EN671 Solar Energy Conversion Technology

Grid Connected PV System

Dr. Pankaj Kalita
Associate Professor
School of Energy Science and Engineering
Indian Institute of Technology, Guwahati

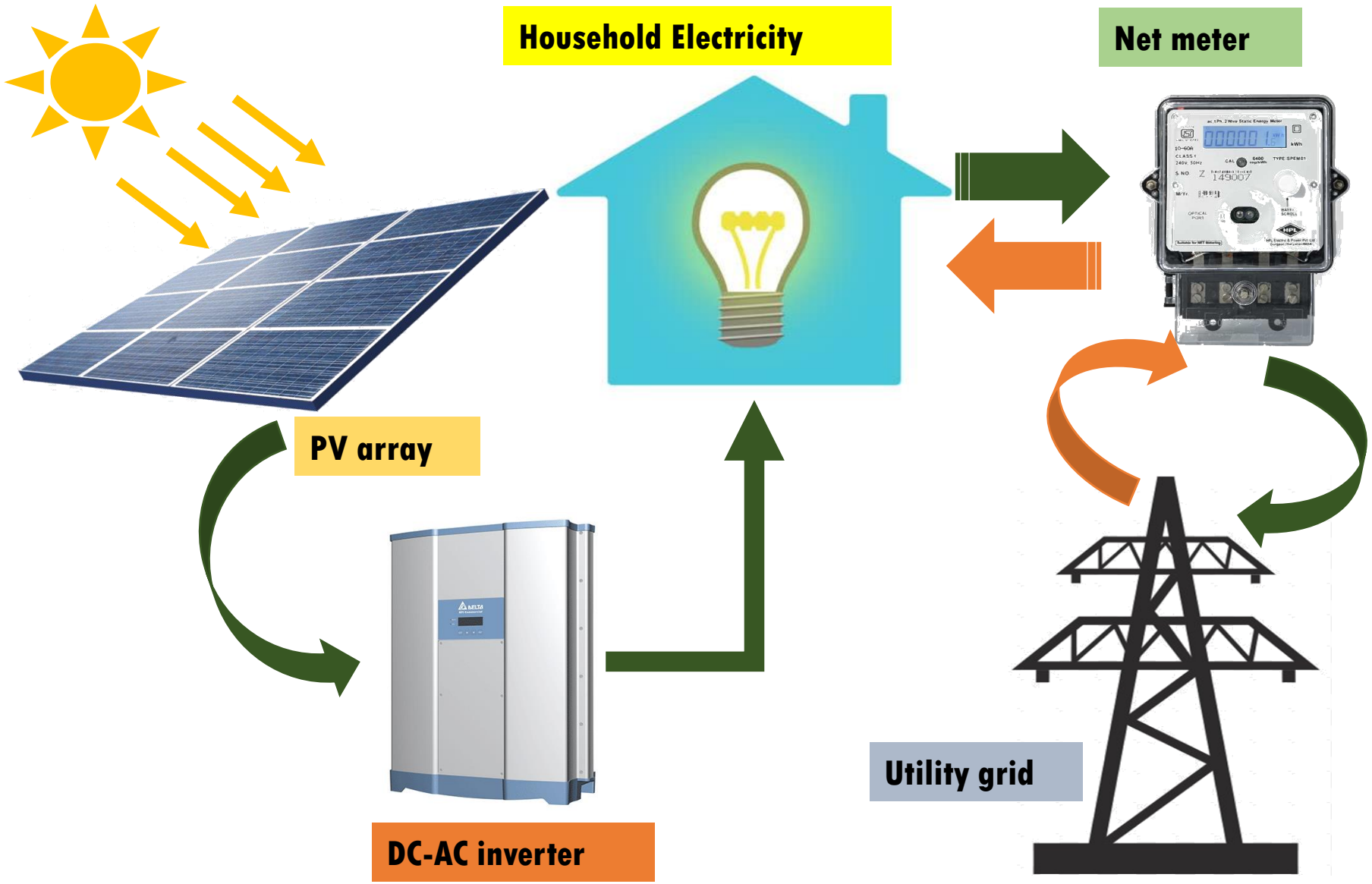
- Functioning and layout of a grid connected PV System
- Different components of a Grid connected PV System.
- Selection of different equipment
- Role of different components for maximization of PV system efficiency

Grid Connected PV System

- A grid-connected PV system is made up of an array of panels mounted on metallic support or integrated into a building.
- Panels are connected in series and parallel to achieve optimal voltage and current, and feed into an inverter transforming direct current into alternating current at a phase and at the same voltage as the grid.
- Operating voltage of an array of panels is around 150- 400 V DC for small systems (1-3 kW) and 400-700 V DC for inverters of 10-500 kW.
- Maximum voltage is generally limited by
  - Problems of insulating panels to avoid any current leakage
  - The maximum voltage accepted by the inverter.
- The inverter will be equipped with a MPPT system that constantly adjusts the entry voltage, which vary according to temperature and solar radiation.

