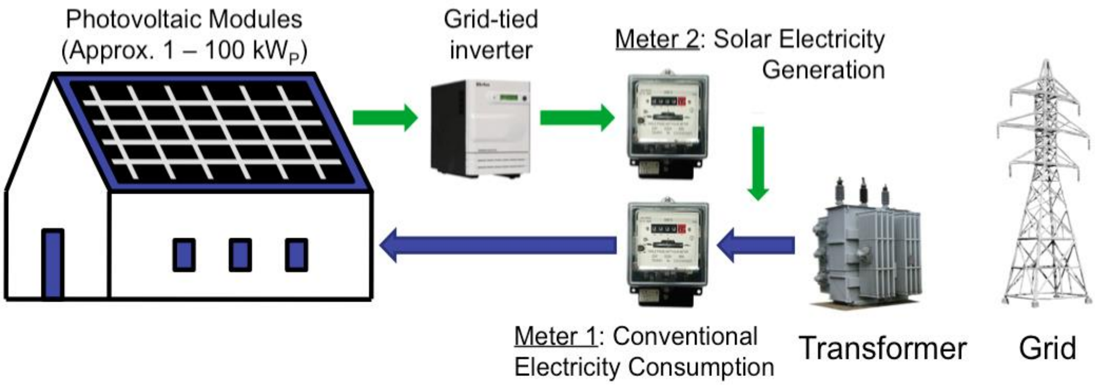


Figure 30: Gross Metering Arrangement

Gross Metering Arrangement: Energy generated from rooftop system is exported to the grid. Energy for self-consumption is imported from the grid. The user gets two line items on their bills, one of energy consumption and another for exported energy.

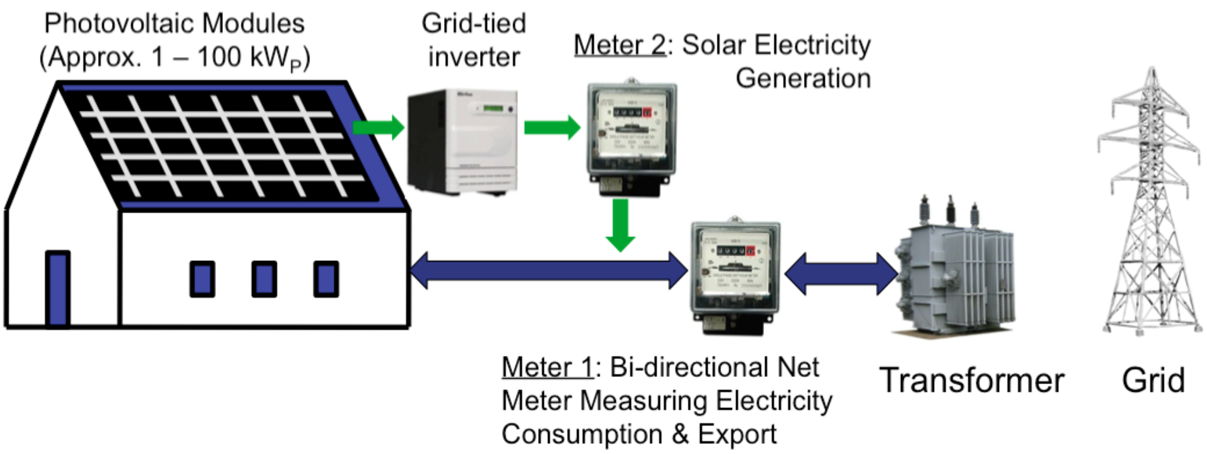


Figure 31: Net Metering Arrangement

Net Metering Arrangement: Energy generated by the rooftop system is primarily used internally and excess electricity is exported to the grid through a bi-directional meter. The bill received by consumer is net of electricity imported from the grid minus electricity exported to the grid.

The Net Metering Impact on Utility, Consumers and Third Party

As the solar PV rooftop market becomes more mainstream, it is expected to create few challenges for the traditional utility operations. Some of these challenges are summarized in Table 8.

Table 8: Impact of Net Metering on Different Stakeholders

Affected Stakeholder	Parameters	Impact
Impact on utilities	Sales of energy	Reduction in sale of electricity units going through the meter as a proportion of energy will be sourced from solar rooftop power systems
	Utility cash flow (0-10 years) agreement	Reduction in cash flow due to reduction in sales volume
	Utility cash flow (11-25 years) agreement	Reduction in cash flow due to reduction in sales volume and continued sourcing of energy units from rooftop systems
	Average power purchase cost (APPC)	Marginal increase in APPC as lesser power will be traded in the system, but grid maintenance costs will still need to be recovered
Impact on consumer	Consumer tariff	Consumer tariff could increase with time due to reduction in the number of units purchased by consumers and operating expenses of the utilities will be shared between lesser volumes of electricity units in the system
	Access to finance	A challenge for third party developers as their payments in turn depend on the credit profile of the consumer
Impact on third party transaction	Investment – Participation by third party	Lower participation by third party due to lack of certainty in returns from rooftop owner
	Project size optimization	Size optimization could not be achieved as system designing would primarily be for self-consumption
	Access to financing	Low due to lower contract enforcement, and redress mechanism
	Contract sanctity – Ease of enforcement	Highly dependent on a complex procure and redress based system, will prove to be a challenge

Key Parameters for Design of Net Metering Regulation

Some of the key parameters that are considered in design of a net metering regulation are listed in Table 109. The key objective of this regulation is to promote the use of renewable energy while maintaining the stability of grid.

Table 9: Key Parameters for Design of Net Metering Regulation

Features	Solutions
Metering mechanism	Net metering
Eligible consumer	The consumer class eligible for installing rooftop PV system
Project capacity	The limit (minimum or maximum capacity) of RTPV allowed under the framework, to avoid overloading transformer capacity
Aggregate capacity	Cumulative capacity of RTPV systems connected on the feeder or distribution transformer
Connecting voltage levels	The voltage level at which the RTPV projects will be connected
Excess generation	Quantity of excess generation allowed and the settlement of excess generation
Settlement period	Period for settlement of excess generation, i.e., yearly or half yearly
RPO/REC	Applicability of RPO and REC on solar energy generated from the RTPV
Metering	Metering provisions, standards, accuracy etc.
Other charges	Applicability of wheeling, banking cross subsidy surcharge etc.

Comparison of Different State Policy/Regulatory Orders

Many states electricity regulation commissions in India have come up with policy and regulatory orders for implementation of net metering scheme. A summary of few state RECs and their policy details have been summarized in Table 10.

Table 10: Summary of few state RECs and their policy

State	Chhattisgarh	Karnataka	Delhi
Issuing Authority	CSERC	KERC	DERC
Eligible Consumer		-	All Consumers
Project Capacity	50 kW – 1 MW	Up to 1 MW	Sanctioned load
Aggregate Capacity	-	-	Not more than 20% of DT
Treatment to Excess Generation	Injection shall not be more than 49% of annual generation	Excess generation shall be paid on tariff determined by KERC	Un-utilitzed energy credits shall be paid by the Discom at DERC determined price
Settlement Period	-	-	1st April to 31st March
Tariff for Excess Gen.	Rs. 4.35/kWh	Rs. 9.56/kWh	-
REC	-	-	Not eligible for REC
RPO for DISCOM	-	-	Shall qualify
Metering	Net Metering	Net Metering	Net Metering
Other Charges	Exempted	Exempted for 10 years	Nil for 5 years
3rd Party Sale	-	Allowed	Allowed

State	Haryana	Himachal Pradesh	Kerala
Issuing Authority	HERC	HPERC	KSERC
Eligible Consumer	All Consumers	All Consumers	All Consumers
Project Capacity	-	Not more than 80% of Sanctioned load	1 kW – 1 MW
Aggregate Capacity	Not more than 15% of the peak capacity of DT	30% of DT capacity	Not more than 80% of Avg. minimum load at the feeder
Treatment to Excess Generation	90% of the energy consumed by the Consumer by the end of settlement period	-	Consumer tariff as applicable for net energy supply.
Settlement Period	1st April to 31st March	-	1st Oct to 30th Sep
Tariff for Excess Gen.	-	As per HPERC	APPC
REC	Allowed under GM	As per CERC	-
RPO for DISCOM	Shall qualify	Shall qualify	Shall qualify
Metering	Gross and Net Metering	Net Metering	Net Metering
Other Charges	NA on Net Metering	Nil	Exempted
3rd Party Sale	Not allowed	Allowed	Allowed

5 Overview of Solar PV Rooftop Systems Design and Safety

Determining PV System Capacity/Size

Capacity or size of a rooftop PV system is generally determined by the roof area availability, installation purpose, and policy and regulatory framework under which the system is to be installed.

Deciding factors for rooftop PV system capacity:

(1) Availability of shadow free area
(2) Installation purpose and budget
(3) Government program and incentive guidelines
(4) State Electricity Regulation:
  a. Distribution transformer capacity
  b. Connected load

Rooftop PV System Design Configuration

Rooftop PV system design configurations are based on the type of inverter used and the arrangement of the PV modules, i.e. how many modules are connected in series (strings) or how many modules are connected in parallel.

The array consists of solar modules wired in series to provide a maximum power point voltage (V_{mp}) that lies within the operating window of the grid-connected inverter. The output voltage of the solar module, and therefore the array, will be dependent on the temperature. So when designing systems, it is important that the solar array operates within the operating range of the inverter voltage for all the expected daytime temperatures for a particular location where solar array is installed.

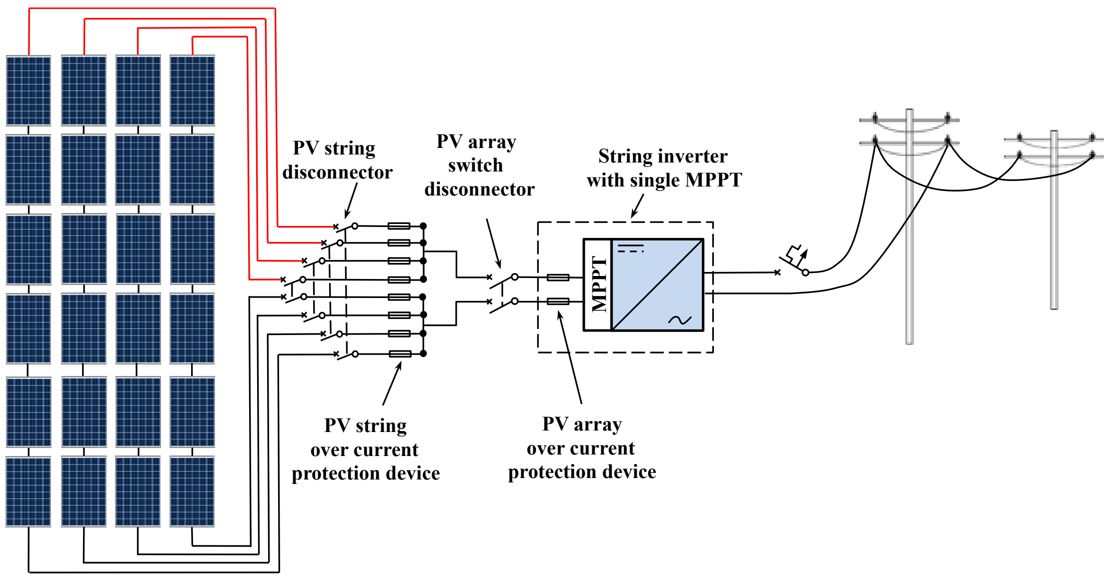


Figure 32: PV Array Connected With String Inverter

The number of modules connected in parallel will be dependent on the input current rating of the inverter and the output current rating of the modules as well as the number of modules connected in each string. This is because the power rating of the array must be suitable for the power rating of the inverter as well as being within the current and voltage limits of the inverter.

