UNIT-II
PV CELLS AND INVERTERS

- Centralized Inverters,
- String Inverters,
- Multi-string Inverters,
- Module Integrated Inverter/Micro inverters,
- Inverter Topology,
- Model of Inverter,
- Sizing Batteries and Inverters for a Solar PV System.

Types of PV Systems:

Grid-Connected Solar PV System,
Stand-Alone Solar PV System

- An inverter is one of the most important pieces of equipment in a solar energy system.
- It’s a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses.
- In DC, electricity is maintained at constant voltage in one direction.
- In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called power electronics that regulate the flow of electrical power.
- Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly.
- As a result, a DC input becomes an AC output. In addition, filters and other electronics can be used to produce a voltage that varies as a clean, repeating sine wave that can be injected into the power grid.
- The sine wave is a shape or pattern the voltage makes over time, and it’s the pattern of power that the grid can use without damaging electrical equipment, which is built to operate at certain frequencies and voltages.
- Today we make electrical switches out of transistors, solid-state devices with no moving parts. Transistors are made of semiconductor materials like silicon or gallium arsenide.
- They control the flow of electricity in response to outside electrical signals.

- electrical power has been predominantly generated by burning a fuel and creating steam, which then spins a turbine generator, which creates electricity.
- The motion of these generators produces AC power as the device rotates, which also sets the frequency, or the number of times the sine wave repeats. Power frequency is an important indicator for monitoring the health of the electrical grid.
- For instance, if there is too much load—too many devices consuming energy—then energy is removed from the grid faster than it can be supplied.
- As a result, the turbines will slow down and the AC frequency will decrease.
- Because the turbines are massive spinning objects, they resist changes in the frequency just as all objects resist changes in their motion, a property known as inertia.
- As more solar systems are added to the grid, more inverters are being connected to the grid than ever before.
- Inverter-based generation can produce energy at any frequency and does not have the same inertial properties as steam-based generation, because there is no turbine involved.
- As a result, transitioning to an electrical grid with more inverters requires building smarter inverters that can respond to changes in frequency and other disruptions that occur during grid operations, and help stabilize the grid against those disruptions.

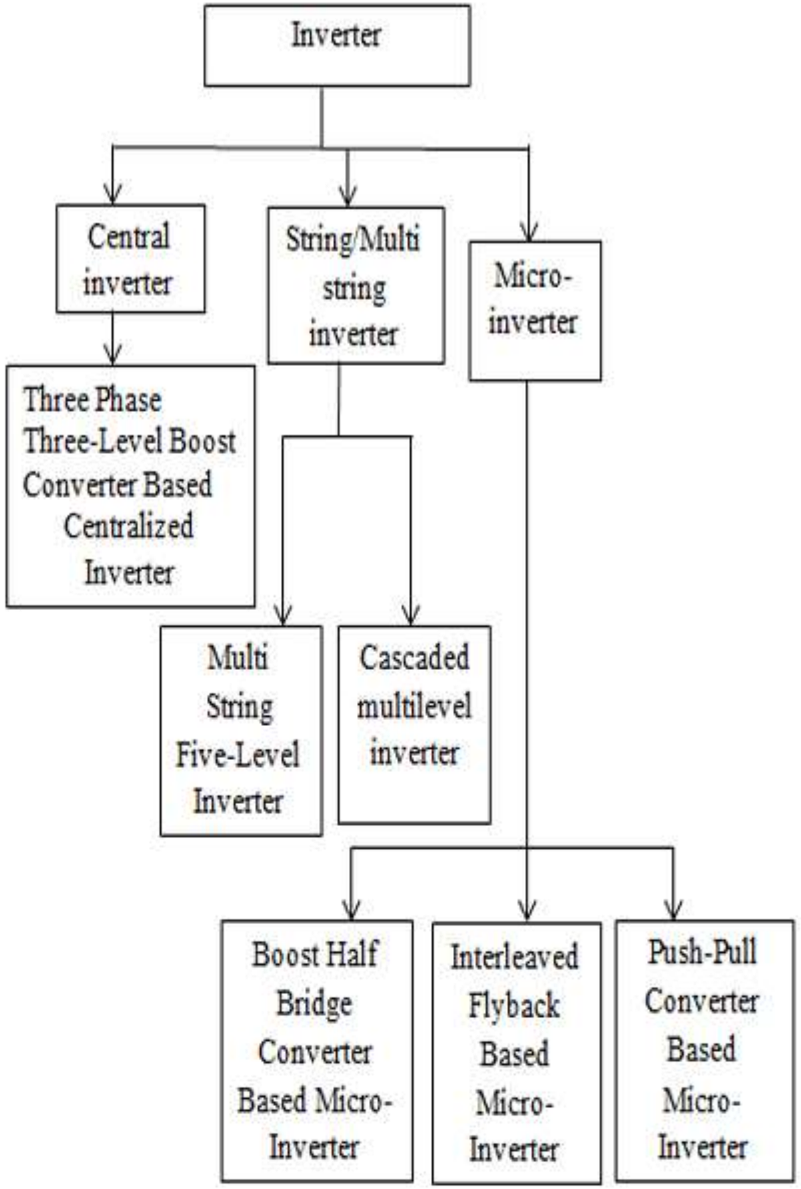


Fig-2: Inverter topology classification tree

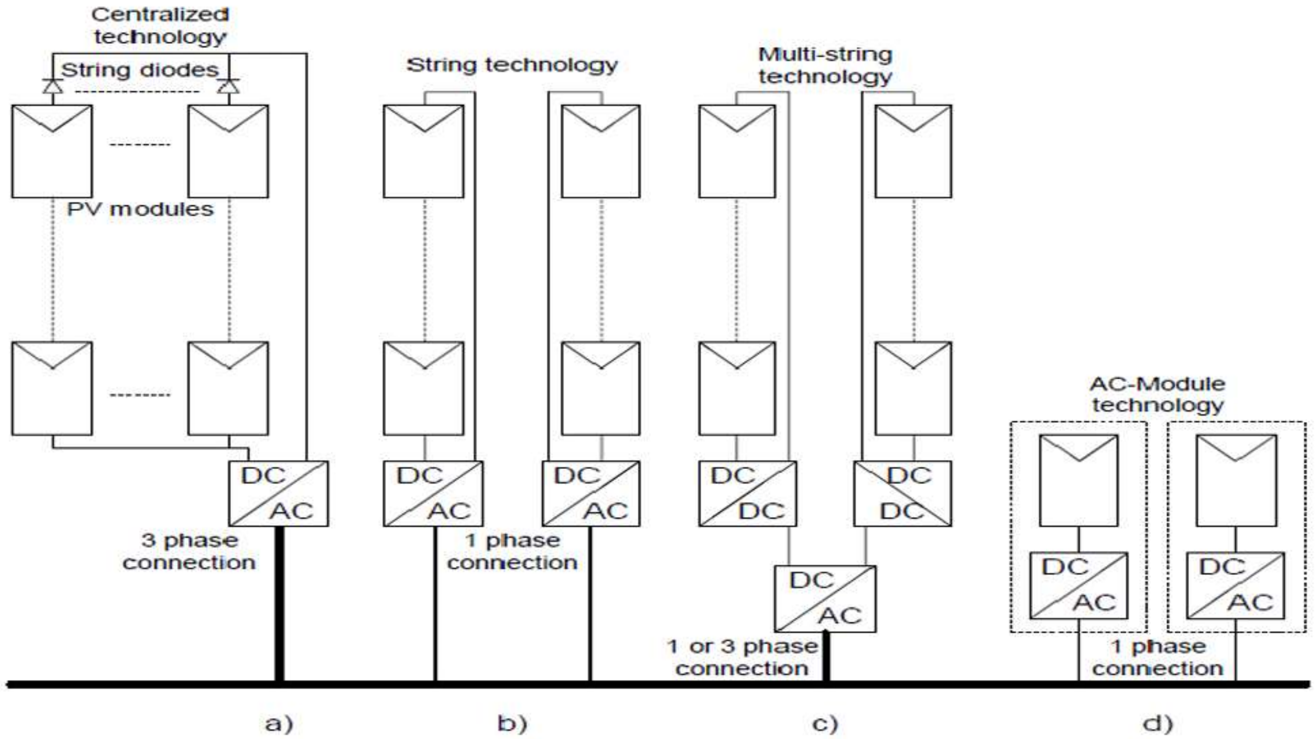
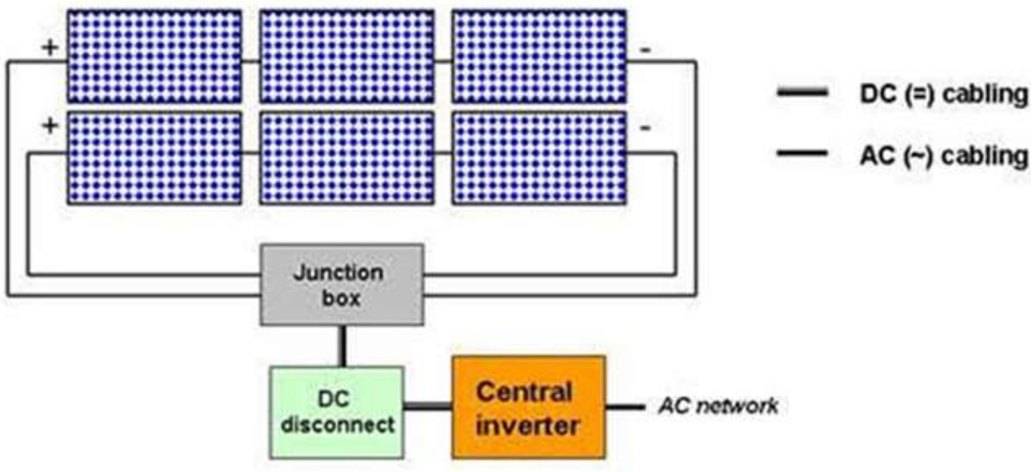