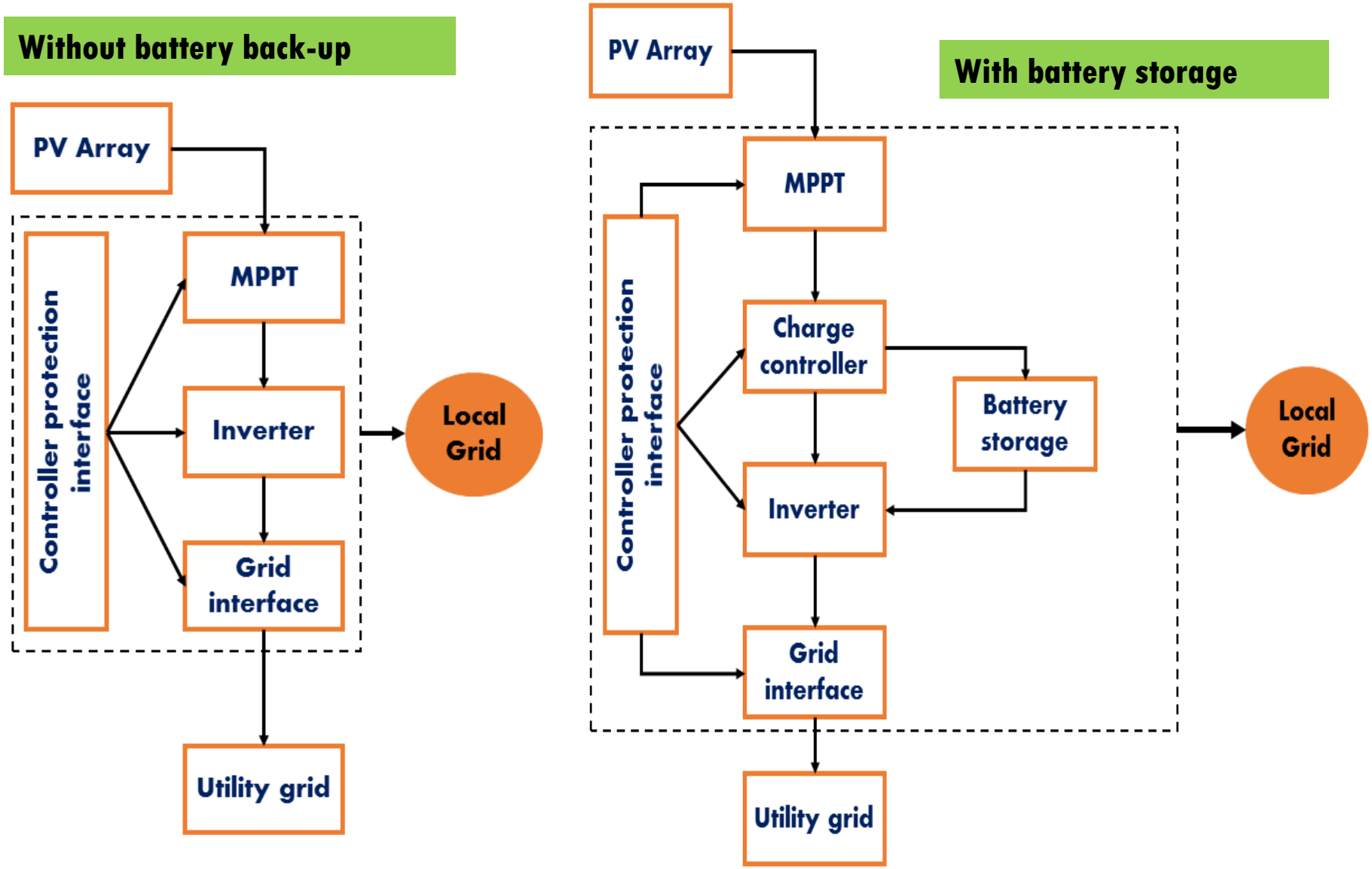
Overview

Basic flow diagram of grid-connected PV system

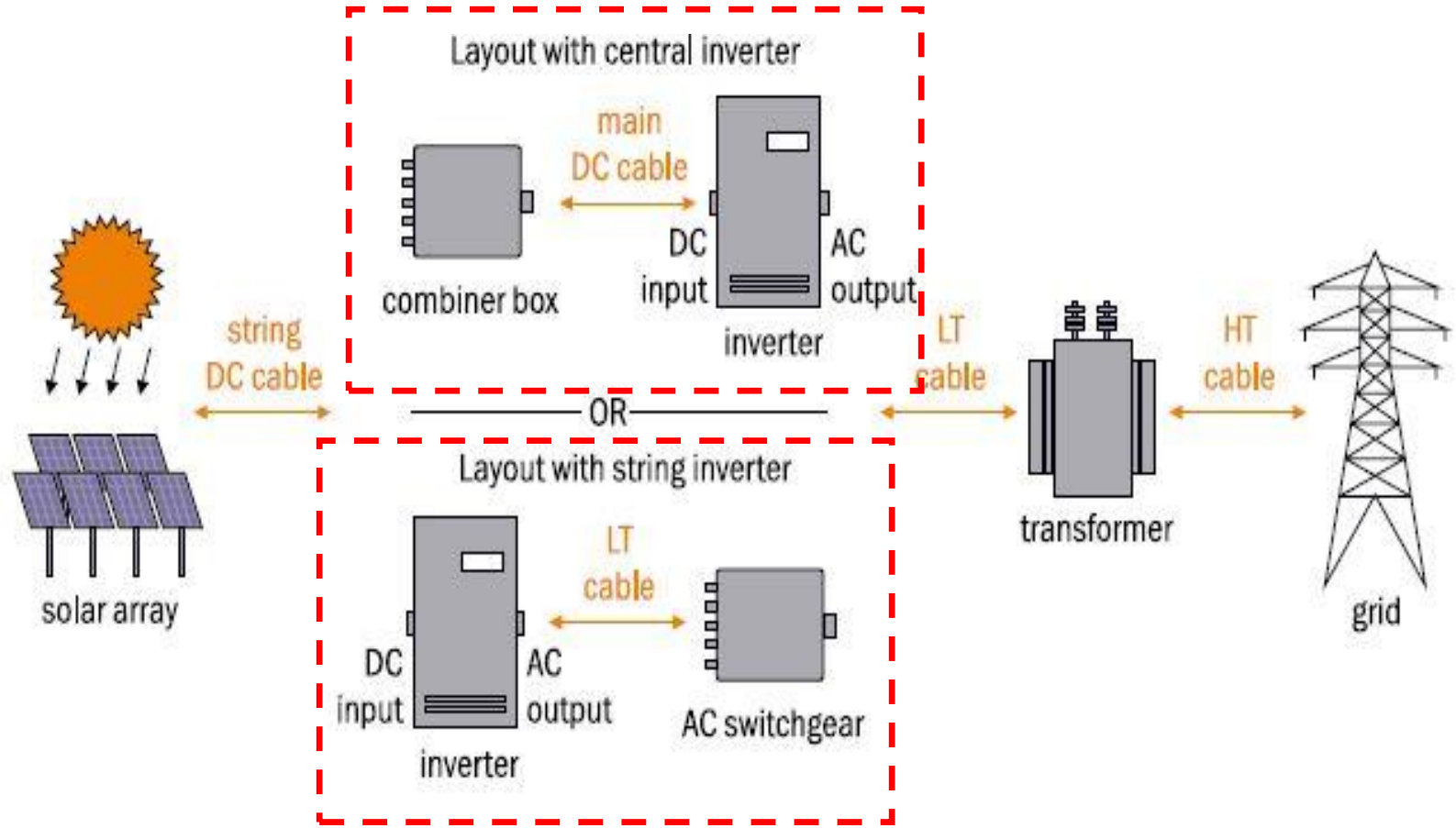


Overview

There are two general types of electrical designs for PV power systems



Layout of a grid connected PV system



Components of a PV plant

Electrical Components

- ✓ PV modules
- ✓ Power conditioning units
- ✓ Cables
- ✓ Combiner box
- ✓ Connectors