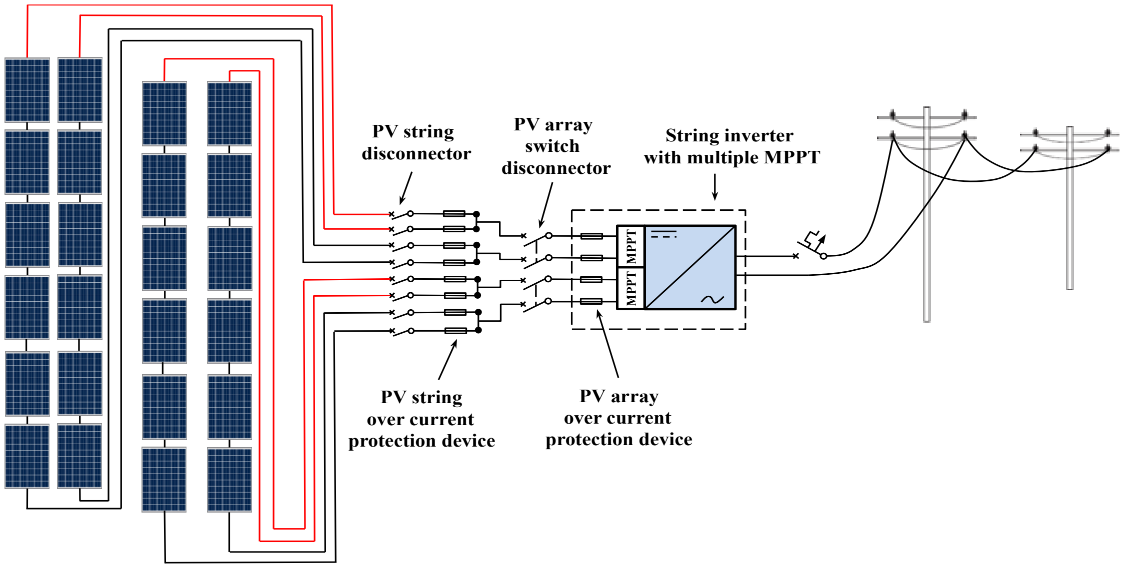


Figure 33: PV Array Connected With Multi-String Inverter

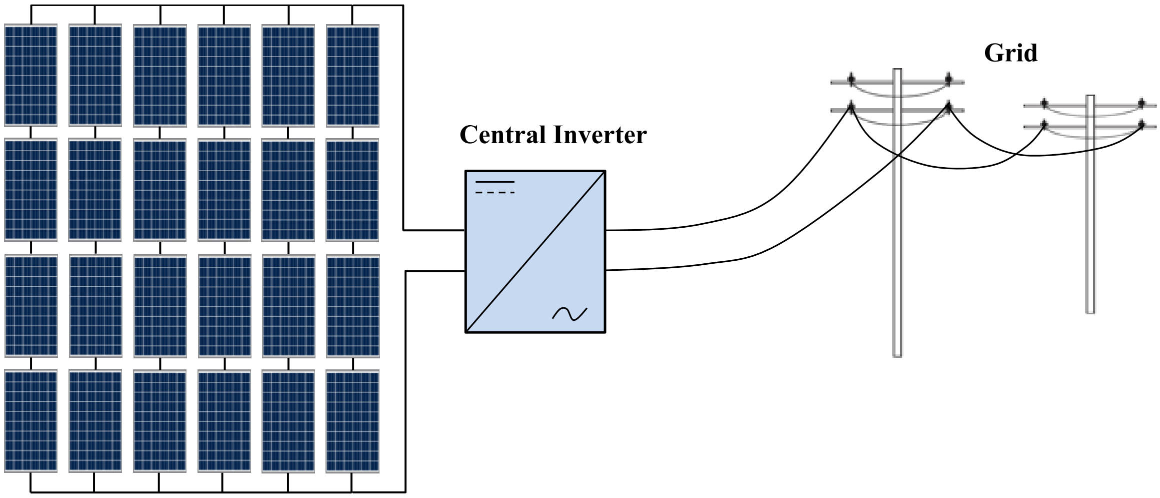


Figure 34: PV Array Connected With Central Inverter

The array configurations are also dependent on the number of MPPT algorithms of the inverter. According to IEC 62548 photovoltaic array design requirement, when an inverter has multiple MPPT inputs, overcurrent protection section of the array may be treated as a separate PV array and each PV array shall have a switch disconnector to provide isolation of the inverter.

Where inverter has a single MPPT and multiple input circuits are internally paralleled onto a common DC bus, each PV section connected to one of those inputs shall be treated as a sub-array and each PV sub-array shall have a switch disconnector to provide isolation of the inverter.

Array Mounting Structure Design

Support structures and module mounting arrangements should comply with applicable building codes regulations and standards and module manufacturer's mounting requirements.

The following aspects are to be considered in designing array mounting structure:

Thermal Aspects

PV modules generally have aluminum frames and are mounted on metal frames that may contract and expand under different operating conditions. Therefore design of mounting structure must consider this aspect as per the manufacturers' recommendation.

Mechanical Loads

The PV array support structures should comply with international standards, industry standards and regulations with respect to loading characteristics. Particular attention should be taken when installing PV array systems in areas of high wind speeds and regions with lots of snowfall.

Corrosion

The metals used in the structure should be made from a corrosion resistant or appropriate protective coating should be applied so that the structure is free from corrosion throughout its life. Special care must be taken when using metals of two dissimilar metals to avoid bi-metallic corrosion.

Wind

PV modules, module mounting frames and the methods used for attaching frames to buildings or to the ground shall be rated for the maximum expected wind speeds at the location according to IS 875 (Part 2).

Material Accumulation on PV Array

Snow, ice or other material may build up on the PV array and should be accounted for when selecting suitably rated modules, calculating the supporting structure for the modules and likewise, when calculating the building capability to support the array.

Safety Issues — Personal and System Safety

Protection Against Electric Shock

For protection against electric shock, the requirements of IEC 60364-4-41 and CEA (measures relating to safety and electric supply) 2010 shall apply.

According to IEC 62548: Photovoltaic array design requirement PV arrays for installation on buildings shall not have maximum voltages greater than 1,000 V DC.

Protection Against Overcurrent

PV modules are current limited sources but can be subjected to over currents because they can be connected in parallel and also connected to external sources. Overcurrent within a PV array can result from earth faults in array wiring of from fault currents due to short circuits in modules, in junction boxes, combiner boxes or in module wiring.

PV System Architecture for Earthing

The relation of a PV array to earth is determined by whether any earthing of the array for functional reasons is in use, the impedance of that connection and also by the earth status of the inverter.

Protective earthing of any of the conductors of the PV array is not permitted. Earthing of one of the conductors of the PV array for functional reasons is not allowed unless there is at least simple separation from mains earth provided either internally in the PCE or externally via a separate transformer.

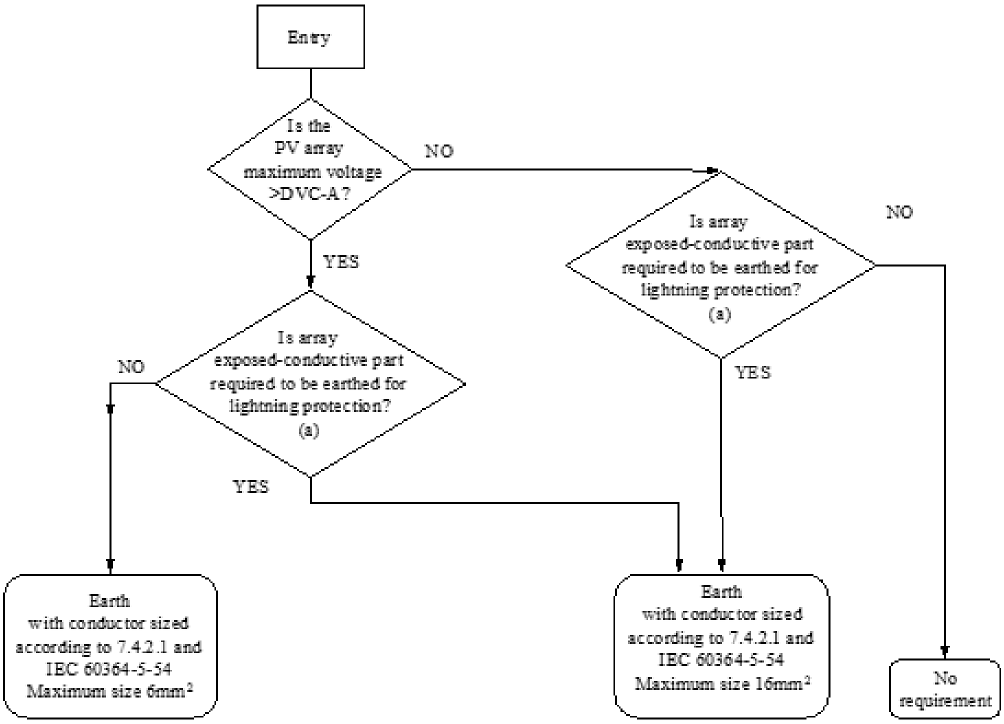
A connection of one conductor to earth through internal connections inherent in the inverter via the neutral conductor is allowed in a system without at least simple separation.

Table 11: Earthing Based on Array Configurations

Array Configuration	Inverter Type	Is there Functional Earthing?	Is Equipotential Bonding Required?
Functionally unearthed array	Isolated inverter	No	Yes
Functionally unearthed array	Non-isolated inverter	No	Yes
Functionally earthed array	Isolated inverter	Yes	Yes
Functionally earthed array	Non-isolated inverter	This configuration is NOT permitted.	

As per IEC 62548 photovoltaic array design requirement. a functionally earthed array shall NOT be connected to a transformer-less (non-isolated) inverter. The configuration is not permitted due to a high probability that the inverter will introduce direct current into the AC electricity grid.

Figure 35 illustrates the different types of system configurations and if there is functional earthing and if equipotential bonding is required.



Source: IEC 62548

Figure 35: PV Array Functional Earthing Decision Tree

Lightning Protection for Rooftop System

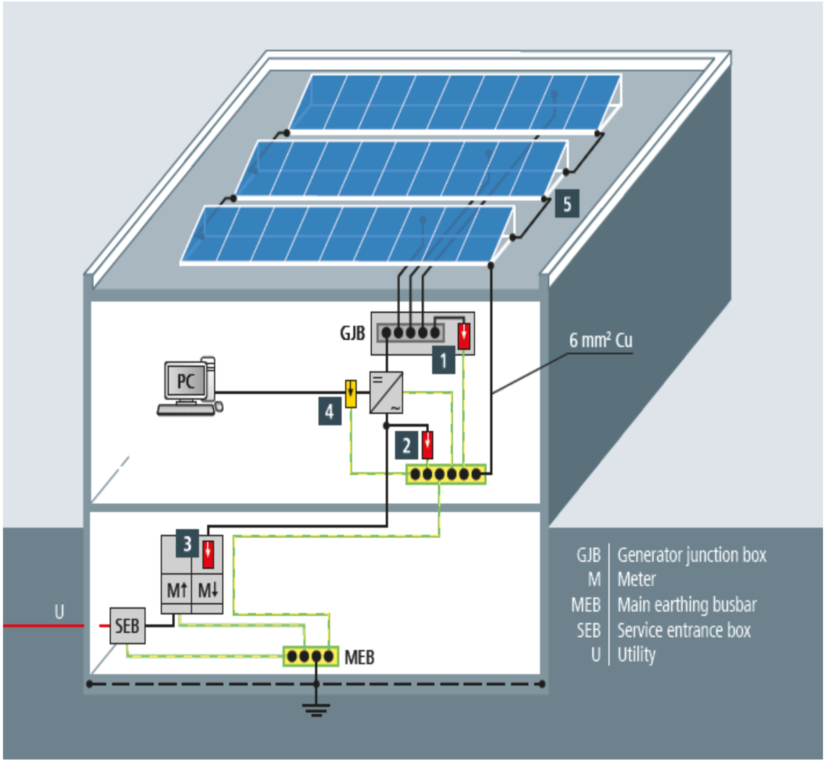
The installation of a PV system has no direct relation to the probability of lightning strikes, but in case the system is installed in regions where thunderstorms are of common occurrence, it is recommended to install a lightning protection system as per the standards in IEC 62305-3.

To protect the system as a whole, surge protection devices can be fitted between the active conductors and earth at the inverter end of the DC cabling and the array. To protect specific equipment, surge protection devices may be fitted as close is practical to the device.

Based on the necessity and the available area, Lighting Surge Protection Devices can be arranged based on the configurations given below:

Case 1: Building Without External Lightning Protection System

If a PV system is installed on a new or on an existing building and no external lightning protection system is installed according to a risk analysis in line with the IEC/EN 62305-2 standard, it is not required to install an external lightning protection system. However, in such case, according to EN 62305-3 standard a Type 2 surge protective device shall be installed on the DC and AC side to protect PV systems against inductive and conducted interference pulses. The number of SPDs depends on the distance between the device to be protected and the SPD. If this distance exceeds 10m, additional SPDs are required.



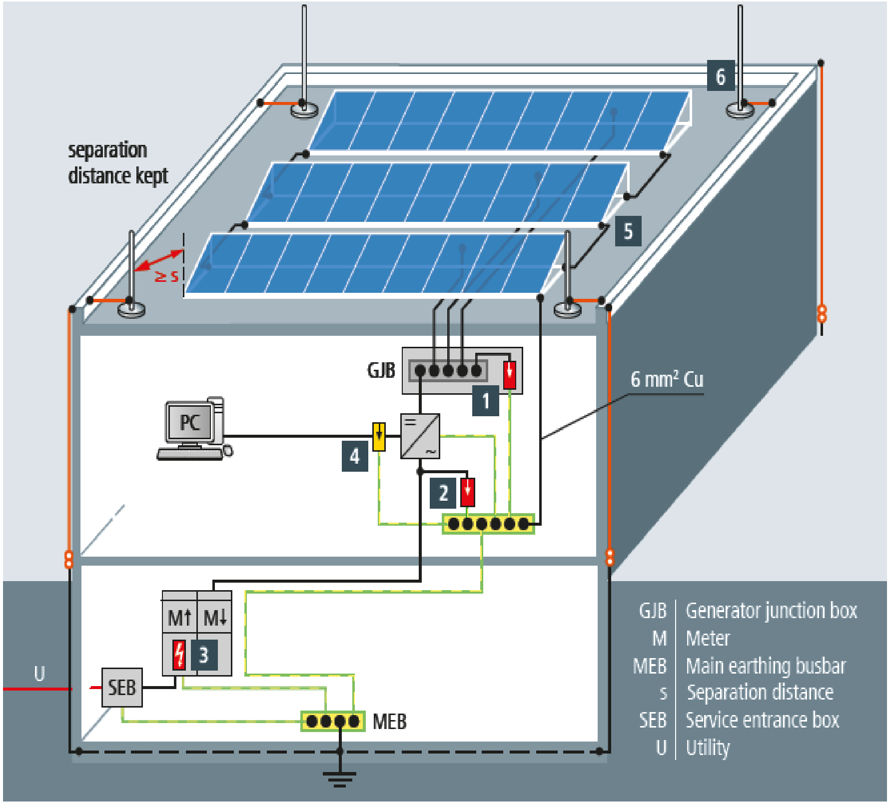
Source: www.dehn-international.com

Figure 36: Installation of a Rooftop PV System Without Lightning Protection

Case 2: Building With External Lightning Protection System and Adequate Separation Distance

If the building has (or require) an external lightning protection system according to risk analysis as well as national regulations, and separation distance are kept between lightening arrestor and PV array structure, a lightning protection system should be preferred which is not directly connected with the PV power supply system. The modules must be located in the protected zone of the isolated air-termination system.