Fig-3: Photovoltaic inverter technologies a) Centralized technology, b) String technology, c) Multi-string technology, d) AC-Module micro-inverter technology [16]

CENTRAL SOLAR INVERTER :

- solar inverter is the heart of the solar plant, it represents the main equipment that converts DC output from solar panels to AC electricity required to run all our appliances/machines/equipment.
- In addition, it takes the responsibility of **monitoring and controlling the PV array system**.
- The central solar inverter usually placed near the main electricity service switchboard, and in protected area, so no worries about harsh environment climate conditions.
- All DC terminals from solar panels will be gathered in **combiner box input** and the output will go to the **central solar inverter,** so its one inverter that will handle all the solar array, that is why the central inverter **power capacity is higher than string solar inverter** and micro solar inverter.
- At solar central inverter DC side, the DC voltage will be high; around 600-1000VDC, and inverter power capacity will be high as well, it may reach to 5MW or so.



Central Inverters

- Used in **large utility-scale** solar plants.
- **All panels** send power to **one big inverter**.
- Converts total DC power to AC.
- **Efficient for large systems**, but not ideal for small setups.

the advantages of central solar inverter

1. **Technology:**

The central solar inverter has been existing for **long time**, many years ago, we deal with, it has **been installed** and doing well years ago, and this gives it more credibility.

2. **Less expensive:**

Compared to other types of solar inverters (string & micro), it is less expensive because **lower components** and **lower installation costs** due to its one inverter that can handle all the solar array.

3. **More reliability:**

As mentioned, we usually place the central inverter inside a room or closed area, and apart from bad weather, it's not exposed to harsh climate conditions, these of course increase the reliability of this system.

The disadvantages of central solar inverter

1. **High influence in case of shaded or failed solar panels:**

As most of solar panels incase of central inverter system are **connected in series**, so if only 5% of solar panels are shaded or failed due to any reason, they will affect on the entire system and we lose approx. 20% of system output power.

2. **High DC voltage risk, and only one inverter:**

The DC voltage incase of central inverter will be high, it reaches 1000VDC or higher, which raise concerns on installer and operators, in addition, its one inverter, so incase of any fault, we shall lose the entire solar system.

3. **High replacement costs:**

Its high capacity and cost solar inverter, so in case of failure, **replacement costs will be higher** than others solar inverters types.

central inverter

- The central inverter transforms high DC power which is greater than 10kW to grid through three phase interconnection [comp 3].
- It contain multiple panels connected in series which form strings and the string diode is applied to form parallel combination of these individual string to satisfy the need of larger system fig. 3(a) shows the series-parallel combination of PV panels.

This centralized inverter technique has certain conditions such as

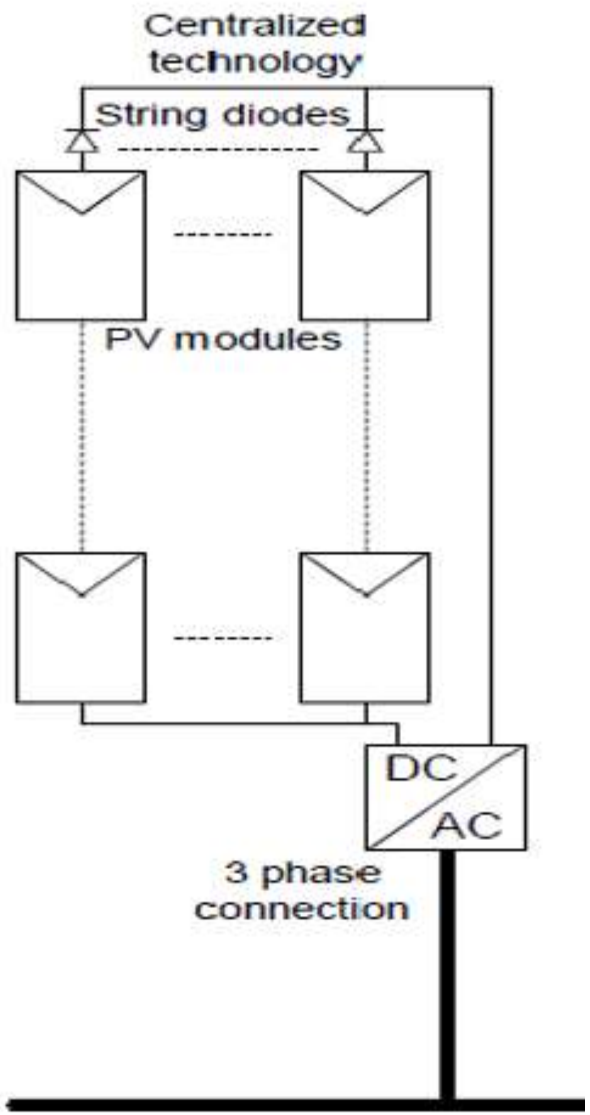
mismatch between the PV modules,

high voltage DC cable and

high rating bulky electrolyte capacitor which decreases the life

period of inverter.

- The centralized inverter system has some drawbacks like
- problematic installation,
- bulky,
- poor power factor (pf),
- high harmonic present in output current,
- inflexible design and complication in incorporating the system in future.
- Absence of MPPT for every PV module is the main limitation of this system.
- If the clouding or partial shading effect appears on some of the PV modules then overall operation of PV system get affected, that reduces the power generation and overall system efficiency decreases. These disadvantages encourage evolution of further inverter topologies [8, 9].

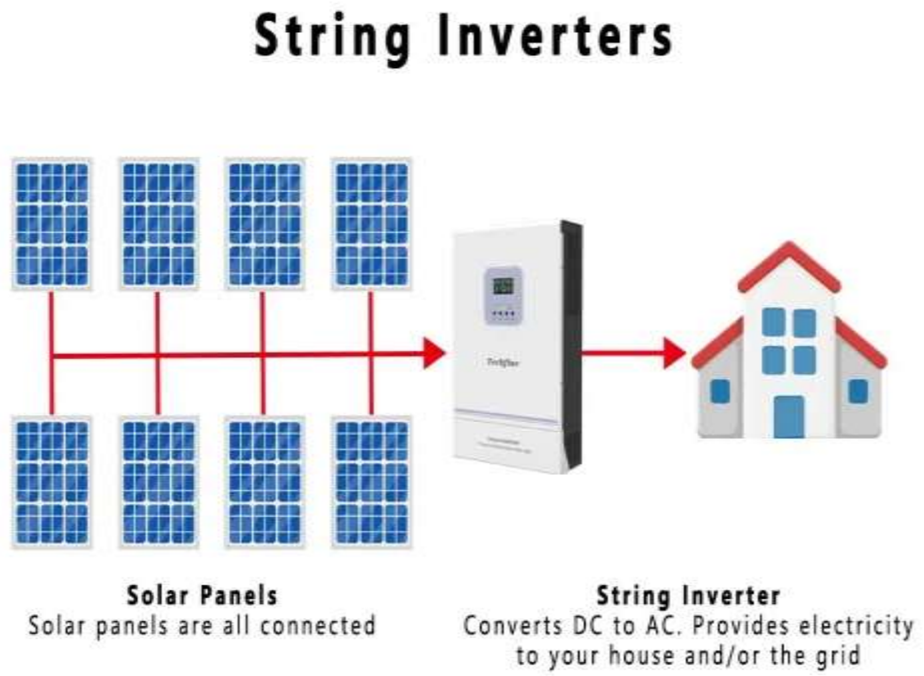


STRING INVERTERS:

String inverters are a type of solar inverter that connects a string of solar panels together and converts the combined DC power into usable AC power.
They are a popular choice for many solar installations due to their **cost-effectiveness** and reliability, especially in situations with consistent sunlight and simple roof layouts

Working:

- A string inverter is connected to a group (or string) of solar panels wired in series.
- The inverter takes the DC power generated by the solar panels and converts it into AC power, which is the type of electricity **used in homes and businesses.**
- String inverters are typically located on a wall or in a designated space, not directly on the roof with the panels.