Civil and mechanical components

- ✓ Module mounting and structure
- ✓ Mounting foundation

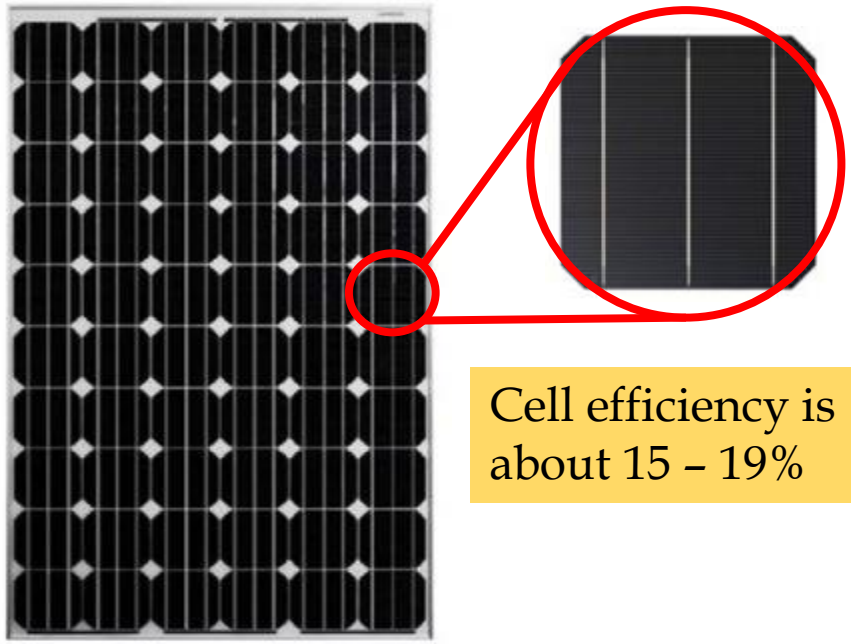
Power monitoring components

- ✓ SCADA
- ✓ Weather station

Solar PV modules

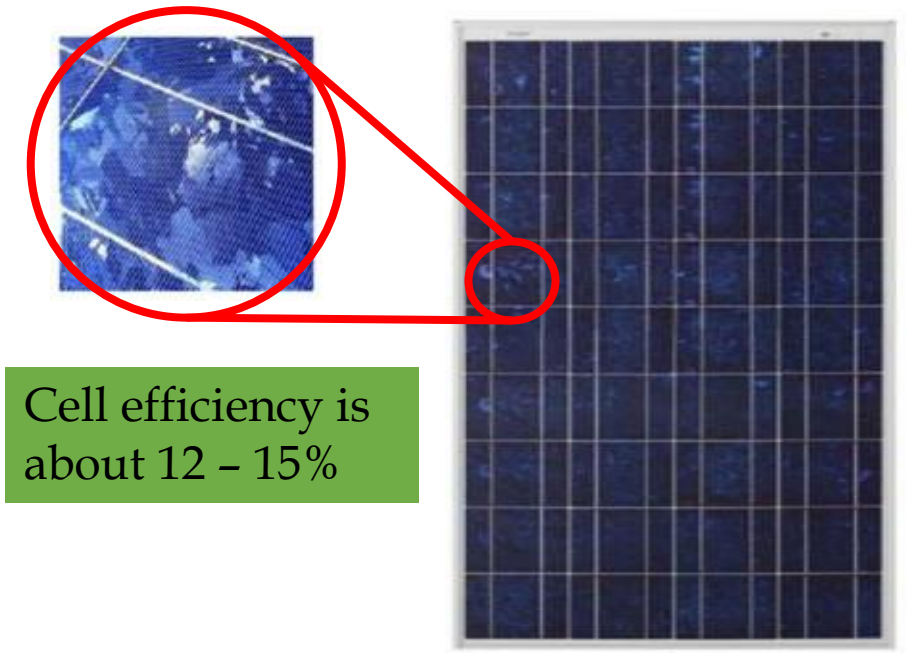
Commercially available PV modules are classified into two types:

Single/Monocrystalline silicon solar cell



Cell efficiency is about 15 – 19%

Multi/Polycrystalline silicon solar cell



Cell efficiency is about 12 – 15%

- **Silicon is formed into bars and cut into wafers**
- **Fragments of silicon are melted together to form the wafers.**

Solar PV modules

Criteria for choosing grid-connected panels

- Reliability and reputation of the manufacturer
- Good price
- Closely power-matching modules
- Good mechanical quality, well-designed frame and easy to installed panels
- Good quality connections
- Cooled anti-return diodes, with a junction box designed to dissipate their heat (in case of a hotspot generation)

Grid Inverters

The major component in Grid-connected PV systems is the DC-AC inverter or also called the power conditioning unit (PCU).

- The Inverter changes the DC current stored in the batteries or directly from the PV array into usable AC current.
- Similar to the function of a Stand-alone inverter, however essential differences are
  - **It must be a sine wave frequency and AC voltage to be fed into the grid must be in phase with it.**
  - **Comply with a number of regulations and safety requirements which are more demanding than stand alone system.**
  - **All inverters are connected to the grid incorporates MPPT.**

Grid Inverters

Several factors must be considered when selecting inverter

- The power conversion efficiency
- Rated power
- Duty rating (the amount of time the inverter can supply maximum load)
- Input voltage
- Voltage regulation
- Voltage protection
- Frequency requirement
- Power factor
- Islanding detection

Grid Inverters

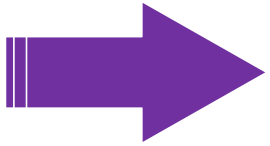
Types of inverters

- Module inverters
- String inverters
- Multi-string inverters
- Central inverters

Grid Inverters

Types of inverters

- **Module inverters**
- **String inverters**
- **Multi-string inverters**
- **Central inverters**

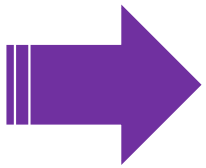


- Power: 100-300 W
- No MPPT
- Single phase Output
- Typical efficiency: 95-96%
- Advantages:
  - No DC cabling
  - Easy to add more modules
- Disadvantages:
  - High cost per power rating
  - Replacing faulty ones is difficult

Grid Inverters

Types of inverters

- **Module inverters**
- **String inverters**
- **Multi-string inverters**
- **Central inverters**