If the separation distance calculated according to the IEC/EN 62305-2 standard is maintained, Type 2 arresters must be used to protect the inverter on the DC side and the modules. The number of SPDs depends on the distance between the device to be protected and the SPD. If this distance exceeds 10m, additional SPDs are required. The AC side is protected by installing a combined arrester at the grid connection. If the distance between the grid connection and the inverter exceeds 10m, it is advisable to install an additional Type 2 arrester on the AC side of the inverter.



Source: www.dehn-international.com

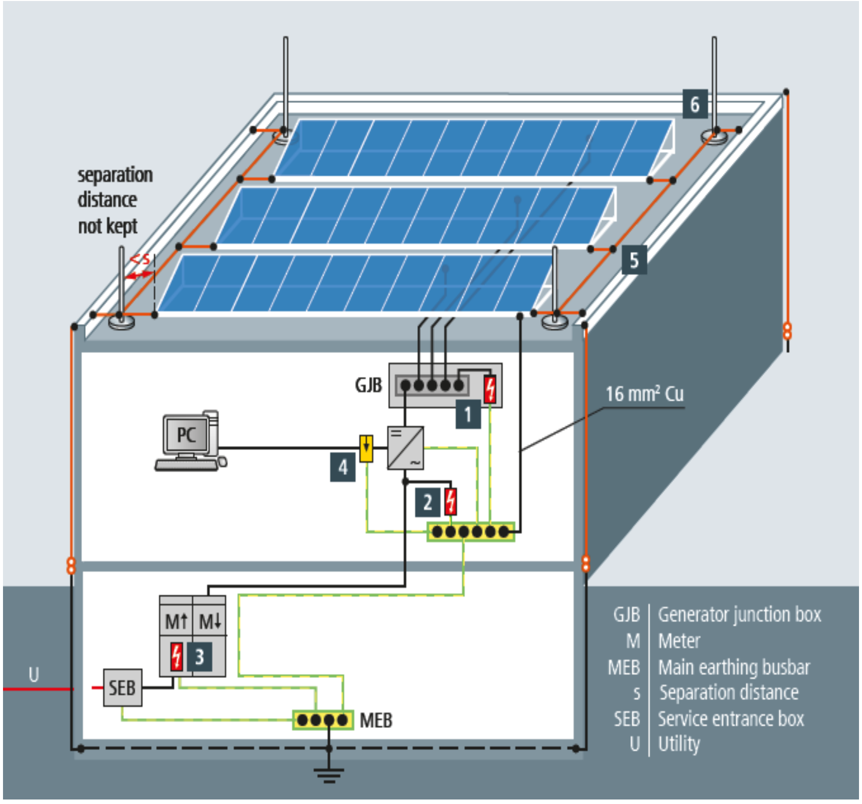
Figure 37: Installation of a Rooftop PV System with a LPS (Ample Roof Space)

Case 3: Building With External Lightning Protection System Without Adequate Separation Distance

If the building has (or require) an external lightning protection system according to risk analysis as well as national regulations, a lightning protection system should be preferred which, if the required separation distances are kept, is not directly connected with the PV power supply system.

If the separation distance calculated according to IEC/EN 62305-2 cannot be maintained, for example in case of metal roofs, lightning equipotential bonding must be established.

Type 1 combined arresters must be provided to protect the inverter on the DC side and the modules. The number of SPDs depends on the distance between the device to be protected and the SPD. If this distance exceeds 10m, additional SPDs are required. The AC side is protected by installing a combined arrester at the grid connection. If the distance between the grid connection and the inverter exceeds 10m, it is advisable to install an additional Type 1 arrester on the AC side of the inverter.



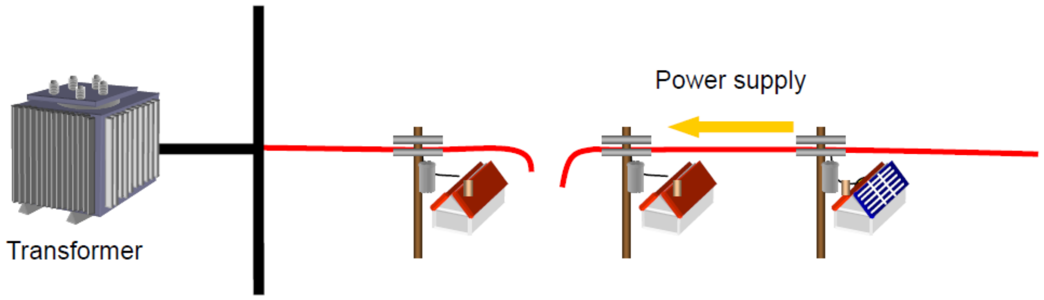
Source: www.dehn-international.com

Figure 38: Installation of a Rooftop PV System With a LPS (Limited Roof Space)

Grid Protection — Unintentional Islanding

One of the major concerns about unintended islanding is the "increased risk of accident". In the case of grid fault or planned grid maintenance, the network operators must repair the distribution lines as soon as possible. Before starting the work, it must be confirmed that the lines are disconnected from the main grid, in other words, out of electricity. However, if PV systems or other distributed power generators are still supplying power to the lines, it could lead to electric shock of workers. It has also been pointed out that since the power is continuously supplied to the fault point, the public is exposed to the risk of electric shock. In addition to physical injury, studies indicate that unintended islanding could also damage grid/end-users' devices.

Another unintended islanding problem is the "risk of overcurrent" during the breaker reclosing process. With the main grid and the distribution line operating independently during unintended islanding, the voltages are not in synchronized operation and could be out of phase. If the breaker is reclosed with a large voltage phase difference, a strong current will flow into the line, which is very dangerous (Overcoming PV Grid Issues in Urban Areas, IEA 2009: Japan).



Source: Overcoming PV Grid Issues in Urban Areas (IEA 2009: Japan)

Figure 39: Unintended Islanding Condition

The Grid protection must disconnect the inverter from the grid when:

- The power supply from the grid is disrupted.
- The grid goes outside the preset parameters of the inverter.

The inverters disconnect from the grid in either of the above situations to avoid 'islanding' through two types of internal protection called passive and active protection

Passive Protection: the inverter disconnects if it detects grid conditions, which are over or under the voltage and/ or over or under the frequency settings of the inverter;

Active Protection: the inverter will include either frequency or voltage drift such that when the inverter is disconnected from the larger grid, the voltage or frequency will drift to the point where the passive protection will cause the inverter to trip.

According to IEEE 1547 and CEA (technical standards for connectivity of the distributed generation resources) Regulation 2013, for an unintentional island the grid tied inverter shall detect the island and cease to energize within two seconds of the formation of an island.

According to IEEE 1547, the grid connected rooftop soar system shall include and adjustable delay (or a fixed delay of 5 minutes) that may delay reconnection for upto five minutes after the grid voltage and frequency restored. As per CEA Regulation 2013 delay in reconnection shall be at least 60 seconds

In case another power generation source like DG set in the consumer facility is operated when grid is not available, the inverter may sense the grid availability and if operation parameters are within the working range, it will start functioning and will start feeding to the DG grid depending on regulation, if allowed or not.

Selection of PV Module and Array BOS Components

PV Array Maximum Voltage

According to IEC 62548, all components, shall be rated for DC use, having a voltage rating equal to or greater than the PV array maximum voltage determined in section 7.2 of IEC 62548 and having a current rating equal to or greater than that shown in Table 12.

Table 12: Voltage Correction Factors for Crystalline Modules

Lowest Expected Operating Temperature (^oC)	Correction Factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
- 26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

Source:IEC 62548

Qualification of PV Modules

Crystalline silicon modules shall comply with IEC 61215. Thin film PV modules shall comply with IEC 61646. Systems with voltages above 50 V DC should include bypass diodes. Only Class A and Class C modules shall be used for grid connected PV systems according to IEC 61730-1 and IEC 61730-2. Class B modules shall not be used for grid connected systems.

Class A: Modules rated under this class may be used in systems operating at greater than 50 V DC or 240W as per safety requirements in IEC 61730 – 1 and IEC 61730.

Class C: Modules rated for use in this application class restricted to systems operating at less than 50 V DC and 240 W, where general contact access is anticipated

Class B: Modules shall not be used (modules rated for Class B are restricted to systems protected from public access by fences, location, etc.)

Qualification of Combiner Boxes
PV array and PV string combiner boxes exposed to the environment shall be at least IP 54 compliant in accordance with IEC 60529, and shall be UV resistant.

PV array and PV string combiner boxes which contain overcurrent and or switching devices shall be capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like.

Qualification of Cables
DC cables must be rated at temperature 40˚C or above, shall be double insulated, shall be UV-resistant, shall be water resistant. If exposed to salt environments be tinned copper, multi stranded conductors to reduce degradation of cable over time.

Installation of Isolator

Isolators are used as protective devices, which help isolate elements of the system during high current flow caused either due to fault or due to external elements such as lighting, storms etc. Another functionality of breakers is that if there is any maintenance work to be done, they can be used to disable a part of the system while still connected to the load (hence they are also termed load breaking) so that maintenance can be performed.

Based on their position in the system, DC and AC isolators are used mainly at the connections between the PV array junction box (To protect the inverter from excess current from the array) and after the inverter respectively (To disconnect the entire system in case of grid fault).

PV Array DC Isolator
A double-pole, load breaking, DC rated isolating (disconnect) switch should be installed on the DC side of the inverter. It should be rated appropriately for the voltage and current of the PV system.

Inverter AC Isolator
Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013 requires an inverter AC isolator to be installed on the output of the inverter.

A Main Switch lockable in off position is required to be installed in the switchboard, which is located at a height of at-least 2.44m above the ground level. This allows the PV system to be disconnected from the mains power supply. This main switch may not be rated for load break nor may have feature of overcurrent protection.

Cable Management at Array

Wiring of PV arrays shall be undertaken with care to protect the cables from any mechanical damage. It is important to note that damage of cables may cause line-to-line or line-to-earth fault, which can cause arc and possible fire.

All connections must verify for tightness and polarity during installation to avoid risk of faults and possible arcs during commissioning, O&M.

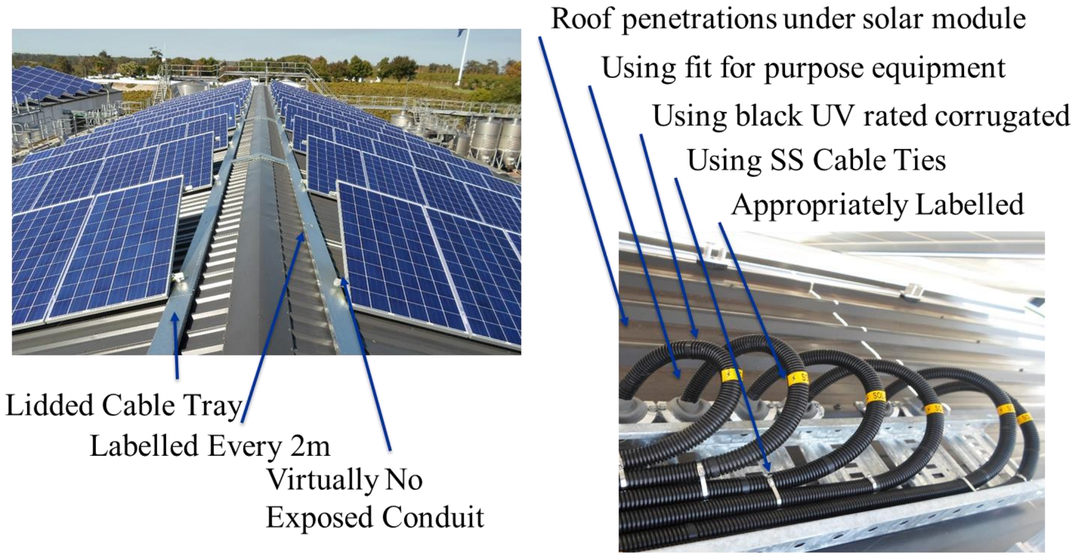


Photo Credit: GSES

Figure 40: Example of Good Cable Management

Cabling and Interconnection

PV array should be laid in such a way that area of conductive loop is minimized. This will reduce the magnitude of lightening-induced overvoltage and disturbance to communication network under the building.