Solar string inverters

- Solar string inverters are used to convert the DC power output from a string of solar panels to an AC power.
- String inverters are commonly used in **residential and smaller commercial installations**. Wide bandgap semiconductors like Silicon carbide (SiC) and Gallium nitride (GaN) allow to operate converters at higher switching frequencies which allows use of smaller magnetic components and in turn drive power density of these systems up.
- To scale power levels up very often such systems are made in modular fashion to get from 10th of kW to 100th of kWs.
- To cope with the fact that Photovoltaic (PV)-systems stop generating energy when sun light goes down, these systems **very often incorporate a power conversion port for a battery energy storage system** (BESS).
- Excess energy generated during day time is stored into the battery and can be used during times the energy from the PV-string is not enough.

Figure 2-1 shows the typical architecture of a solar string inverter.

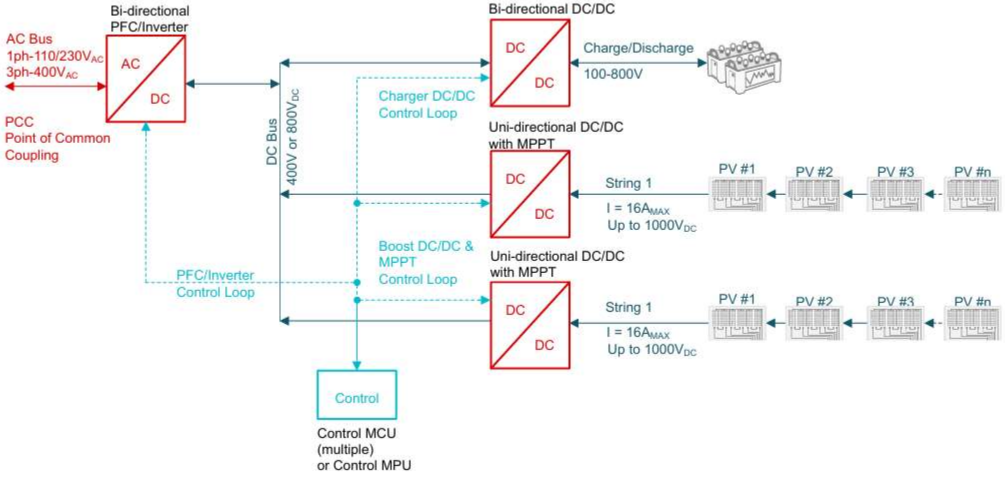


Figure 2-1. Solar String Inverter Block Diagram

Figure 2-1 shows the typical architecture of a solar string inverter.

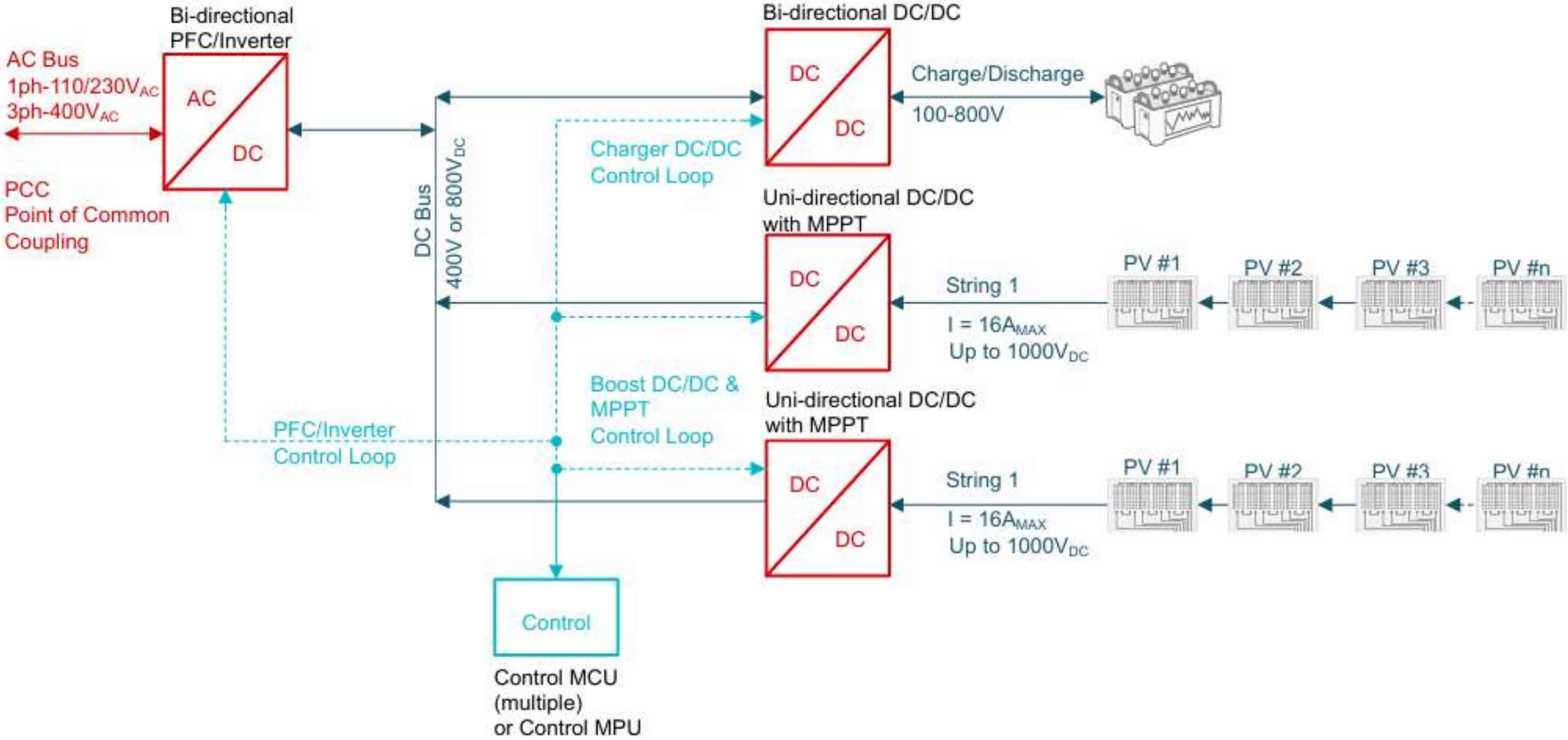


Figure 2-1. Solar String Inverter Block Diagram

- As Figure 2-1 illustrates, there are three major power blocks in the string inverter.
- The first stage is a uni directional DC/DC converter stage that converts the variable string output to a stable high-voltage DC link suitable for the next stages,
- the second is a bidirectional DC/DC power stage the third a bidirectional DC/AC inverter stage.
- For single-phase systems the DC Bus voltage is typically 400VDC.
- For three-phase systems the DC-Bus voltage is around 800VDC or even higher up to 1500VDC.
- This first DC/DC stage is also able to perform the Maximum Power Point Tracking (MPPT) for a complete string.
- It simply searches for the maximum power by changing voltage and current across a complete string.
- This DC Bus voltage is then converted to an AC voltage at the grid voltage level by the DC/AC inverter power stage.
- In today’s systems, the AC/DC is built as bidirectional PFC/Inverter to allow the operation of the DC/DC power stage that connects to a battery energy storage system, and allows to charge and discharge the ESS in both directions.
- DC Bus 400V or 800V Charger DC/DC Uni-directional DC/DC A more detailed block diagram of Solar String inverter is available on TI's String inverter applications page

Advantages of String Inverters

- **Cost-effective:**
  - String inverters are generally less expensive than other types of inverters, such as microinverters.
- **Reliable and Durable:**
  - They have a long history in the solar industry and are known for their robustness and reliability.
- **Ease of Maintenance:**
  - String inverters are often mounted on walls or in a common area, making them easier to access for maintenance and troubleshooting.
- **Suitable for Various Installations:**
  - While traditionally used for installations with southern exposure and minimal shading, newer models are suitable for a wider range of applications.

Disadvantages of String Inverters:

- **Shading Issues:**
  - If one panel in a string is shaded, it can affect the performance of the entire string.
- **Centralized Monitoring:**
  - String inverters monitor the performance of the entire string, not individual panels. This means that if one panel has an issue, it may not be immediately apparent.
- **Potential for Reduced Efficiency:**
  - In situations with shading or varying panel orientations, microinverters or power optimizers may offer better performance.

Applications:

- **Residential Solar Systems:**
  - String inverters are commonly used in residential solar installations, especially where roof orientation and shading are not significant factors.
- **Commercial Solar Projects:**
  - They are also used in commercial solar installations, including utility-scale projects, due to their cost-effectiveness and scalability.