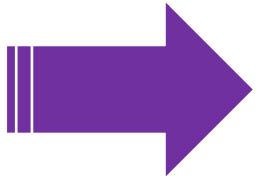


- Power: 700-1200 W
- MPPT
- Single or three phase Output
- Typical efficiency: 93-97%
- Advantages:
  - Has MPPT
  - Readily available
  - Lower cost per power rating than module inverter
- Disadvantages:
  - Only one MPPT

Grid Inverters

Types of inverters

- Module inverters
- String inverters
- Multi-string inverters
- Central inverters

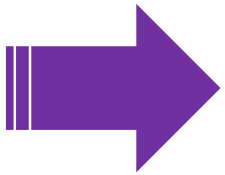


- Power: 2000-17000 W
- Multiple MPPT
- Single or three phase Output
- Typical efficiency: 97%
- Advantages:
  - Has multiple MPPTs
  - Readily available
  - Lower cost per power rating than module inverter
- Disadvantages:
  - More expensive
  - Increases system cost due to use to DC protection on each string

Grid Inverters

Types of inverters

- Module inverters
- String inverters
- Multi-string inverters
- Central inverters



- Power: 30 kW- MW
- Multiple or single MPPT
- Three phase Output
- Typical efficiency: 97%
- Advantages:
  - Lower cost per power rating than module inverter
  - Can have higher efficiency
  - One location for maintenance
- Disadvantages:
  - No redundancy if inverter fails

Types of Inverter

Inverter type	Module inverters	String inverters	Multi-string inverters	Central inverters (used for large grid systems)
Power range	100-300 W	700-1200 W	2000-17000 W	30kW-MW
MPPT	No	Yes	Multiple	Multiple or single
Output	Single phase	Single or three phase	Single or three phase	Three phase
Typical efficiency	95-96 %	93-97 %	97 %	97 %
Advantages	1) No DC cabling 2) Easy to add more modules	1) Has MPPT 2) Readily available 3) Lower cost per power rating than modular inverters	1) Has multiple MPPTs 2) Readily available 3) Lower cost per power rating than modular inverters	1) Lower cost per power rating 2) Can have higher efficiency 3) One location for maintenance
Disadvantages	1) High cost per power rating 2) Replacing faulty ones is difficult	1) Only one MPPT	1) More expensive than a single string 2) Increases system costs because DC protection must be used on each string	1) No redundancy if inverter fails

Islanding

- A potential danger of grid-connected systems is islanding.
- Imagine that a potential PV system is installed in a street where the electricity grid is shut-down in order to do maintenance work on the electricity cables.
- If it is a sunny day, the PV system will produce power and would deliver the power to the grid without protection. The electricity worker thus can be in danger. This phenomenon is called islanding and due to its danger it must be prevented.
- The inverter therefore must be able to detect, when the electricity grid is shut-down and Inverter must stop delivering power to the grid.

Cables

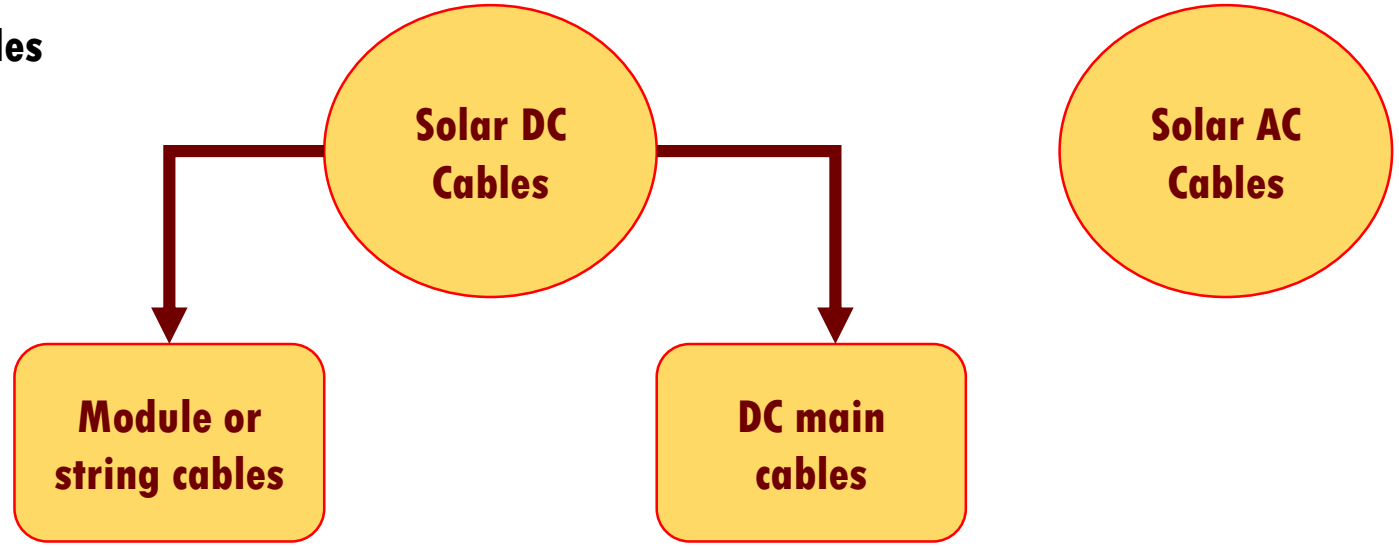
- Selection of accurate size and type of cable would enhance the performance and reliability of the PV system.
- Correct sizing ensures very little loss of energy and prevent causing fire due to overheating.
- The size of the cable must be large enough to carry the maximum current expected without undue voltage losses.