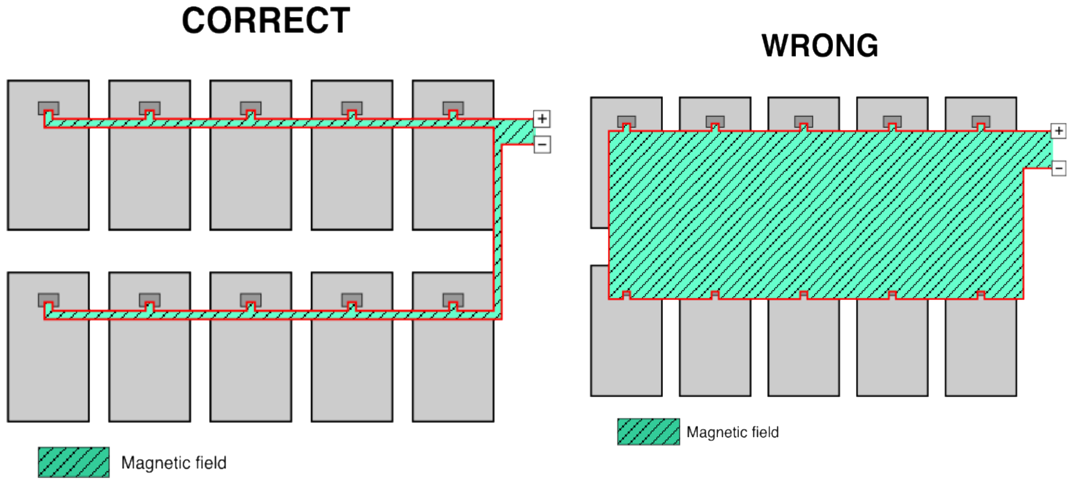


Figure 41: Example of Good Cable Interconnection

Documentation

As per IEC 62446: Grid-connected photovoltaic systems — Minimum requirements for system documentation, commissioning tests, and inspection.

- System data.
- Nameplate data – Rated power, manufacturers, models and quantities of PV modules and inverters.
- Cover page data - Contact information for the customer, system designer and installer, and relevant project dates.
- Wiring diagrams (single line diagram with equipment information).
- Data sheets (module and inverter).
- O&M information.
- Test results and commission data.

6 GRID CONNECTIVITY AND INSPECTION PROCEDURE

Grid connectivity, inspection and approval mark the final steps within the solar PV rooftop project process. A successful connectivity and inspection procedure requires adherence to certain standards, regulations and guidelines, which are designed to commission a technically safe and compliant project and ensuring that the system is operational.

The standards and regulations relevant to the grid connectivity and inspection procedure are listed below. These standards detail the requirements related to performances, operation, testing, safety, and maintenance of grid connectivity and inspection activities.

These standards can either be purchased or sourced from the web. Full text description of the standards is beyond the scope of this training manual. However, general principles of these standards are summarized in the following sections.

Applicable Standards and Regulations

- Central Electricity Authority (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations, 2013
- IEEE 1547 — Standard for Interconnecting Distributed Resources With Electric Power System, 2003
- Central Electricity Authority (Measures Relating to Safety and Electricity Supply) Regulations, 2010
- Central Electricity Authority (Technical Standards for Connectivity to the Grid) Regulations, 2007
- IEEE 519: Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, 2014

Interconnection Technical Specifications and Requirements

As mentioned previously, the interconnection process is guided by specific standards and procedures, which outline the technical specifications to which an interconnection process must adhere.

The requirements outlined in the specifications shall be met at the point of interconnection, although the instruments used to meet these requirements can be located away from the point of interconnection. However, all the interconnection system hardware and software that affect the grid are required to meet the standard regardless of their location within the electric power system.

These requirements apply to interconnection of either a single solar PV rooftop system or multiple PV systems.

The following section highlights the key specifications of an interconnection process. Please note that the specifications have been separated on three conditions of operations – general requirements, response to abnormal conditions, and power quality.

General Requirements:

- **Voltage Regulations —** The distributed resources shall not actively regulate the voltage at the point of interconnection**.**

- **Synchronization —** The distributed resource synchronized with electric system shall not cause a voltage fluctuation at the point of interconnection greater than ±5 percent.

- **Monitoring Provision —** Each distributed resource of 250 kVA or more at a single point of interconnection shall have provisions for monitoring its connection status, real power output, reactive power output, and voltages at the point of interconnection.

- **Isolation Device —** There should be a manually operating isolating switch between distributed generation resource and electric system, which shall meet the following requirements:

    - Allow visible verification that separation has established.
    - Indicators to show clearly closed and open position.
    - Be capable of readily accessible and be capable of being locked in open position
    - May not be rated for load-break.
    - Be located at height of 2.44 m above ground level.

Interconnect Integrity:

- Interconnection system shall have the capability to withstand electromagnetic interference.
- Paralleling device shall withstand 220 percent of interconnection system rated voltage.
- Interconnection system shall have the capability to withstand voltage and current surge.

Response to Abnormal Conditions:

- **Voltage —** Inverter must have over and under voltage trip functions, if voltage reaches above 110 percent or below 80 percent respectively with clearing time up to two seconds.

- **Frequency —** Inverter must have over and under frequency trip functions, if frequency reaches 50.5 hertz (Hz) and below 47.5 Hz with a clearing time of 0.2 seconds.

- **Islanding —** Inverter must have function to prevent formation of unintended island, and cease to energise the electricity system within 2 seconds.

Power Quality:

- **Limitation on DC Injection —** The solar rooftop and its interconnection system shall not inject DC current greater than 0.5 percent of the full rated output current.
- **Limitation of Flicker —** The distributed resource shall not cause objectionable flicker on the electric system (IEC 61000).
- **Harmonics —**The distributed resource shall not inject harmonic current greater than 5 percent at the electric system (IEEE 519).

Interconnection Voltages

In India, the SERCs specify and regulate the interconnection voltages for connecting solar PV rooftop to the grid.

The specifics and technical details of connecting voltage requirements varies from state to state. A general guideline on rated capacity and connecting voltages are summarized in Table 13. These capacities usually fall under the grid codes of respective states.

Table 13: System Capacity and Connecting Voltage

System Capacity	Connecting Voltage
Less than 4 kW (or 5/6/ 7/10 kW in some states)	240 V_{AC}, 1φ, 50 Hz
More than 4 kW (or 5/6/ 7/10 kW in some states) but less than 50 kW (or 75/ 100/112 kW in some states)	415 V_{AC}, 3φ, 50 Hz
More than 50 kW (or 75/100/112 kW in some states) but less than 1 MW (or 2/3/4/5 MW in some states)	11 kVAC, 3φ, 50 Hz

Interconnection Parameters

The grid is a complex system comprising of various electrical and magnetic properties associated with an AC electrical supply system. Traditionally, the grid has been used to transmit power produced at centralized generation plants, and already has established norms, and performance standards for power quality, safety, and service.

The introduction of grid connected solar PV rooftop systems creates multiple power injection points within the electrical supply system, thus exposing the grid to the risk of destabilization in the event of lack of interconnection guidelines and standards.

The interconnection process, therefore, needs to comply with the established standards regulating various electrical supply parameters. This is to ensure the safety, quality and stability of the grid.

The relevant electrical supply parameters, their prescribed standards, and requirements within these standards have been listed in Table 14.

Table 14: Interconnection Parameters

Parameter	Reference	Requirement
Overall Conditions of Service	State Distribution/Supply Code	Reference to State Distribution Code
Overall Grid Standards	Central Electricity Authority (Grid Standard) Regulations 2010	Compliance
Equipment	BIS/IEC/IEEE	Compliance
Meters	Central Electricity Authority (Installation and Operation of Meters) Regulation 2006 Amendments Thereof, OERC Generic Tariff Order 2013	Compliance
Safety and Supply	Central Electricity Authority (Measures of Safety and Electricity Supply) Regulations, 2010	Compliance
Harmonic Current	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	Harmonic current injections from a generating station shall not exceed the limits specified in IEEE 519
Synchronization	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	RTPV system must be equipped with a grid frequency synchronization device, every time the generating station is synchronized to the electricity system. It shall not cause voltage fluctuation greater than +/- 5 percent at the point of connection
Voltage	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	The voltage-operating window should minimize nuisance tripping and should be under the operating range of 80 percent to 110 percent of the nominal connected voltage. Beyond a clearing time of 2 seconds, the RTPV system must isolate itself from the grid.
Flicker	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	Operation of solar PV rooftop system should not cause voltage flicker in excess of the limits stated in IEC 61000 standards or other equivalent Indian standards, if any.
Frequency	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	When the distribution system frequency deviates outside the specified conditions (50.5 Hz on upper side and 47.5 Hz on lower side), there should be over and

Parameter	Reference	Requirement
		under frequency trip functions with a clearing time of 0.2 seconds.
DC Injection	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	RTPV system should not inject DC power more than 0.5 percent of full rated output at the interconnection point 1 percent of rated inverter output current into distribution system under any operating conditions.
Power Factor	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	While the output of the inverter is greater than 50 percent, a lagging power factor of greater than 0.9 should operate.
Islanding and Disconnection	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	The RTPV system in the event of fault, voltage or frequency variations must island/disconnect itself within IEC standard on stipulated period.
Overload and Overheat	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	The inverter should have the facility to automatically switch off in case of overload or overheating and should restart when normal conditions are restored.
Paralleling Device	IEEE 519 CEA (Technical Standards for Connectivity of the Distributed Generation Resources) Regulations 2013	Parallel device of RTPV system shall be capable of withstanding 220 percent of the normal voltage at the interconnection point.

Component Inspection Checklist

A sample checklist, which can be used to validate the components used within the grid connected solar PV rooftop installation at an interconnection inspection schedule is provided in Table 15. The checklist is only a guide and can be amended to suit an organization's specific requirements.

Table 15: Component Inspection Checklist

Sr. No.	Item Type	Yes	No
1	Installation Layout – Is it as per drawing?		
2	Inverter IEC standard qualified		
3	PV panel IEC standards qualified		
4	PV isolators/PV cables IS/IEC standards qualified		
5	AC disconnect manual switch provided with locking arrangements		
6	Meters approved by concerned authority		

Grid Connected Functional Safety Checklist

A sample checklist, which can be used to validate the functionality of components used within the grid connected solar PV rooftop installation at an interconnection inspection schedule is provided in Table 16. The checklist is only a guide and can be amended to suit an organization's specific requirements.

Table 16: Gird Connected Functional Safety Checklist

Sr. No.	Item Type	Yes	No
1	Check whether solar generation stops automatically when DISCOM supply is shut off		
2	Confirm bi-directional flow recorded on net meter		
3	Check 'Consumption (Import) Only' mode operation		
4	Check operation of solar (generation) meter		
5	Check all protection and earthing points		
6	Confirm solar and bi-directional meter tested and sealed by DISCOM meter testing lab		
7	Confirm the manual isolating switch is installed at accessible location and is with locking arrangement		
8	Check whether manual isolating switch stops feeding supply in grid when in OFF position		

Interconnection Test Specifications and Requirements

After completion of the grid interconnection process, testing and approval of the interconnection circuits is required to ensure that they are adhering to the technical specifications of relevant standards. Tests are done on the following points of the interconnection system:

- **Isolation Device —** A system design verification shall be made to ensure that the requirements have been met.
- **Monitoring Provision —** A system design verification shall be made to ensure that the provisions for monitoring are in accordance with the requirements.
- **Grid Fault —** A system design verification shall be made to ensure that in case of grid fault, the solar inverter shall cease to energize the grid to which it is connected.
- **Grounding Integration With Grid —** A system design verification shall be made to ensure that solar inverter shall not cause over voltage and shall not disrupt the coordination of the ground fault protection connected to the grid.

Commissioning Tests

Commissioning tests are critical to ensure proper working of the system. These parameters are specifics of a well-managed commissioning test as follows:

- All commissioning tests shall be performed based on written test procedures of equipment manufacturer/system integrator.

- A visual inspection shall be made to ensure that the system earthing is adequate as per standard/regulation.

- A visual inspection shall be made to confirm the presence of the isolation device as required by the standard/regulation.

- The following initial commissioning tests shall be performed on the installed solar system and grid connected inverter prior to the initial parallel connection to the grid:
    - Operability test on the isolation device.
    - Unintentional-islanding functionality.
    - Cease to energize functionality.

Unintentional Islanding Functionality Test

Unintentional islanding can have undesirable impact on customer and utility equipment integrity. If the unintentional island is sustained for a significant period of time, personnel safety could become a cause for concern. Even if the unintentional islanding period is short, the potential degraded power quality could still be a concern. For these reasons, the risk of unintentional islanding must be kept low. To manage these risks, a series of functionality tests are required.