Parameters	Central inverter	String / multi string inverter	Micro-inverter
Reliability	Low	Medium	High
Installation cost	Low	More than central inverter	Higher than both the inverter
Maintenance cost	High	Less than central	Very low
Shading effect	Overall perform ance get affected due to shading on any one module	Performanc e of modules connected to that string get affected due to shading on any one module	Performanc e of only that module get affected due to shading on any one module
Efficiency	Average	More than central	Greater than both inverter
Rating	High (greater than 2kW)	Medium (upto 2kW)	Low (upto 400W)
Phases	3 phase	1 phase /3 phase	1 phase
Power harvesting	Less	More than central inverter	Greater than both inverter
Design	Non - flexible design	Flexible in the design	Flexible & expandable in design

Multi-String Inverter

- The Multi-string inverter is the further development string inverter [7], where several strings are in interfaced with their own DC-DC converter to a common DC-AC inverter.
- The multi-string inverter concept [15], [17] has been developed to **combine the advantage of higher energy yield of a string inverter with the lower cost of a central inverter.**
- In this topology shown Fig. 9 every string can be controlled individually.
- To expand the system within a certain power range only **a new string with a DC/DC converter** has to be included. All DC/DC converters are connected via a DC bus through a central inverter to the grid.

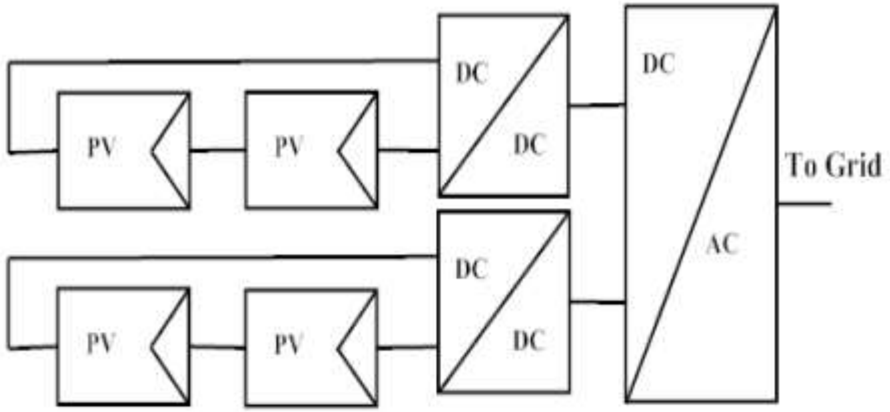


Fig. 9 Multi string inverter topology

Types of Grid-connected Inverters

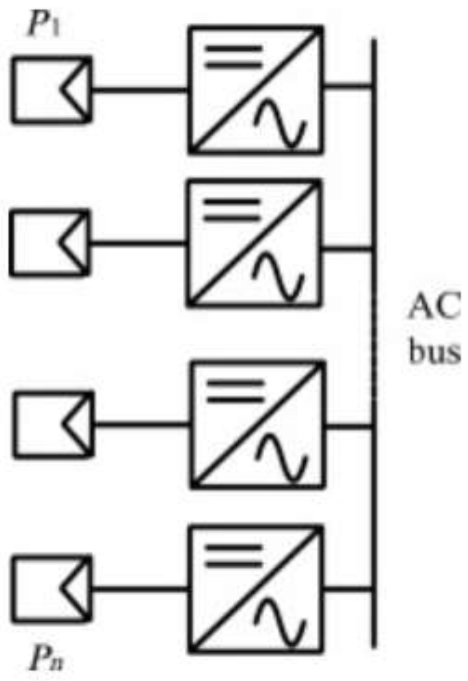
Aside from the modes of operation, grid-connected inverters are also classified according to configuration topology. There are four different categories under this classification.

1. Central inverters, which are usually around several kW to 100 MW range.
2. String inverters, typically rated around a few hundred Watts to a few kW.
3. Multi-string inverters, typically rated around 1 kW to 10 kW range.
4. And finally, Module Inverters or Micro Inverters, typically rated around 50 to 500 W.

Microinverters

- The microinverters are usually attached on the back of all individual solar panels, instead of a single inverter on entire solar array.
- Microinverters are highly cost-inefficient, but offer the **high energy efficiencies.**
- The ultimate statement about relative effectiveness of microinverters, depend on the situation and area of the working solar power plant.

- The structure of microinverter is very simple as it consists of **very small box** placed at the back or very close to the panel.
- As the design of the inverter is very small with regards to its size and rating, they are classified **under small inverters.**
- Microinverters are small inverters (both size-wise and rating-wise) that are designed to be attached to the back of each solar panel of the array.
- In some cases, they are attached to two solar panels instead of just one.
- With these, the direct current produced from the respective panels is inverted to alternating current and is then sent into the appliances. Fig. 8.10 shows the simple arrangement of a microinverter.



- Micro inverters convert power individually which allows them to have a number of electrical, wiring, and power optimization advantages.
- String inverters require a specific number of panels and certain orientation limitations, limiting the number of solar panels, or raising costs for residences with small or oddly shaped roofs.
- Micro inverters also work around **shaded areas of** a roof, because they collect power from performing panels, and undeforming ones do not affect the rest.
- **No DC Line** – Micro inverters automatically convert DC to AC, removing the need for a DC line altogether. This makes installation easier when connecting the system to the grid, because AC lines plug in similarly to traditional power circuit boxes.
- **Modular System** – A **single failing inverter** or panel **does not take out the entire string**. With one failed panel, the rest remain productive.
- **Potential Power Output** – Studies show that Micro inverters can increase power output by an average of 5-10% over the lifetime of the system. Over10-15 years (the average lifespan of a micro inverter) MCIs can achieve parity in most systems, but an intensive cost analysis is necessary, because this is not always the case.
- **Fewer Issues** – MCIs reduce many of the issues present in central inverters simply because of their reduced size. For example, many small solar panel systems oversize inverters, purchasing and paying for conversion power they cannot use due to the limited range of solar converters.
- A 2800 watt solar array will likely require a 3,000 watt inverter, despite being unable to use the full capacity. Micro inverters also reduce the need for large transformers and large electrolytic capacitors, meaning that they typically last longer.
- In some cases, long-lasting thin-film capacitors are used, which have the added benefit of storing more power in a smaller housing. I
- n the case of thin film capacitors, a larger storage area means more efficiency, because the film capacitor stores power for longer, keeping energy when the grid AC is at zero, and distributing it when it goes up.
-

Key Metrics	String Inverters	Microinverters
Functionality	Converts DC to AC for all solar panels connected in a string	Typically converts DC to AC for each individual or a group of two panels
Efficiency	Lower efficiency in partially shaded conditions	More efficient than string inverters, especially in partially shaded conditions
Cost	Cheaper	High upfront cost but deliver higher lifetime value
Installation	Installation is complex and time consuming	Installation is easier and safer
Point of failure	If one inverter in a string has a failure, the entire string will stop producing electricity, leading to larger losses affecting the rest of the system	If a microinverter stops working, then only the panels connected to that microinverter will stop working, without affecting the rest of the system

Inverter modeling

- Inverter modeling is a critical component of PV simulation, as it directly impacts the accuracy of energy output predictions and overall system performance.
- Through Maximum Power Point (MPP) tracking, the inverter dynamically adjusts to changes in irradiance, temperature, and other environmental factors, ensuring that the PV system operates at its optimal efficiency while adhering to system constraints.
- This capability is essential for achieving reliable and efficient energy production under real-world conditions.
- A comprehensive understanding of the inverter's performance is vital, particularly in the DC-to-AC conversion process.
- Accurate modeling of this conversion not only predicts the energy output but also evaluates the inverter's ability to manage power quality and reactive power requirements.
- These aspects are crucial for maintaining grid stability and ensuring compliance with modern energy standards.
- Additionally, **auxiliary losses**—energy consumed by support systems such as cooling, lighting, and motor drives—must be incorporated into performance and efficiency calculations.

Key features of inverters

- **Power factor (pf) setting**: The power factor (cos(ϕ)) determines the ratio of active to reactive power at the inverter outputs and at the grid injection point. The calculated apparent power at the inverter output will not exceed the maximum apparent AC power specified in the inverter's datasheet.
- **Power grid limitation**: If required by grid operators, a power limit can be set at the inverter to control the injected electrical active power at the grid injection point.
- **Night power consumption**: An important feature of inverters is their night power consumption, usually specified in watts in the technical datasheet. This represents standby mode consumption when GHI = 0 and DNI = 0.