The size of the wire to be used depends upon:

- ✓ The generating capacity of the Solar Panel (larger the current generated, bigger the size)
- ✓ The distance from the solar panel system to the loads (greater the distance, bigger the size)

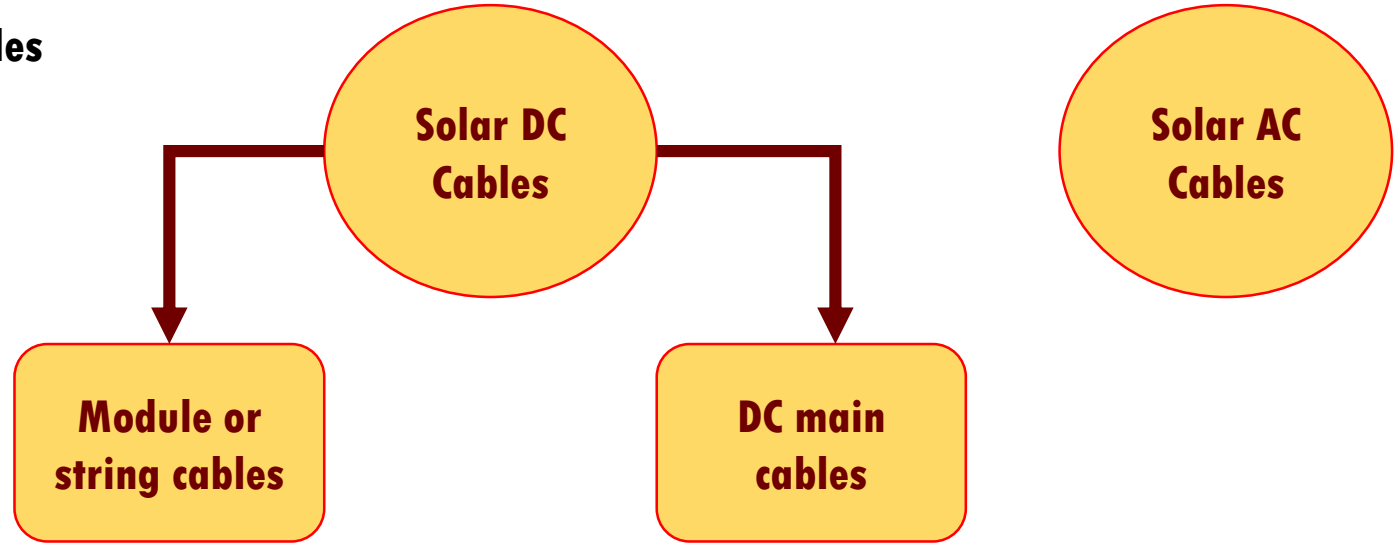
Cables

Types of Solar cables



Cables

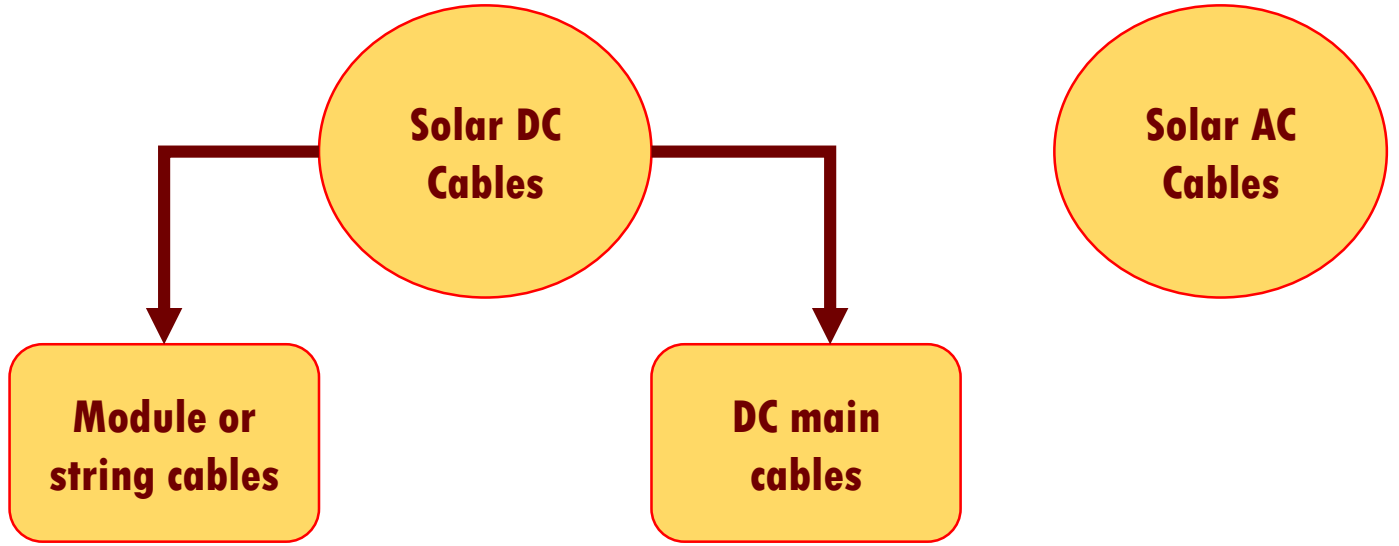
Types of Solar cables



- These cables are usually integrated into the PV panels
- Equipped with suitable connectors to be interconnected

Cables

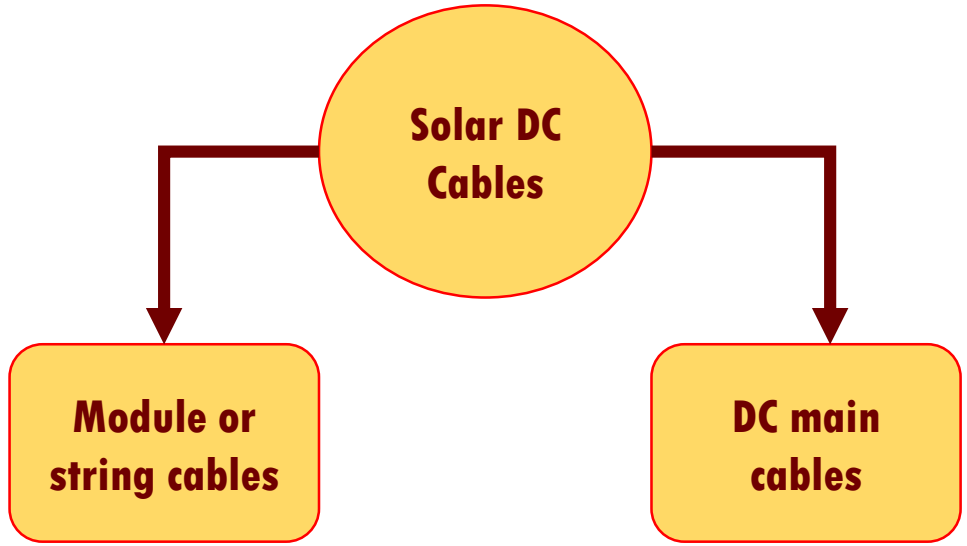
Types of Solar cables



- For connecting the positive and negative terminals from strings to generator combine box or directly to the solar inverter.
- Single-wire cables with double insulation are practically proven and offers high reliability.

Cables

Types of Solar cables



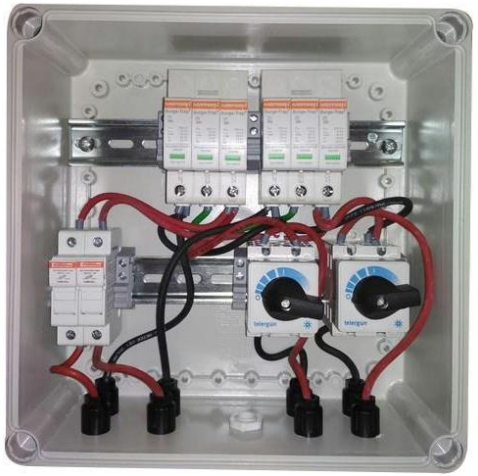
Solar AC Cables

- These cables connects the inverter to the electric grid through protection equipments.
- For three phase inverters, five core AC cables are used (for connection to the low voltage grid).
- For single phase inverter, three core cables are used.

Combiner box

Combiner boxes are used to bring multiple series strings together into single line. The strings are typically combined in parallel. Combiner boxes are typically located close to the photovoltaic array.

- ✓ Wires from individual PV modules or strings are connected to the combiner box.
- ✓ These wires may be single conductor pigtails with connectors that are pre-wired onto the PV modules.
- ✓ A combiner box typically includes a safety fuse or breaker for each string.



Solar connectors

Solar connectors are used to connect solar panels to form strings.

MC4 Connectors

- **MC4 connectors** are single-contact electrical connectors commonly used for connecting solar panels
- The MC in MC4 stands for the manufacturer Multi-Contact and the 4 for the 4 mm diameter contact pin.
- The connectors come in both male and female types which are designed to snap together.

Connector (cable socket) must comply following requirements:

- stability against dynamic load
- strength
- absolute protecting from dust and water infiltration
- voltage overload stability
- fireproof
- insulant stability to negative effects of ultraviolet radiation

Module Mounting

A grid-connected PV system is made up of an array of panels mounted on metallic support or integrated into a building.