These tests must be conducted at a time of day when the prevailing weather conditions allow the PV system to be producing greater than 20 percent of the rated output of the PV array or the inverter; whichever is less. If there is more than one inverter, tests should be carried out for each inverter.

Test 1: Inverter Must Cease Supplying Power Within Two Seconds of a Loss of Mains

The PV array main switch is to be turned OFF. The time taken for the inverter to cease attempting to export power is to be measured with a timing device and recorded.

A voltage probe placed on the installation side of the main solar switch is to be used to determine when the inverter has ceased attempting to export power.

The DC supply from the solar array is to remain connected to the inverter for the duration of this test.

Test 2: Inverter Must Not Resume Supplying Power Until Mains Have Been Present for More Than 60 Seconds.

The time taken for the inverter to resume power supply after installation has been re-energised is to be measured and recorded.

A current probe is to be placed on the installation side of the main switch to determine when the inverter recommences exporting power.

The DC supply from the solar array is to remain connected to the inverter for the duration of this test. Records the tester must make copies of the test record.

Periodic Interconnection Tests

- All interconnection-related protective functions and associated batteries shall be periodically tested at intervals specified by the manufacturer, system integrator or the authority who has jurisdiction over the DR interconnection.

- Periodic test reports shall be maintained.

7 Administrative Procedure for Implementing RTPV Projects

Implementation Steps for Solar PV Rooftop Projects

There can be four distinct steps for implementation of solar PV rooftop projects. These steps are shared between the consumer or the developer and the utility.

The flow of work is typically in the following order:

1. Consumer, or developer on consumer's behalf approach the DISCOM with grid interconnection application.
2. The DISCOM examines the technical feasibility of the project within the distribution area of the transformer.
3. Upon satisfactory completion of all the relevant procedures, the system is installed and connected to the grid.
4. The utility performs final inspection and gives a verdict on commissioning of system.

This above process is illustrated in Figure 42.

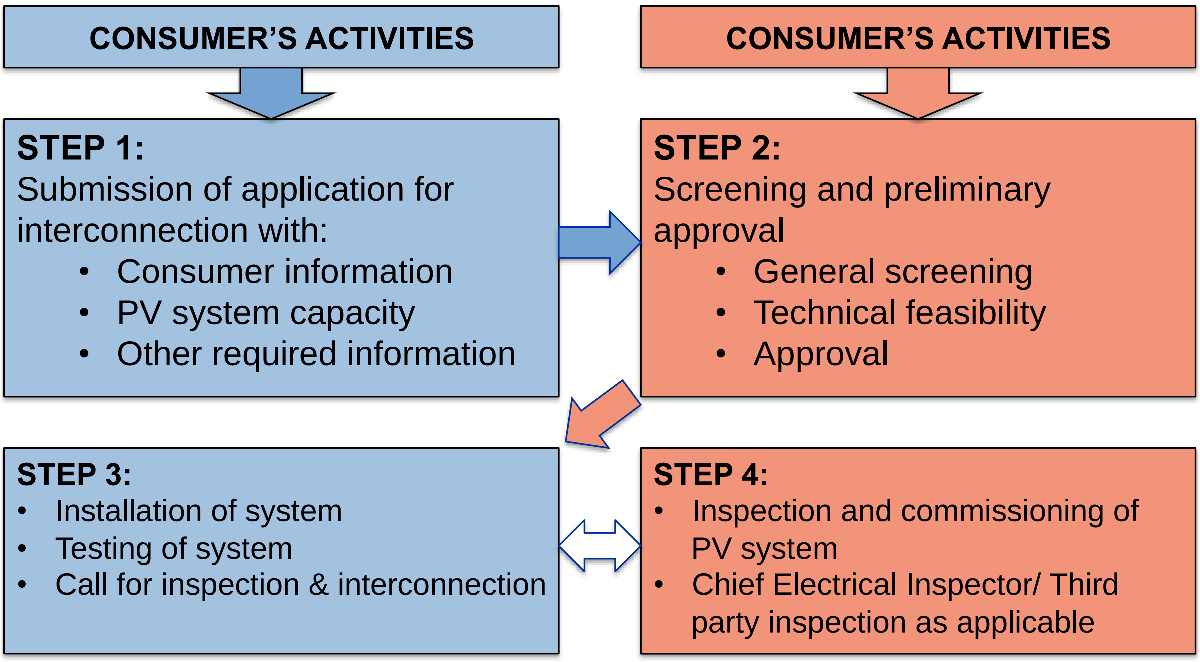


Figure 42: Implementation Steps for Solar PV Rooftop Projects

Roles and Responsibilities of Consumer and Utility

During every step of the project process, from customer's first approach to the utility, final commissioning, and billing of the rooftop PV installation, there are a number of information and decision points where customers and utilities interact.

In absence of a formal procedure, and lack of understanding of roles and responsibilities of both the stakeholders, the entire process runs the risk of becoming inefficient, cumbersome and unproductive. To avoid this situation, it is recommended that the utilities implement comprehensive procures and systems to make this process as standardized and consistent as possible.

Examples of such procedures followed by the Bangalore Electric Supply Company Limited (BESCOM) right from the initial stage to interconnection and billing, along with the details of activities within each step of the project is illustrated in Figure 43.

STEP 1: **APPLICATION PROCESS**	1. Applicant downloads the application format and guidelines from the BESCOM website 2. Submits the applications form online or offline duly attaching / enclosing the required documents 3. Pay registration fee at Sub- division.
STEP 2: **REVIEW OF APPLICATION**	1. Upon review at Sub- division, Assistant Executive Engineer issues approval letter for LT installations while Executive Engineer (EE) issues approval letter for HT installations.
STEP 3: **INSTALLATION**	1. Applicant get the PV system installed 2. Applicant pays facilitation fee, procures bi-directional meter, gets it tested at MT division and submits test reports. 3. AEE/EE(O & M) sub-division signs PPA with consumer.
STEP 4: **TESTING & COMMISSIONING**	1. Applicant request for commissioning of system 2. AEE/EE (O&M) tests, commissions and synchronizes PV system. 3. If PV system fails any of the commissioning tests – utility provides suggestion and reasons for failure 4. Applicant takes corrective measures and apply for commissioning the system again 5. If PV system passes all the tests, utility issue certificate of synchronization
STEP 5: **METERING AND BILLING**	1. Utility issues certification of synchronization to applicant. 2. File is sent to Revenue Section in O&M Sub – division for billing

Figure 43: Implementation Steps for Solar PV Rooftop Projects (BESCOM Example)

Detailed roles and responsibilities of consumer and BESCOM at each stage of project implementation is described in Table 17.

Table 17: Roles and Responsibilities of Consumer and BESCOM

Phase	Consumer	BESCOM
Phase – 1: Information Access	• Study of contracted load, connected load, voltage levels etc. • Estimation of usable rooftop area • Meeting with utility personal • Cost benefit analysis • Engaging technical expert • System designing as per utility requirements • Network layout designing	• Establishing various modes for providing information • Drafting of Information manual for eligible consumers • Study of consumer profile Network, load flow study etc. • Study of protection relays and available feeder capacity • Assisting consumers in collating key information
Phase – 2 (a) Application Access	• Accessing key information, forms, formats, agreements etc. • Collating information about timelines, fees, charges etc. • Filling application forms in utility prescribed format • Preparing documents to be attached	• Drafting of forms, formats, Agreements, certificates etc. • Making key documents available through multiple channels • Inviting applications for net metering • Setting timelines, fee, charges etc. for the application process
Phase – 2 (b) Submission of Application Form	• Submission of dully filled application form • Submission of attaching documents and processing fees • Collection of application reference number • Tracking of application status • Submission of additional information, if required by utility	• Collection of application forms from various channels • Shortlisting of applications based on terms and conditions • Issuing reference number to accepted applications forms • Updating the status of application for consumer reference
Phase – 3: Application Processing	• Tracking of application status • Submission of additional information, if required by utility • Preparing utility response • Meeting with utility (if required)	• General/Technical review of application form • Conducting interconnection study based on information provided • Seeking additional information for interconnection study • Meeting with consumer (if required)
Phase – 4: Approval/ Rejection of Application Form	• Tracking of application status • If accepted, proceed for installation of project • If rejected, seeking reason for rejection • Meeting with utility • Preparing required documents • Submission of revised documents • Repeating steps under Phase – 2 and 3	• If accepted, utility shall provide approval for interconnection • Utility shall initiate metering/ billing systems of consumer • If rejected, utility may call consumer for a meeting or submission of revised documents • On receiving revised information utility shall repeat Phase – 2 • and 3
Phase – 5: Installation/ Inspection	• Project installation as per utility guidelines • Getting approval from utility and Electrical Inspector	• Utility shall inspect the project site, electrical wiring, technical standards, parameters etc. • On getting desired result, utility shall

Phase	Consumer	BESCOM
	(if required) • Getting the project synchronised with the grid • Frequent monitoring of technical and operational parameters • O&M of project	start synchronisation process • On successful synchronisation utility shall issue completion certificate to consumer • Cont. monitoring and inspection

Procedure for Interconnection Approval

The documents and methods typically followed by DISCOM during different stages of interconnection approval process is illustrated in Table 18. The procedure may differ from state to state, and per the organization's prevailing conditions.

Table 18: Documents and Methods Followed by DISCOM

Steps	Procedures	Requirements
Step — 0 Pre- Application Activities — Information Access and Establishing Communication Channel	Accessing requirements for interconnection process	**Utility Requirements:** • To develop Information Manual, Guidebooks, Forms/Formats etc. for consumers • To develop an effective system for communication with consumer in the form of web portal, emails, establishing an individual cell/department etc. • To designate an officer or employee to educate consumer on interconnection process • To develop a system for tracking status of application form and grievances registered in similar matter • To update real time status of application request/grievances **Consumer Requirements:** • Collate information from the designated officer or any other communication channel. • Fill-in the pre-application form with all the required information • Submission of application for and processing fees and required documents • Getting acknowledgement receipt from the utility • Tracking of application request
Step — 1 General Application Screening (Seven Days)	General screening of application form	• On receiving the information on interconnection process, Applicant will collect the pre-application form • Applicant will submit the application form to the utility with all required attachments and processing fees • On receiving of pre-application, utility will provide acknowledgement receipt to the applicant • Receipt number will help the applicant for checking the status of its application • Utility will go for general review of application form and if found suitable utility will clear the application request for next stage. • Under general review, utility will check the Applicant's general information, location of proposed interconnection, capacity of rooftop facility, available

Steps	Procedures	Requirements
		capacity at DT level
Step — 2 Seeking Technical Information (Seven Days)	Technical screening of application form	• Once the application clears the general screening process, then utility will require technical information for Interconnection study • For this, Applicant needs to fill in the technical details and attached supporting documents to proceed with the application process. • Technical details to be submitted after receiving request from utility within seven days
Step — 3 Submission of Additional Documents	Documents to be submitted with technical information	• Documentation of site control needs to be submitted with the application form, the documents required are as follows: - Ownership of roof - NOC from the owner (in case of leasehold property) - Approval from structural Engineer - Electrical Line diagram of the rooftop facility and location of Manual disconnect switch - Safety equipment, equipment specs. and other supporting documents
Step — 4 Notice for Additional Information (10 Days)	Additional information for processing of application form	• The consumer will submit the duly filled application form to utility • If required, utility will send a notice to the applicant for additional information required to process the application form. • On receiving the application form, consumer will have to respond within 10 business days to utility, failing which the application request will be cancelled
Step — 5	Modification of Interconnection Request	• Only per requirement

Steps	Procedures	Requirements
Step — 6 Technical Screening (20 Days)	Pre-Application request and utility feasibility study	• Consumer is required to fill the pre- application request with non-refundable processing fees for utility to access the feasibility of interconnection at proposed feeder • Based on information provided by the consumer, Utility will check the feasibility of proposed interconnection by evaluating the following parameters • Total capacity (in MW) of substation/area bus, bank or circuit likely to serve the proposed Point of Interconnection • Existing aggregate generation capacity (in MW), aggregate queued generation capacity (in MW), available capacity (in MW) interconnected at the proposed point of interconnection • Approximate circuit distance between the proposed Interconnection and substation • Load flow analysis and number of protective device between the proposed point of interconnection and the substation/area • Number of phases available at the proposed point of interconnection. If single phase, distance from the three-phase circuit • Checking, If the point of interconnection is located on a spot network, grid network, or radial supply

Procedure for Fast Track Interconnection Approval

In cases where there is a greater level of certainty and information is available on key components of a project, including, certification of system components, system capacity, location of interconnection, capacity of distribution transformers, mechanisms for grid protection, a fast track interconnection process can be adopted to save time and resources on the project. An example of such a proposal is provided in Table 19.