Maximum Power Point (MPP) calculation

- The Maximum Power Point (MPP) calculation identifies the optimal operating point on the IV curve on the inverter input. This point is critical for ensuring the PV system operates efficiently, maximizing the energy harvested under varying environmental and operational conditions.
- **Process**: The Maximum Power Point (MPP) calculation utilizes the **IV curve** at the inverter input, which is derived from the previous simulation steps. Multiple Maximum Power Point Tracking (MPPT) circuits are simulated to continuously adjust the operating points of PV modules, ensuring maximum power delivery.
- **Inputs**: The inputs for MPP calculation include the P-V characteristics, calculated as $P = V \times I$. If the inverter's power output needs to be limited due to its capabilities or grid restrictions, the input circuits regulate power from the DC array accordingly.

DC/AC conversion

- Once the Maximum Power Point (MPP) is identified, the inverter converts the DC power generated by the PV modules into usable AC power.
- This critical step ensures that the energy harvested from the solar panels can be effectively delivered to the grid or used in local applications, maximizing the system's overall efficiency and utility.
- To simulate this conversion process, we employ the Inverter Model, which provides a detailed and accurate framework to determine the efficiency curve under different operating conditions, specifically varying DC input power and voltage levels.
- This model considers various factors, including the **inverter's efficiency** and other dynamic operating characteristics, enabling precise predictions of the AC output under diverse environmental and operational conditions.
- Following this, we calculate the **Complex output working point**, which involves determining both the active and reactive components of the electrical power output.

- **complex output working point**
- In Solargis Evaluate, electrical power within the AC network consists of both active and reactive power. The resulting complex AC output of the inverter can be expressed as
- S=P+i*Q=S*cos(ϕ)+i*S*sin(ϕ)
- where:
- S is the complex value of apparent electrical power,
- P is active electrical power,
- Q is reactive electrical power,
- ϕ can be calculated as ***φ=arccos(pf).***

solar PV system sizing

- **1. Determine power consumption demands**The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:
- **1.1 Calculate total Watt-hours per day for each appliance used.** Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

  1.2 Calculate total Watt-hours per day needed from the PV modules. Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.
- **2. Size the PV modules**Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced needs. The peak watt (Wp) produced depends on size of the PV module and climate of site location. We have to consider �panel generation factor� which is different in each site location. For Thailand, the panel generation factor is 3.43. To determine the sizing of PV modules, calculate as follows:
- **2.1 Calculate the total Watt-peak rating needed for PV modules** Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by 3.43 to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.
- **2.2 Calculate the number of PV panels for the system** Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.
- Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened.

- **. Inverter sizing**An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.
- For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting.
- For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation.
-

  4. Battery sizing The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculate as follows:
- 4.1 Calculate total Watt-hours per day used by appliances.
  4.2 Divide the total Watt-hours per day used by 0.85 for battery loss.
  4.3 Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
  4.4 Divide the answer obtained in item 4.3 by the nominal battery voltage.
  4.5 Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.
- Battery Capacity (Ah) = $\dfrac{\text{Total Watt-hours per day used by appliances}}{(0.85 \times 0.6 \times \text{nominal battery voltage})}$ x Days of autonomy

- **5. Solar charge controller sizing**The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.
- For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).
- According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3
- Solar charge controller rating = Total short circuit current of PV array x 1.3

Example: A house has the following electrical appliance usage:

One 18 Watt fluorescent lamp with electronic ballast used 4 hours per day.
One 60 Watt fan used for 2 hours per day.
One 75 Watt refrigerator that runs 24 hours per day with compressor run 12 hours and off 12 hours.
The system will be powered by 12 Vdc, 110 Wp PV module.

1. Determine power consumption demands

Total appliance use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 24 x 0.5 hours)
= 1,092 Wh/day
Total PV panels energy needed = 1,092 x 1.3
= 1,419.6 Wh/day.

2. Size the PV panel

2.1 Total Wp of PV panel capacity
needed = 1,419.6 / 3.4
= 413.9 Wp
2.2 Number of PV panels needed = 413.9 / 110
= 3.76 modules

Actual requirement = 4 modules
So this system should be powered by at least 4 modules of 110 Wp PV module.

3. Inverter sizing

Total Watt of all appliances = 18 + 60 + 75 = 153 W
For safety, the inverter should be considered 25-30% bigger size.
The inverter size should be about 190 W or greater.

4. Battery sizing

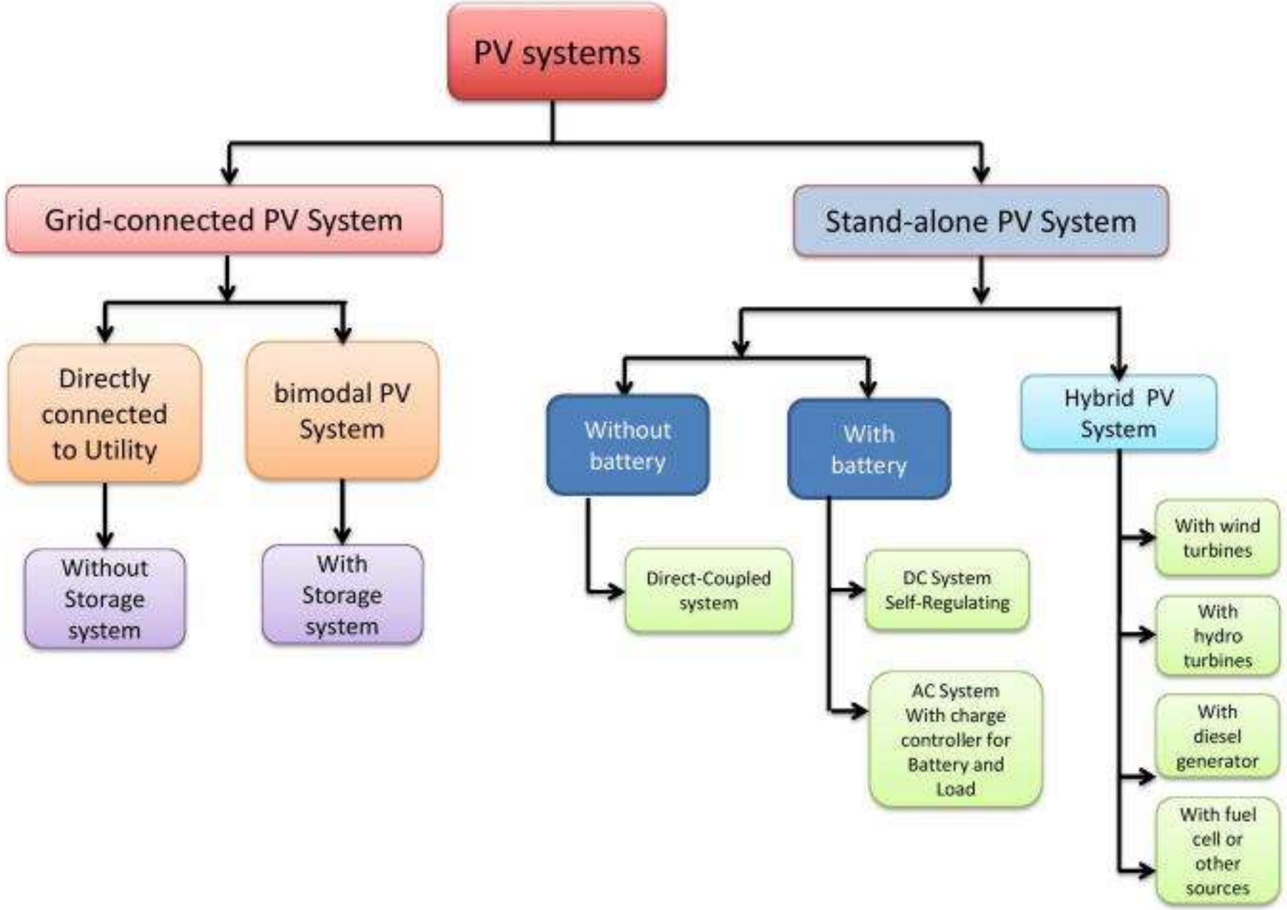
Total appliances use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours)
Nominal battery voltage = 12 V
Days of autonomy = 3 days

Battery capacity = [(18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours)] x 3
(0.85 x 0.6 x 12)
Total Ampere-hours required 535.29 Ah
So the battery should be rated 12 V 600 Ah for 3 day autonomy.