Roof Mounted

Ground mounted

Module Mounting

Roof mounted

- PV arrays are affix to brackets on the roofs, generally with a few inches gap and parallel to the surface of the roof.
- Roof mounts are less expensive because it uses existing roof structure as a foundation.

Advantages

- Less expensive
- Less material requirement for installation
- Labor cost is lower
- Utilizes unused space

Disadvantages

- Hard to access – especially if the roof is steep or slippery
- Harder to troubleshoot errors
- Space constraints on the roof limits the size of the system
- Replacement of the roof is difficult within the panel's lifetime
- Putting holes in the roof could lead to water leakage

Module Mounting

Ground mounted

- PV array are held in place by racks or frames that are attached to ground-based mounting supports.
- Ground mounts take more space, but easier to access for installation and repair.
- Provide greater control over the orientation of PV arrays to maximize production.

Advantages

- Easy to access
- Easy to clean
- Easier to troubleshoot

Disadvantages

- Installation is more labor intensive
- Installation is more expensive
- Requires more parts and pieces
- Not aesthetically pleasing to everyone

SCADA

- SCADA (Supervisory Control And Data Acquisition) is used to monitor data from a plethora of devices, including meters, inverters, weather stations, trackers, DC strings and substation equipment.

- Provide the information about the health of the plant.

SCADA provides measurement options for

- ✓ Lifetime Power Production (kWh)
- ✓ Record of Daily Power Production for a Month or so (kWh)
- ✓ Money Saved Using Solar Power ($)
- ✓ Amount of CO_2 Reduction (kg, lbs, or tons)
- ✓ Record of any System Warnings or Faults
- ✓ Current System Power Generation (Watts)
- ✓ Total Everyday Energy Production (kWh)
- ✓ Photovoltaic Input Voltage (Volts)
- ✓ Photovoltaic Input Current (Amps)

Weather monitoring station

- Weather Monitoring Station (WMS) is one of the important instruments for a solar power plant.
- A weather monitoring station can be immensely helpful in monitoring the efficiency and performance of any solar power plant.
- The data from the WMS can be used to get many insights about the plant operation and possible avenues to increase the plant output.

The Weather Monitoring Station provides measurement options for

→ Wind Direction

→ Wind Speed

→ Temperature

→ Humidity

→ Rainfall

→ Solar Radiation

→ Barometric Pressure

Miscellaneous components

Cable glands

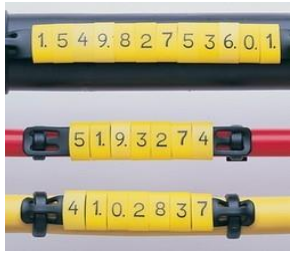
- It is a device designed to attach and secure the end of a cable to the equipment.
- These mechanical cable entry devices constructed from metallic or non-metallic materials.
- These are the four main materials from which cable glands are made: Plastic, Brass, Aluminium, Stainless steel

Cable lugs

- To connect cables to electrical appliances, other cables, surfaces, and mechanisms.
- Available in different types as copper ring type, tubular type, pin type, aluminum lug, battery lugs, etc.

Cable ties, ferrules

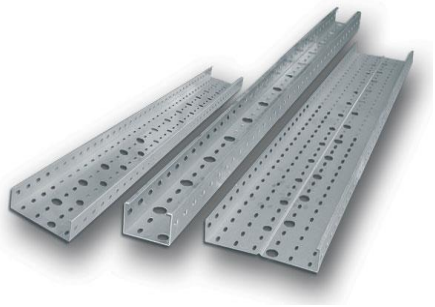
- A cable tie is a type of fastener, for holding items together, primarily electric cables or wires.
- This allows several cables to be bound together into a cable bundle and/or to form a cable tree.
- Ferrules can be used in marking or labeling cables. Ferrules can be sleeve type or universal T type.



Miscellaneous components

Cable Tray

- Cable tray system supports insulated electric cables used for power distribution and communication.
- Cable trays are used as an alternative to open wiring or electrical conduit systems.
- Common cable trays are made of galvanized steel, stainless steel, aluminium, or glass-fiber reinforced plastic.



Lightning arrestor

- A significant concern for photovoltaic (PV) power plant operators is equipment damage caused by direct or indirect lightning strikes.
- To avoid the destructive effects of lightning strikes, overvoltage protection must be installed at the inverter and at various other locations in the PV facility.

Fuses

- Fuse plays a very important role in solar power projects.
- Fuses are used in the string combiner boxes, inverters, on the DC side of the system.
- Fuses are also used in the AC side of the system.
- The AC fuses are different as compared to the DC fuses.

Summary

- Functioning and layout of a Grid connected PV System.
- Different components of a Grid connected PV System.
- Selection of different equipment.
- Role of different components for maximization of PV system efficiency.

Thank you