Table 19: Interconnection Process Proposal

Steps	Fast Track Process
Eligibility	Consumer are eligible to take part in fast track process based on the following conditions: • System capacity • Module (type, model, standard, manufacturers etc.) • Inverter (model, make, technical specification etc.) • Voltage level (location, type of line at the point of interconnection) • Network condition (feeder capacity, DT loading, substation) • Code, standards, and certification requirements
Initial Review (15 Days)	Screening: • Location of interconnection • Aggregate generation on proposed line including the proposed RTPV

Steps	Fast Track Process
	• Proposed RTPV, inverter specifications and operation parameters • Study of maximum fault current of distribution circuit • Study of impact on protective device and other equipment connected on the same network • Study of type of interconnect (Single or 3 Phase) including line configuration and transformer connections • Checking of phase imbalance, If interconnection is single phase • Checking the limit of cumulative generation capacity on the network
Interconnection Agreement (Five Days)	• On passing the screening process, the utility will approve the interconnection application and signs the interconnection agreement • If the application fails the screening, then utility may provide another opportunity to make system modification and suggest way forward

Implementation Framework and Institutional Setup of Utility

Utilities are the most important agency in achieving effective implementation of a grid-connected solar PV rooftop project. With an increase in the number of these projects, utilities across the world are facing a common challenge of re-orienting their traditional customer interface to more flexible, service providing information based customer service.

In the traditional administrative regime, maintenance contractors and billing collection interests dominates utility's customer base. With the arrival of solar PV, a utility's customer base now includes a variety of stakeholders, each having different, and at times, related information needs throughout the rooftop PV projects implementation process.

These stakeholders require continuous exchange of information with the utilities to take a proposal from feasibility study through to specification, procurement, works, commissioning and handover. It therefore becomes imperative for the utilities to create transparent administrative procedures, which will provide access to a consistent source of information and guidelines to all the stakeholders. This will assist in avoiding wastage of time and resources during project implementation process.

Some key features of an administrative procedure for project implementation process are summarized below:

1. **Information Access:** Stakeholders must be able to access key information documents to make decision on- feasibility of the project, speciation of components for procurement purposes, documents required for interconnection

2. **Application Process:** The application process must outline the steps and documents required to make a good application for grid connection. This includes options such as provision of application form and status update of completed applications, appointment of a point of contact for enquiries and complaints and list of key documents to be submitted with the application.

3. **Processing of Application:** Standard operating procedures for staff at the utility to enable them identify and accept, reject or suggest changes to applications made by project proponents. This may include technical checklists, risk assessment templates, approval and disapproval letters.

4. **Other Requirements:** Documents which are anticipatory in nature, and can be provided as standard responses to customers at different stages of project. These include completion certificated, line diagrams, utility inspection requirements, frequently asked questions (FAQ)

A utility's approach of creating a set of procedures will be influenced by multiple factors such as resourcing, organization culture, existing customer service processes.

The overall objective of an administration procedure should be to provide user friendly information to both technical and non-technical stakeholders, on matters relating to standards, design and interconnection parameters and other important requirements which will enable informed decision making through the project implementation process.

Institutional Setup of Utility

Having an administration procedure is a great starting point, however, its usefulness depends entirely on the capacity of an organization, or institution to absorb and employ these changes within its structure. It is common to find examples of instances where a new procedure implementation did not go per plan as the process wasn't aligned with structures within the organization.

With regards to utilities, understanding their organization structure and respective service delivery functions becomes extremely important in assigning deliverables within the grid-connected rooftop project implementation process, which best fit their core service areas.

For example, the Utility Head Quarters can undertake drafting of guidelines, manuals, agreements and important activities to effectively implement a process for handing project decision, development and implementation.

At the other end of the spectrum, a substation is better equipped with undertaking ground level operational activities such as evaluating technical feasibility of individual customers for solar rooftop, commissioning of projects, meter reading and maintain safety of networks. Similarly, Division and Sub Division levels will have a different level of involvement.

Some of the key issues that may face the utilities in organizing their institutional setup are listed below:

- Who signs the Interconnection Agreement — (PPA)/DISCOM Headquarters (HQ) or Divisions or Sub-Divisions?
- Identifying certified inverters and meters? Who does that, at what level? What is the process and how can this information be ensured to reach the operational levels?

Other considerations, which will influence the level of success of grid-connected programs from the utilities end include:

- Overall institutional structure and roles and responsibilities at different levels.
- Training, capacity building, and technical backstopping for utility personnel.
- Customer interactions and awareness generation.

Part of configuring institutional setup is already well ahead in some aspects. At operational level, some of the requirements for carrying out synchronization to the grid are getting standardized.

For example, all installations must be approved by Electrical Inspector (EI) of the state before synchronization with grid. Some states have announced certain capacities not requiring such approvals from EI.

However, it is to be noted that the (Chief) Electrical Inspector's procedure and requirements may be slightly different for each state.

An example of organizational/institutional setup of a typical utility and indicative roles and responsibility to implement solar PV rooftop project is illustrated in Figure 44.

Utility Setup	Indicative Roles and Responsibility
Utility HQ	• Framing guidelines, manual, forms/formats, agreements etc. • Approving equipment suppliers, equipment models, meters etc. • Managing the overall implementation framework • Organizing training programs for utility staff and key stakeholders
Division	• Signing of commercial agreements/PPA • Monitoring Grievance/Complaints registered by the consumer • Recording and managing operations of the grievance handling cell
Sub-Division	• Metering, billing and payment • Records of applications and consumers • Application screening and interconnection approvals • Receiving feedback and addressing complaints • Providing information to consumers about application process
Substation	• General and technical feasibility study of application form • Before and post installation inspection of solar rooftop facility • Commissioning and synchronization of solar rooftop facility • Meter reading and maintenance of safety of the network

Figure 44: Organizational/Institutional Setup

Approval Procedures Example (Karnataka State)

The India State of Karnataka has already established an approval process for grid-connected rooftop projects. This section highlights the major steps, which has been set forward at the time of writing this manual.

Relevant approving authorities have been identified and defined per the capacity of the project. These are listed in Table 20.

Table 20: System Capacity and Approving Authority

Rooftop PV System Capacity	Approving Authority
Up to 10 kWp	Assistant Executive Engineer (AEE) of the concerned ESCOM Sub-division
Above 10 kWp capacity up to 100 kWp	Additional Chief Electrical Inspector of the Department of Electrical Inspectorate
Above 100 kWp	Chief Electrical Inspector to Govt. (CEIG)

Post approval, major steps to the synchronization of grid is listed below:

Stage I: Approval of Electrical Drawings

The following documents shall be furnished for obtaining approval of drawings:

- Requisition letter of the owner/tenant of the installation.
- Computer print/blue print of electrical drawings showing: Single line diagram of the installation indicating rating, size and details of protection, details of loading, net metering system (bi-directional).
- Site plan locating the proposed solar rooftop equipment.
- Plan and elevation of the solar unit, inverter unit and control panel showing all round clearances etc.
- Details of earthing provided for the proposed installation.
- Requisite fees paid receipt/challan for drawing approval.
- No objection certificate (NOC) issued from Supply Company (DISCOM), to the consumer indicating R.R. Number of installation.
- NOC issued from Karnataka Renewable Energy Development Limited (KREDL), if MNRE subsidies are claimed by the consumer.
- Copy of Licensed Electrical Contractor and Supervisor permit duly endorsed in favor of Licensed Electrical Contractor (LEC).
- Authorization of owner of the installation to the LEC.
- Estimate and agreement made with the LEC and consumer shall be executed.

Stage II: Inspection and Issue of Safety Approval

After completion of solar rooftop installation work, the following documents shall be submitted by the consumer for pre-commissioning inspection:

- Requisition letter of the owner/tenant of the installation
- Work completion reports in the prescribed format, which is duly signed by LEC, concerned supervisor, and the prospective consumer.
- Requisite inspection fees paid receipt /challan as per fees notification.
- Manufacturers test report of the solar roof top installation and calibration report of energy meter and connected current transformers and protective relays, if any.
- List of authorized persons who will operate at the said installation.
- At the time of inspection, a responsible representative of the consumer/Electrical Supervisor should be present along with the testing instruments.
- The defects pointed out during the inspection should be rectified to bring the installation in general conformity with the CEA (Measures Relating to Safety and Electric Supply) Regulations, 2010 and a rectification report signed by the consumer, and contractor should be sent to the jurisdictional officer of the Electrical Inspectorate.
- After verification of the compliance report by the inspecting officer safety approval will be granted under Regulation 32 of CEA (Measures Relating to Safety and Electric Supply) Regulations, 2010

Settlement Framework

Settlement framework is the mechanism of accounting and treating solar energy generated from rooftop PV system and used or exported to the grid by the customer. This will depend on the metering architecture of different type of metering systems, viz. net metering and gross metering, and the billing policy adopted by the relevant State Electricity Board.

The net metering scheme is currently operating in many Indian states. A net meter measures energy from and to utility grid. Some of the key working features of the settlement framework using net metering are:

- Net result of energy consumed and exported at the end of billing cycle recorded.
- The energy settlement cycle normally same as the existing billing cycle.
- Consumer pays for net consumed units, if any.
- Net exported units, if any, carried forward to next cycle.
- At the end of settlement period (normally financial year) utility pays to consumer for units net exported to grid, if any.
- Tariff for consumed energy equal to applicable regular consumer tariff decided by SERC from time to time.
- Tariff for exported energy as per interconnection agreement – either equal to APPC of the year, or feed in tariff or rooftop PV tariff as decided by the SERC.

Architecture of Various Types of Metering Systems

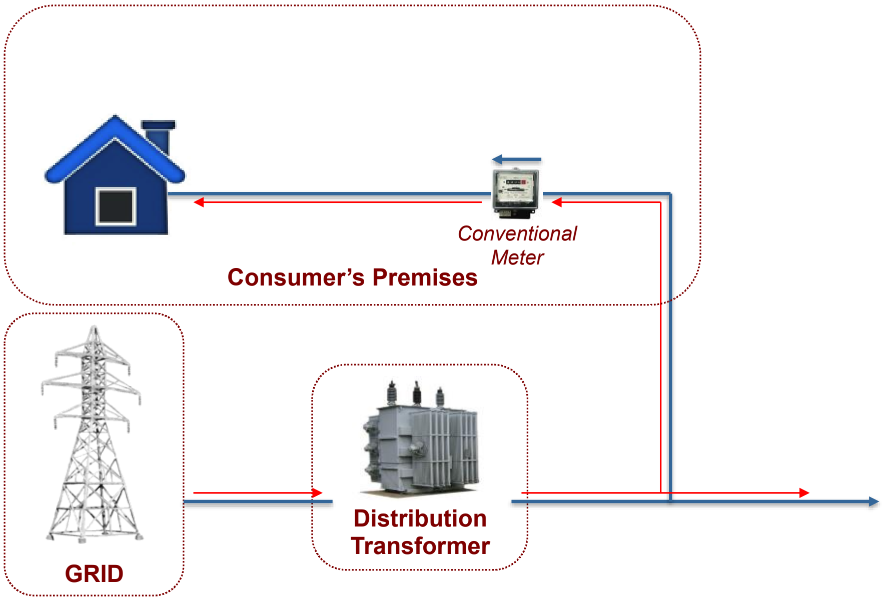


Figure 45: Conventional Metering System Architecture

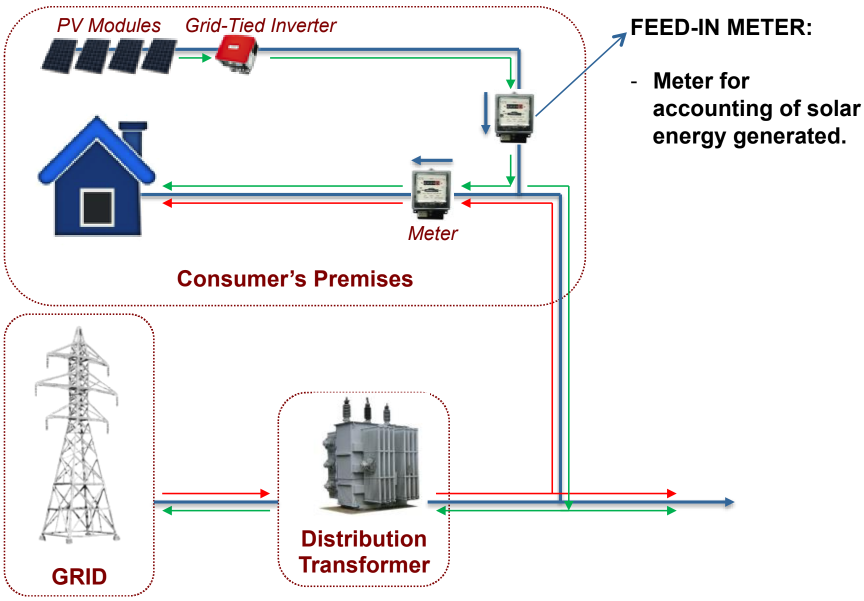


Figure 46: Gross Metering System Architecture

The different types of metering architectures available in India are illustrated in Figures 47 to 51. A more detailed description of these architectures and the state employing them are provided in the Chapter Solar PV Rooftop Policy and Regulatory Framework in India.