5**. Solar charge controller sizing**

PV module specification
Pm = 110 Wp
Vm = 16.7 Vdc
Im = 6.6 A
Voc = 20.7 A
Isc = 7.5 A
Solar charge controller rating = (4 strings x 7.5 A) x 1.3 = 39 A
So the solar charge controller should be rated 40 A at 12 V or greater.

different types of PV configurations that work for both **Grid-connected and Stand-alone** applications.
We can see that the main difference between these two main types is **utility grid availability.**



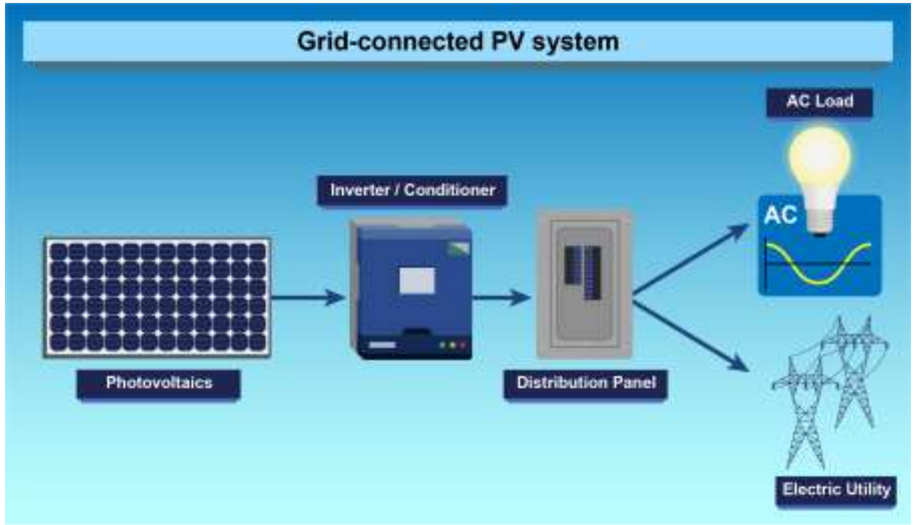
PV System Types and Components

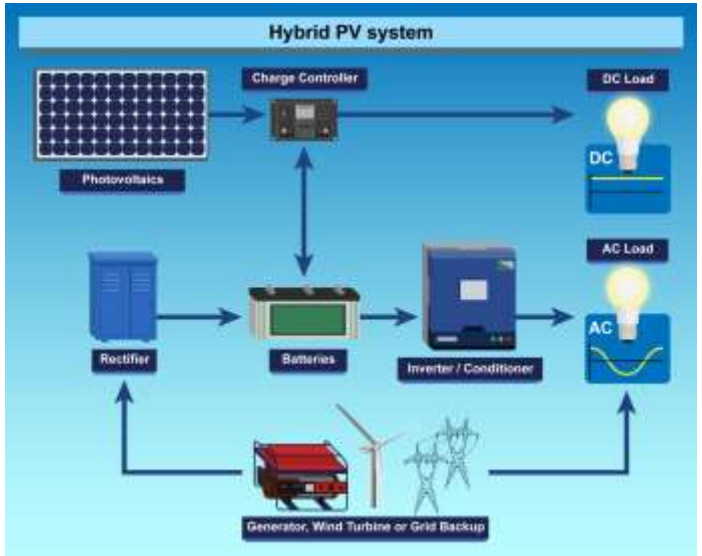
- The two principal classifications are

  >grid-connected or utility-interactive systems

  >stand-alone systems.

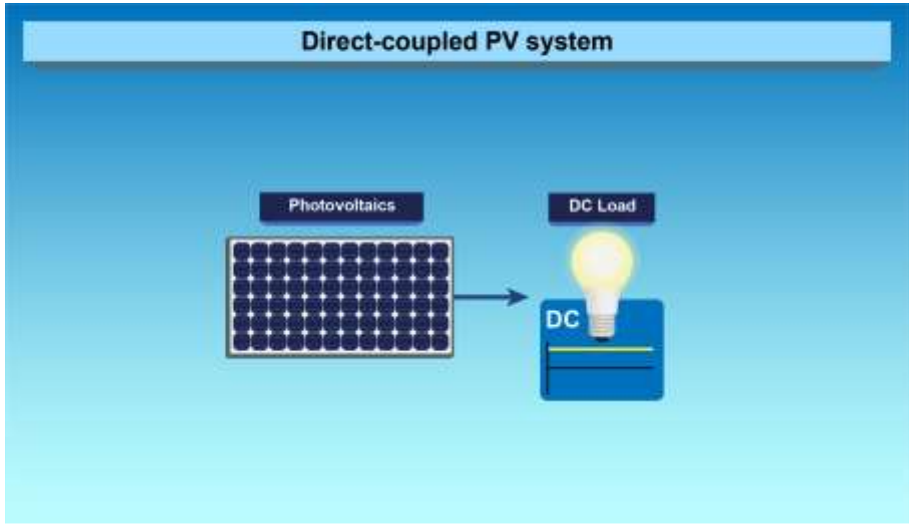
- Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.
- **grid-connected** or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid.
- The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU).
- The PCU converts the DC power produced by the PV array into AC poAwer consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized.
- A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance.
- This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back-feed the grid when the PV system output is greater than the on-site load demand.
- At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair.

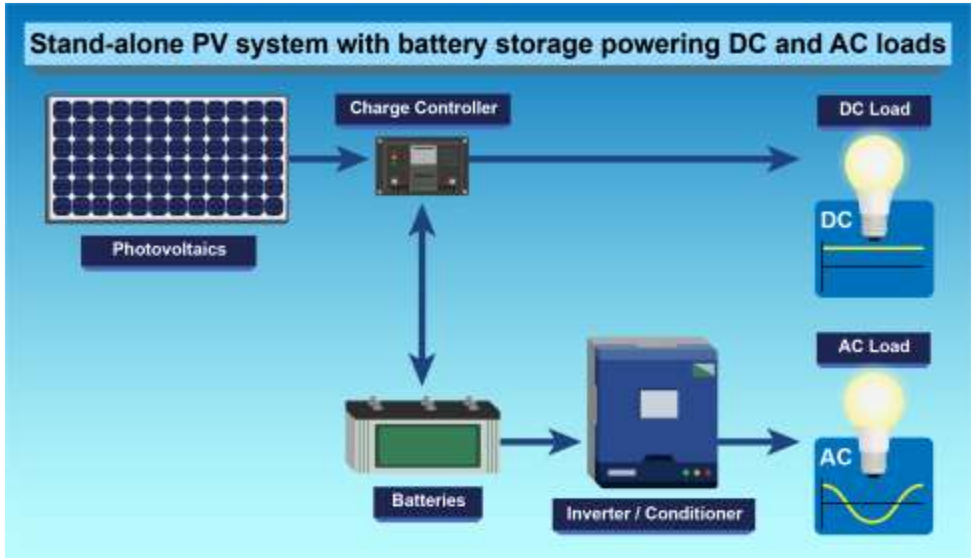




Stand-alone PV systems

- Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads.
- These types of systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as an auxiliary power source in what is called a PV-hybrid system.
- The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load (Figure 1).
- Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems.
- Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled system.
- For certain loads such as positive-displacement water pumps, a type of electronic DC-DC converter, called a maximum power point tracker (MPPT), is used between the array and load to help better utilize the available array maximum power output.
- In many stand-alone PV systems, batteries are used for energy storage. The figures below show two possible configurations.

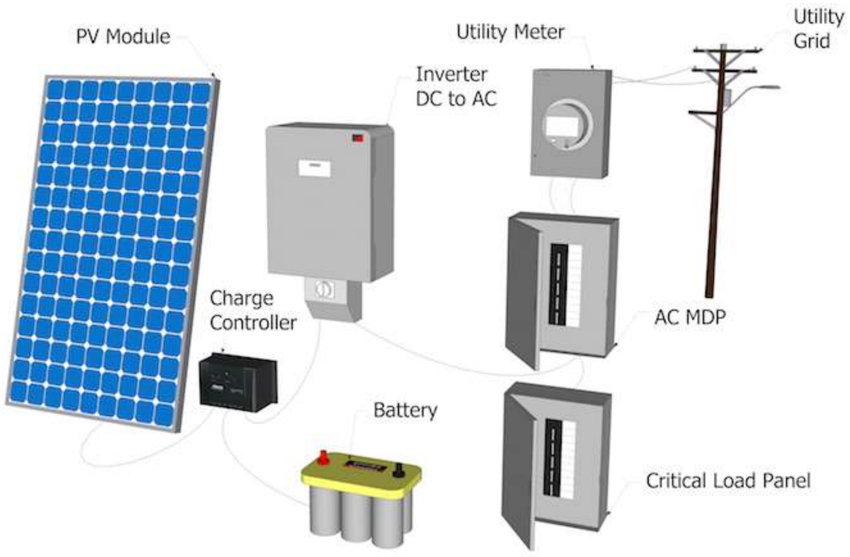




grid-Connected system:

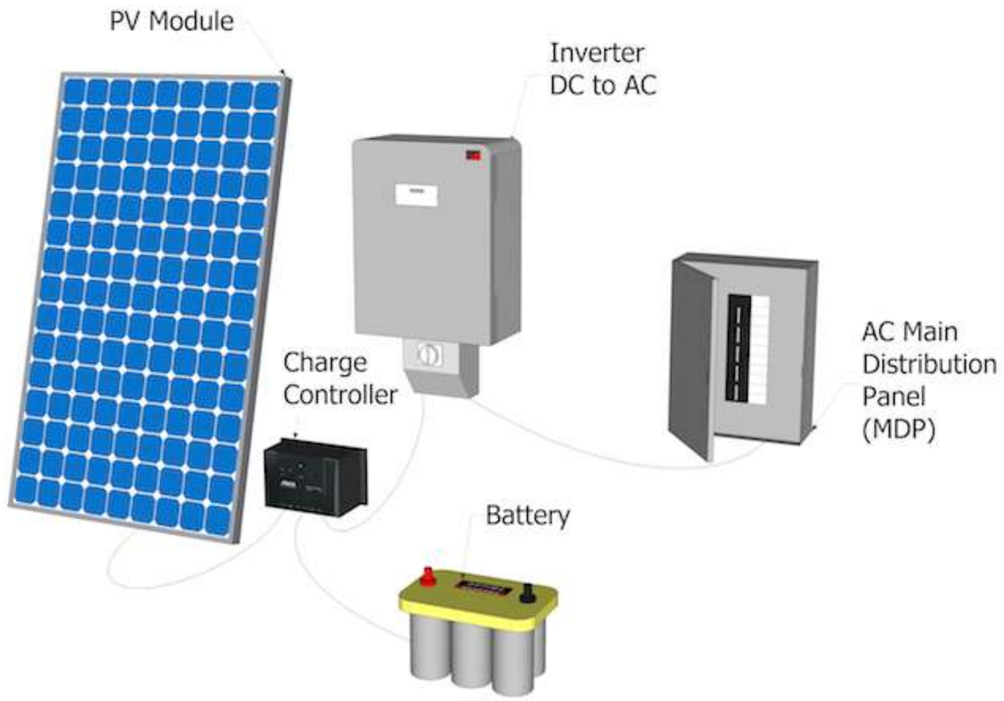
- This type of configuration is the most common type for applications where clients want to save energy on their utility bills and while the utility grid exists for use when the PV array is not generating any energy.
- The PV array can be directly coupled to the grid without any storage system and is called "Utility-Interactive PV System or Grid-Tied PV System," as illustrated in Figure 1.10.
- Alternatively, it can store excess energy into battery banks for later use, and in this case, it is called a "Bimodal PV System or Battery Backup PV System," as shown in Figure 1.11.

- https://www.youtube.com/watch?v=r50ECWepd6M&t=58s



Stand-alone PV systems:

- All stand-alone (AKA off-grid) systems work in general without the utility grid, as shown in Figure 1.8. It can be seen that we expect a perfect match between the supply and demand, or in other words between PV system size and load requirement. When this match is done perfectly for a single load, the PV system in this case can be called a "Direct-Coupled PV System," and very minimal components are needed without the need for storage systems.
- Another type of stand-alone requires a storage system to allow excess energy to be stored when it is not needed by the load and can later be drawn when the sun is not available. This type can be connected directly to DC loads or to AC loads through an additional power conditioning component, or “Inverter,” as we will learn later.
- The other common type of stand-alone system is the "Hybrid PV System," as illustrated in Figure 1.9, which uses other energy sources in parallel to the PV array to supply loads. These energy sources can be Wind Turbines, Hydro Turbines, Diesel Generators, or Fuel cells. Hybrid PV Systems can also use Batteries for energy storage.



- A solar system connected to the utility grid through a bi-directional net meter is known as a grid-connected PV system. It is known by various names, including a grid-connected energy system, a grid-tied solar system, and an on-grid solar system.
- The grid-connected system has a fairly simple working mechanism:
- **Panels capture the sunlight**: The solar panels in the grid-connected PV system capture solar energy and transform it into DC (direct current) power.
- **Inverter converts DC power**: The solar inverter in a grid-connected solar system converts DC power into AC (alternating current) power, supplying it to homes where various electronic devices can utilize it.
- **The bi-directional net meter keeps a record of energy exchange**: The net meter records the unit exchange between the local utility grid and the solar system. This record is used to generate the solar bill.
- **Daytime functioning**: When excess power is produced, the bidirectional meter in the grid-connected solar PV system exports extra units of electricity to the grid.
- **Nighttime functioning**: Later on (at night), the exported units are imported to keep the power supply on. Additionally, the grid-connected PV system provides consumers with the flexibility to use electricity from the grid when sunlight is scarce or absent.
- When the grid-connected PV system is installed on residential or commercial rooftops, it provides solar electricity to all the electrical ports and sockets. This PV system has a simple design and requires minimal maintenance, making it more cost-efficient than other **types of solar systems**.
- Ready to explore the ins and outs of a grid-connected PV system, including its components, types, working, and rates? If yes, this page is a goldmine of answers. Let’s begin with the basics – the components of a grid-connected system.

- **What Are the Components of a Grid-Connected PV System and How Do They Produce Electricity?**
- A grid-connected solar system without batteries aka an **on-grid solar system** has five major components:
- Solar panels
- Solar inverter
- Bi-directional net meter
- Main utility grid
- Mounting structures
- Let’s understand the role of each component in detail.

- **1. Solar Panels**
- Solar panels are the most visible parts of a grid-connected solar PV system. They're made up of small solar cells that absorb energy from sunlight and convert it into DC (direct current) power in real-time. It's essential to select an appropriate **solar panel type**, as different types have varying efficiencies.
- Here are some ideal solar panels, most suited for residential solar installations at homes and housing societies:
- **Monocrystalline solar panels**: 19-20% efficiency
- **Bifacial solar panels**: Up to 22% efficiency
- **Mono-perc half-cut bifacial solar panels**: Up to 22.5% efficiency
- The DC power generated by these solar panels in the grid-connected PV system ranges in thousands of volts. It can't be supplied to homes as it is, since DC power can be lethal. Therefore, DC power is sent to a solar inverter for conversion to a usable energy form that's safe for households.

- **2. Solar Inverter**
- The inverter is a crucial component in a grid-connected PV system, as it ***converts the DC power received from the solar panels into AC (alternating current)*** power. The inverter then sends the AC supply to the house, allowing all connected devices to run on solar electricity.
- *But what happens if it's an unusually sunny summer afternoon and your grid-connected system ends up generating more electricity than your household can consume in real time?* That's where the net meter (a bidirectional meter) comes into play. This meter is responsible for the to-and-fro of electricity between your solar system and the local utility grid based on your household's energy consumption.

- **3. Net Meter (Bidirectional Meter)**
- There's no guarantee that the electricity being generated by the rooftop solar system for homes is just enough for household consumption:
- **Excess power generation**: During the summer months, the panels can produce significantly more electricity than your household can consume.
- **Less power generation**: During monsoons, the panels might end up generating less power than what's required to meet your electricity demands.
- **No power generation**: At night, the panels will not generate any electricity at all.
- Each of the three conditions listed above is tackled by a net meter. It's a bidirectional meter, which means that the meter can control (and track) the flow of electricity between the solar system and the utility grid.
- Here's how a balance is achieved:
- **When the system generates more electricity**: If extra units are produced that aren't being consumed, the net meter transfers these units to the electricity grid.
- **When lesser units are generated or it's nighttime**: The net meter imports electricity from the grid, which keeps the house running at all times without interruption.
- The bi-directional net meter keeps a tab of this entire unit exchange between the grid-connected PV system and the grid. This process is called net metering. Here's why net metering is beneficial (and mandatory):
- **Consumers get credits**: When your grid-connected system supplies more electricity to the grid than what it imports, your discom gives you credits.
- **Consumers pay the bill**: When you import more power than what your grid-connected solar system supplies to the grid, you pay for the extra units consumed. However, any excess energy your system generates also earns you credits. These credits can offset your electricity bill. You only need to pay the distribution company (discom) if your energy usage exceeds the total credits you've earned.

- **4. Grid**
- It should be clear by now that without a grid, a grid-connected solar PV system can’t be operational. A grid is indeed the most quintessential part of a grid-connected system. It’s more akin to a battery, as that’s where excess power is stored and then retrieved when needed. So, it’s essentially a backup power source.

- **5. Mounting Structures**
- Mounting structures, also known as **mounting stands**, are the structures where solar panels are mounted. They have to be strong enough to support the solar panels. Why? Because solar panels can be heavy. For instance, even a small 1 KW solar system mounted on 6ft to 9ft raised mounting structures on an RCC rooftop can weigh anywhere between 25-30 kg per square meter.
- Moreover, mounting structures should be sturdy enough to withstand India's tropical climate. Which is why, SolarSquare launched the **WindPro Mount™ mounting structures** specifically designed to withstand cyclonic winds that often hit India during the monsoons. Here are the most exciting features of our WindPro Mount™:
- **Stand tall in cyclonic winds**: They ***withstand winds up to 170 kmph***.
- **Corrosion-resistant**: Made of virgin steel, our mounts have an ***80-micron HDGI (hot-dipped galvanized iron) coating*** that prevents corrosion and rust for a minimum of 25 years.
- **Excellent storm safety record**: Our mounts are sturdy even in the face of severe cyclones. As a result, SolarSquare has had a ***99.91% storm safety record*** for the last two years

- there are two types of grid-connected solar systems, explained below:
- **On-grid systems**: In this type, the solar system is integrated with a grid. The structure is similar to traditional electricity infrastructure. It is the most popular and widely trusted grid-connected PV system available in the market.
- **On-grid systems with a battery backup**: This grid-connected PV system is similar to the first one, except that it features a battery backup in addition to being connected to the utility grid. It's ***also known as a hybrid solar system***. The batteries store the extra electricity from the sunlight and save it for emergencies.

Grid-Connected System Without Batteries (On-Grid System)	Grid-Connected PV System With Batteries (Hybrid Solar System)	Off-Grid PV System
Connected to the main utility grid	Connected to the main utility grid and a battery bank, usually composed on lithium batteries	Standalone system not connected to the grid Connected only to a battery bank usually composed of lithium batteries
Equipment required: Solar inverter Solar panels Bidirectional meter A grid Mounting structures Solar accessories	Equipment required: Solar inverter Solar panels Bidirectional meter A grid Batteries Mounting structures Solar accessories	Equipment required: Solar inverter + solar charge controller Solar panels Batteries Mounting structures DC disconnect Backup generator(optional) Solar accessories
Cheapest and most cost-efficient	Most expensive	More expensive than on-grid solar systems
It is highly efficient as the energy is drawn directly from the sunlight	The efficiency decreases over time as the battery bank gets older	The efficiency decreases over time as the battery bank gets older
Government provides subsidy for residential installations	Government provides subsidy for residential installations	Government does not provide any subsidy

A grid-connected PV system has many benefits. Some of them are as follows:

- **Does not incur high maintenance charges**: The grid-connected PV system, without batteries, is the least expensive and easiest to maintain.
- **Simple to install**: Since no batteries are involved in an on-grid system, it’s easier to install due to its simple design. Moreover, it can be installed in vacant roof space without requiring any additional land.
- **Protects the environment**: Installing something as small as a 1 kW grid-connected PV system offsets 1,176 kg of carbon dioxide in one year. It’s equivalent to planting 34 full-grown trees.
- **Scalable and suited for commercial establishments**: A grid-connected PV solar system with batteries is more than powerful to support the power consumption at large housing societies and commercial establishments.
- **Excellent ROI**: The cost for installing a grid-connected PV system without batteries breaks even in 3-5 years. Since the system remains operational for a minimum of 25 years, you will enjoy free solar electricity throughout its lifespan.

the Disadvantages of a Grid-Connected Solar System

- While they aren’t exactly disadvantages, grid-connected PV systems do have a few limitations. These include:
- **Power outages**: If the grid fails for any reason, a grid-connected system will stop working. This, however, is an intentional safety feature incorporated into a grid-connected system, ensuring that linemen working to repair a faulty line do not come into contact with live electricity. If your locality experiences frequent power cuts, you can install a grid-connected PV system with batteries for an uninterrupted power supply.
- **The initial installation cost**: While some may argue that the cost of installing grid-connected solar PV systems is in lakhs, when you compare the investment with returns, the returns are substantially high. Moreover, electricity tariffs in India increase by 3-6% annually. So, investing money to install grid-connected systems saves more money than you can imagine.

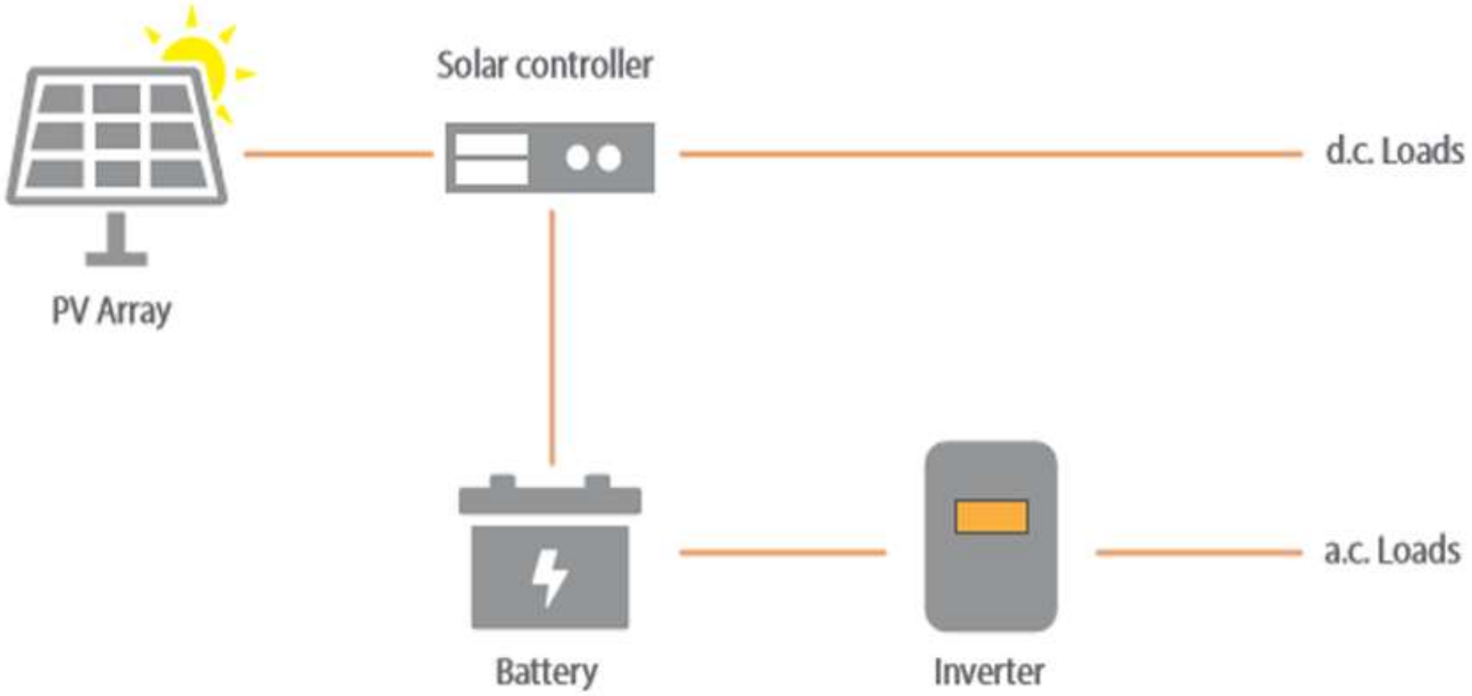


Figure 2: dc bus system

While a major component and cost of a stand alone PV system is the solar array, several other components are typically needed. These include:

- • Batteries: Batteries are an important element in any stand alone PV system but can be optional depending upon the design. Batteries are used to store the solar-produced electricity for night time or emergency use during the day. Depending upon the solar array configuration, battery banks can be of 12V, 24V or 48V and many hundreds of amperes in total.
- • Charge Controller: A charge controller regulates and controls the output from the solar array to prevent the batteries from being over charged (or over discharged) by dissipating the excess power into a load resistance. Charge controllers within a stand alone PV system are optional but it is a good idea to have one for safety reasons.
- • Fuses and Isolation Switches: These allow PV installations to be protected from accidental shorting of wires allowing power from the PV modules and system to be turned "OFF" when not required saving energy and improving battery life.
- • Inverter: The inverter can be another optional unit in a stand alone system. Inverters are used to convert the 12V, 24V or 48 Volts direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity and power of either 120 VAC or 240 VAC for use in the home to power AC mains appliances such as TV's, washing machines, freezers, etc.

- • Wiring: The final component required in and PV solar system is the electrical wiring. The cables need to be correctly rated for the voltage and power requirements. Thin telephone wire will not work!.

Batteries are an important element and the heart of any stand alone solar power system, whether that is one using a large array of panels to power a home or a small pico solar system used to power the garden, shed or fish pond.

Batteries are needed because of the fluctuating nature of the output being delivered by the PV panels or array. They also convert the electrical energy into stored chemical energy for use when the solar array is not producing power. During the hours of sunshine, the PV system is directly fed to the load, with excess electrical energy being stored in the batteries for later use. During the night, or during a period of low solar irradiance, such as a cloudy, rainy days, energy is supplied to the load from the battery.

So battery storage allows a stand alone PV system to be run when the solar panels are not producing enough energy on their own with the battery storage size tied to the electrical usage. There are basically two types of batteries used for solar energy storage: deep cycle batteries and shallow cycle batteries.