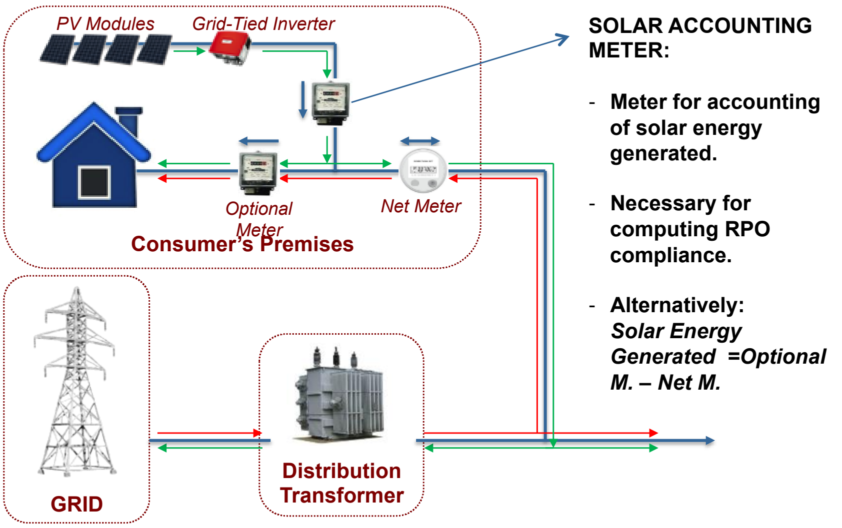


Figure 47: Net Metering System Architecture

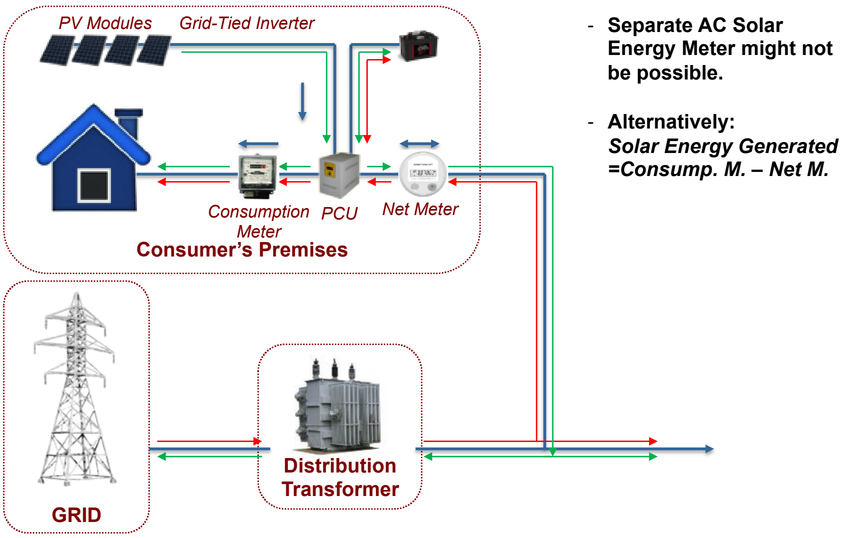


Figure 48: Hybrid Net Metering System Architecture

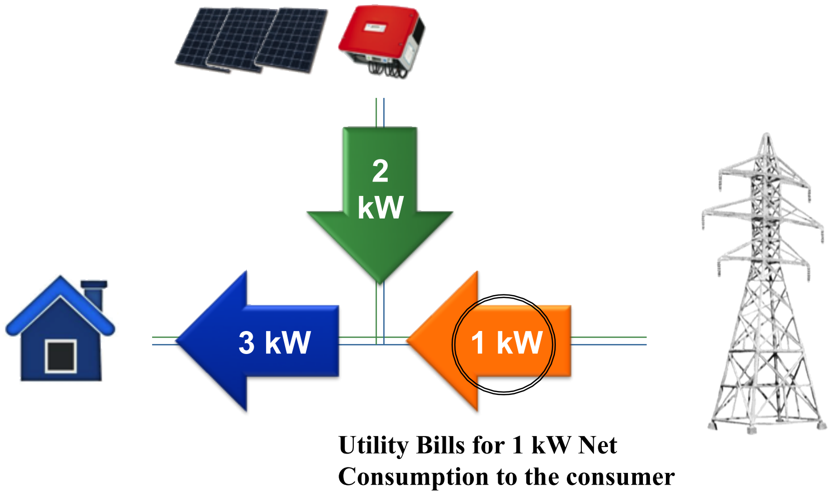


Figure 49: Billing Concept: Net – Metered Case 1

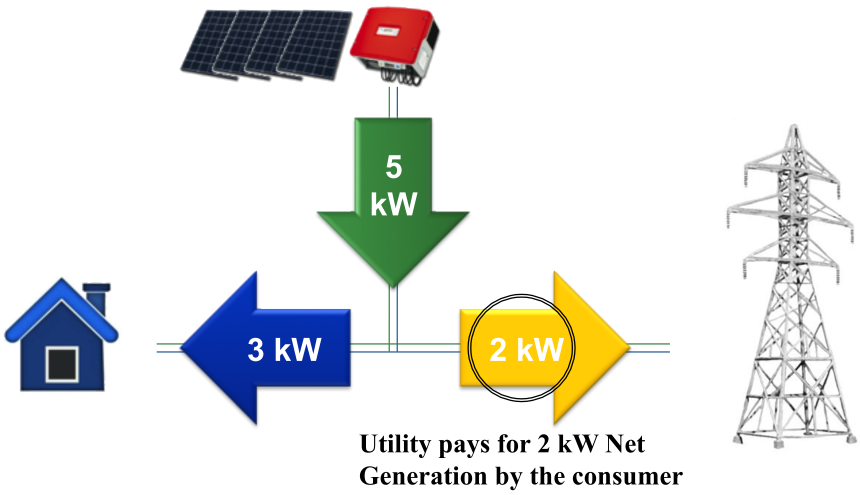


Figure 50: Billing Concept: Net – Metered Case 2

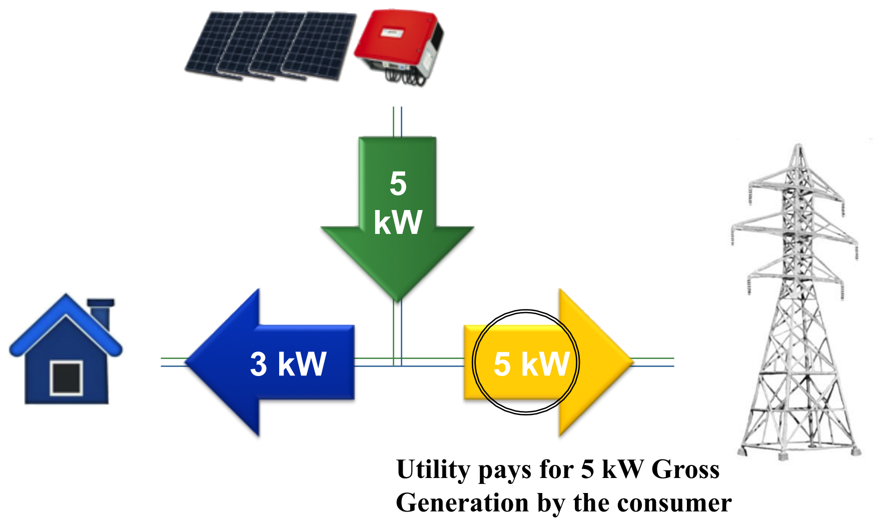


Figure 51: Billing Concept: Gross – Metered

Commercial Settlement Aspects

Meter Recording Parameters

Information recording parameters of typical LT and HT meters are listed in Table 21 and 22. The final settlement includes a measured value against these parameters.

Table 21: Billing Parameters Bi-Directional LT Meters

Sl. No.	Parameter
1.	Import energy cumulative kWh
2.	Export energy cumulative kWh
3.	Billing MD
4.	Billing power factor
In Case of LT Installation With Time of Day Tariff	
S.no.	Parameter
1.	Import energy cumulative kWh zone 1
2.	Import energy cumulative kWh zone 2
3.	Import energy cumulative kWh zone 3
Cumulative kWh recorded in solar generation Meter should be cross checked	

Table 22: Billing Parameters of Bi-Directional HT Meters

Sl. No.	Parameter
1.	Import energy cumulative kWh
2.	Export energy cumulative kWh
3.	Billing MD in kVA
4.	Billing power factor
In case of Time of Day tariff	

Sl. No.	Parameter
S.no.	Parameter
1.	Import energy cumulative kWh zone 1
2.	Import energy cumulative kWh zone 2
3.	Import energy cumulative kWh zone 3
4.	Import MD in kVA Zone 1
5.	Import MD in kVA Zone 2
6.	Import MD in kVA Zone 3
Cumulative kWh recorded in solar generation meter should be cross checked	

Examples of bills with net metered and gross metered settlements are illustrated in Figures 52 and 53 respectively. The bills represent a typical domestic use profile.

BSES

Meter Details Annexure

Name : Mr. KISHORE K GUPTA
Billing Address : SH T R GUPTA 122-C C-8/2 LANE SAINIKFARAM NEW DELHI NEAR . DELHI 110062
Supply Address : 122-C C-8/2 LANE SAINIKFARAM NEW DELHI
Mobile / Tel. No. : 9811017219
District / Division : Saket
Meter Reading Status : MR
Bill Month : JAN-16
Bill Date : 12-01-2016

Sanctioned Load : 20.00 (KW)
Contract Demand :
M D I : 6.76 (KW)
Power Factor : 0.995
Pole No. : DUMMY
Walking Sequence : MHBKC0130A0AA
Cycle No. : KC
Tariff Category : Domestic [Residential]

CA No. : **150008771**
Energisation Date : 13-11-2009
Meter Type : 3PSK
Supply Type : LT
Bill No. : 100062678786
Bill Basis : Actual

Net Meter Consumption Details (Date Of Reading:)														
B/F Units (If any)	Export Reading			Import Reading			Net Difference			Moderated Units			C/F Units (If any)
	Normal	Peak	Offpeak	Normal	Peak	Offpeak	Normal	Peak	Offpeak	Normal	Peak	Offpeak	

(Consumption in the above table are in kWh/kVah, as applicable)

Meter No	Units	Billed Consumption (Current)		Billed Consumption (Previous)		Multiplication Factor	Current Consumption	
		Date of Meter Reading(24:00Hrs)	Reading	Date of Meter Reading	Reading		Days	Units
48650018	KWH	31-12-2015	1935.40	30-11-2015	613.40	1.00	31	1322.00
48650018	KW	31-12-2015	6.76			1.00		6.76
48650018	KVAH	31-12-2015	1953.00	30-11-2015	625.10	1.00	31	1328.00
48650018	KVA	31-12-2015	6.76			1.00		6.76
48650018	KWH_N	31-12-2015	685.40	30-11-2015	413.40	1.00	31	272.00

Figure 52: Billing Concept: Gross – Metered

BANGALORE ELECTRICTY SUPPLY COMPANY LIMITED

Office Of The
Asst Executive Engineer Ele
C3 Sub Division, BESCOM
Jalahalli Bangalore

Electrcity Bill (Solar Roof Top)

RR NUMBER	C3EH49928			
ACCOUNT ID	9257327779			
MTR RDR CODE & Rdg Day	MR35 / 1st			
Name & Address	SUMA.S.H	NO-46 BLOOM FIELD GARDEN, RC Pura B 'lore-97		
Tariff	LT2A-1			
Sanctioned Load	3KW			
Billing Period	18-11-2014	09-12-2014		
Reading Date	09-12-2014			
	IMPORT	EXPORT		
PRESENT READING	00092	00176		
PREVIOUS READING	00000	00000		
CONSTANT	-	-		
CONSUMPTION	92			
Net CONSUMPTION (IMP-EXP)	-84			
FIXED CHARGES 1 Kw 25RS / 30 X 13	17.50			
2 Kw 35Rs x2 /30 x 13Days	49.00			
Total	66.50			
Amount Payable to consumer By BESCOM 84 x 9.56	803.04			
billing Amount	-66.50			
Net Payable To Consumer	736.54			

Rs.737/- Total Amount of Payable to consumer

Yours Faithfully

Asst Executive Engineer Ele
C3 Sub Division, BESCOM
Jalahalli Bangalore

Figure 53: Billing Concept: Gross – Metered

Improving Administrative Preparedness

In the initial stages of setting up organizational structures to streamline the responsibilities and roles for implementation of solar PV projects, it is anticipated that there will be many key learning opportunities, which will help the overall organizational/institutional setup of a typical utility mature and establish its processes.

Some of the key learning observed in working programs are summarized below.

- **Promotion and Awareness of the Program**
  More promotion is needed to increase awareness of grid connected solar rooftop program. Aspects that require promotion include project planning, role of relevant departments, budget considerations. More media activities are suggested.

- **Inter Department Coordination**
  Coordination is required in the areas of meter testing, billing, demand side management, O&M, commercial and legal agreements.

- **Finalization of Forms and Formats**
  The forms should be made available both as hard copies and uploading online. The information in these files should be consistent.

- **Fast tracking Implementation**
  Responsibilities and authorities within the organization should be clearly defined.

Finally, accurate and consistent communication should be provided to the consumers, irrespective of the source within the department.

8 CHALLENGES IN INTEGRATION OF RTPV WITH UTILITY GRID

Types of Challenges

Typically, there are three areas of challenges in the process of developing, managing, and commissioning a grid connected solar PV project. These are:

1. Project development related challenges
2. Project management related challenges and
3. Project technology related challenges

A summary of these changes are illustrated in Figure 54, and further highlighted in the following section.

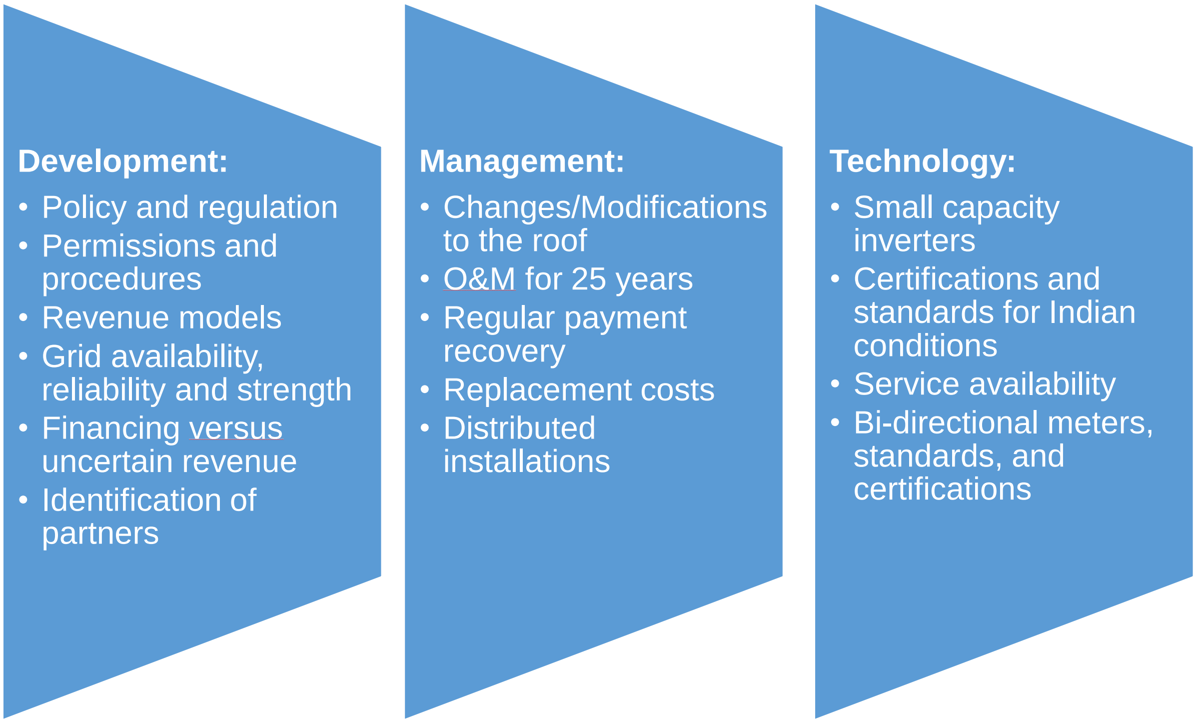


Figure 54: Types of Challenges in Implementing Rooftop PV Projects

These challenges are typically faced during the scoping and feasibility stage of the project. Many of the components of these challenges relate to acquisition of data and quality of information available to project developers, to make informed decisions.

Typically, information on the following matters is needed at feasibility phase of a project.

- Policy and regulations related to incentives, metering framework and grid connectivity requirement. These are critical in determining the financial and technical feasibility of the project proposal.

- Permissions and procedures related to system capacity and connectivity approval. These are required to understand the parameters of project design and system sizing.
- Revenue models, which are possible for project developers within the jurisdiction area of the project.
- Grid availability, reliability, and strength within the distribution area of the proposed project location.
- Financing options available to the developer and risk of uncertain revenue for third party developers.
- Identification of partners for procurement of components and installation of works.

A more detailed discussion of these matters and sources of relevant information have been provided in earlier chapters.

Key Management Challenges

These challenges are faced during the development stage of a project, when the work program is being finalized, and more detailed investigation is being carried out to assess the viability of the project with respect to the available infrastructure, interconnection process, and any additional cost items which were not identified in the first stage.

Typically, information on the following matters is needed at this phase of a project.

- Grid availability and quality at low voltage (LV) level. Some of the main concerns raised by the utility engineering teams include safety of the grid, power quality of the grid, reverse power flows and tail end voltages, which may result due to introduction of solar PV generation sources within the overall grid system.
- Payment security mechanism for PPA arrangements, usually monthly settlement. This aspect more relates to the integrity and honoring of long term contracts. Uncertainty can pose risks for the project developers and may end up increasing solar power costs for end consumers, as project financers may charge a premium interest rate as a hedge.
- Changes that may be required in the roof design. This may occur due to age of the roof, need for waterproofing, need for elevated structures. These challenges usually are unknown and can appear at a later stage of the project.
- Identification of location of system's placement – Own roof vs. neighbors roof. This will depend on the business model selected for developing a solar PV project.
- Identification of manpower responsible for service and spares. In a early stage market like India, sourcing of skilled manpower can be a challenge. However, this is quickly changing as training and skill development programs continue to roll out across the country.
- Revalidation of different agreements to ensure that changes during the project process have been captured and everyone's expectation is documented.
- Incorporate any changes in consumer loads for system design during project design process.
- Emergency backup supply for buildings, if required, usually in form of provision of UPS to critical loads.

Key Technology Challenges

These challenges relate more to the utilities, faced during the development and implementation stage of a project. The objective here is to ensure that the choice of components and execution of works is in compliance with relevant standards and procedures.

Typically, information of the following areas is needed at this phase of a project.

- For grid tied inverters, information on certifications and standards. Some of the widely accepted standards and certifications are:

  - Grid connectivity standard/utility interface: IEC 61727.
  - Test procedure for islanding prevention measures for utility-interconnected PV inverters: IEC 62116 or IEEE 1547.
  - Efficiency measurements: IEC 61683.
  - Product safety standard: IEC - 62109-1 and IEC - 62109-2.

- For bi-directional meters and solar meters, information on certifications and standards. Some of the widely accepted standards and certifications are:

  - IS 13779 is applicable to static watt-hour meters of class 1 and 2.
  - The IS 14697 for static transformer operated watt-hour and VAR hour meters, of accuracy class 0.2 S and 0.5 S.

  The CEA minimum accuracy class requirement for consumer meters in the distribution network is either class 1 or class 0.5 S.

  All the technical requirements of meters in India are guided through the regulation 'Installation and Operation of Meters, 2006'.

- PV module quality and reliability, information on certifications and standards. Some of the widely accepted standard are:
  - IEC 61215123 for crystalline silicon PV modules.
  - IEC 61646124 for thin-film PV modules.
  - IEC 61730125:
    - Part 1 - Requirements for construction of the module.
    - Part 2 - Requirements for testing and for safety qualification.
  - IEC 61701126 for salt mist corrosion testing for modules that are used in coastal environments.

- Quality and standards of balance of system must comply with the following standards:

  - Cables and connectors - IEC 60227/IS 694; IEC 60502/IS 1554-I&II; IEC 60189, EN 50521 (MNRE).
  - Junction boxes - IEC 529- IP 54, IP 21 (MNRE).
  - Battery - IEC 61427, IS 1651,IS 13369 or IS 15549 (MNRE).
  - Charge Controller - IEC 60068-2, IEC 62093 (MNRE).

- Steps undertaken to ensure system protection and safety of personnel. Thorough implementation of OH&S systems is very necessary to avoid accidents at site.
- Containment measures for fire hazards which may arise from high voltage DC arc
- Timely replacement of components which may affect system performance and compromise system security.
- Online system monitoring and control and remote access, fault detection, system safety and performance analysis of the installation.

Suggestions to Utility When Implementing Net Metering

Following are few suggestions utilities can use when implementing projects with net metering service.

Implementation Phase	Typical Challenges	Suggestions
Phase — I (Information Access)	• To encourage subsidised consumers to opt for net metering • To educate consumers on a relatively new subject • To develop data bank meeting requirement of all consumers	• To establish multiple channels for decimating information • To enable information access though web portal, emails etc. • To develop information manual covering key requirements, guidelines, forms/formats etc.
Phase — II (Application Process)	• To develop application process with respect to all consumer categories • Technical and safety Requirements • Process and procedures • Reporting requirements • Time lines, charges and fees etc.	• To develop single multi user application form to avoid any confusion • Different sections to gather information like personal details, technical, safety etc. • Minimum layers of process and checks to reduce the processing time
Phase — III (Application Screening)	• To design strict and fast screening process • Design screening criteria • Interconnection Study • Training of utility personal • Determine timelines and charges	• To develop fast track screening process • Organise training program for utility personal to reduce the processing time • To communicate majorly through on-line media

Phase — IV
(Installation and Inspection)
	• To inspect the facility with respect to:
	  • Safety and security
	  • Standardised equipment
	  • Compliance with rules and regulations
	  • To check and Install meters
	  • Up grading of distribution network
		• To establish a dedicated cell for periodic inspection and checks of approved rooftop facilities
		• Approval/Empanelment of system installers or implementing agencies
		• Certification of key equipment (mainly meters and inverter)
		• Continuous training of utility personals

Phase — V (Post Installation)	• To inspect the rooftop facility and safety equipment • To take meter readings and check accuracy of meters • To resolve post installation technical issues of consumers • Data monitoring, recording, and reporting requirements • Improvement in utility practices from time to time •	• To designate competent authority at substation level to resolve concerns and queries of consumers • To create online solar help desk centre either through web portal or phone line or both. • Use of information technology (IT) tools to monitor, record and maintain useful data • Adopting best practices followed to implement net metering

Suggestions to Utility When Implementing Net Metering

Following are few suggestions utilities can use when implementing projects with net metering service.

Examples of Action Taken to Resolve Specific Issues

Some specific issues faced as utilities prepare to incorporate net metering administration process within their business operations are listed in Table 24. A list of proposed actions is also provided to resolve this issue. The list is not comprehensive and intended to be used a thought starting point only, as each utility may face challenges which are unique to their organization.

Table 23: Issues Faced as Utilities and Action Taken

Issues Identified	Action Taken to Resolve Issues
No guidelines for consumers	Guidelines prepared for consumers as well staff – included administrative procedures, implementation processes, technical specifications, Q&A, inspection of fulfilment of safety requirements
Online submission of fees with application form - Consumers could apply online but needed to deposit the fees in person	Developing complete online procedure for consumers
Capacity building of implementation staff – Ground staff was not trained to resolve day to day query of consumers	Arranged four training programs for officers and engineers – an ongoing feature
Grievance Handling – Solar help desk (common email ID and phone number)	Trying to keep both helplines alive and up-to-date
Promotion of Scheme - Reach of scheme was restricted, as its promotion was only through web portal	Arranged a day event in Green Summit 2015 and had open discussions with consumers, developers and others
Availability, testing, certification, and procurement of net meters and small capacity grid tied inverters	Available now: - Vendor empanelment procedure - Product certification by own laboratory testing
Empanelment of implementing agencies	MNRE empanelment referred

Issues Identified	Action Taken to Resolve Issues
Publishing one time standard approved drawings by CEIG instead of insisting on approved drawings for every RTPV installation.	Approval by CEIG received: - 10 kW set as minimum cut off capacity requiring CEIG inspection - Lower capacities inspected by AEE and certified by SE (O&M)

Examples of Action Taken to Resolve Technical Issues

Similar to the above section, this table provides examples of some technical issues faced by the utilities. A list of proposed actions is also provided to resolve this issue. Similar to the earlier table, the list is not comprehensive and intended to be used as a starting point only, as each utility may face challenges which are unique to their organization.

Issues Identified	Action Taken to Resolve Issues
To remove the provision of automatic relay as this feature is already there as "inbuilt" feature	The automatic relay has been removed in the schematic diagram and updated in the BESCOM website -> Solar RTPV online services link -> Forms and guidelines of the Solar RTPV link
Some of the system Integrators are questioning the manual disconnection switch, they feel it is also not necessary	The committee decided to retain the same – No change
In case of hybrid inverters in RTPV the DC line is tapped before inverter. In this case solar generation meter will not reflect TRUE solar generation	Decided to ignore DC energy drawn by the Hybrid inverters and the same to be updated in the guidelines, Forms & formats
Should Micro inverters be allowed?	It was decided that even micro inverters, meeting all standards and specifications in the program, could be allowed
Can applicant be allowed to install oversized PV modules than the capacity of Inverter?	It was decided to allow maximum 20 percent over capacity on DC side (i.e. of modules) than the inverter AC capacity, as is the industry practice.
Which system capacity to be considered for approval?	Inverter AC capacity to be considered for approval
Consumers raised issue that 'open spaces' be allowed in addition to rooftops for installation	It was decided that 'open spaces' will be allowed in the 'same premises' as the consumer connection
Developers requested for hiring out a roof to third party investors and allow provision of 'escrow account' for security of payment to the investor	Third party investment is allowed Tripartite agreement is being designed and BESCOM has decided to make payments to escrow accounts wherever applicable, based on request by the consumer

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