Grid Integrated Photovoltaic sources

Harnessing the Sun







Outline

- Need
- Basics of PV system
- Types of PV systems
- Role of power electronics in PV system
- Challenges faced and solutions

Need

- Traditional electric power systems are designed in large part to utilize large base load power plants, with limited ability to rapidly ramp output or reduce output below a certain level.
- Renewable sources like PV system enables the system to achieve this flexibility.
- Stand alone PV systems suffer with non-optimum utilization of generated power.
- Grid interconnection of PV power generation system has the advantage of more effective utilization of generated power.

Prospect of PV based generation

- PV based generation of electricity has seen a consistent growth of nearly 20% per year in past two decades.
- Reasons:

1) an increasing efficiency of solar cells

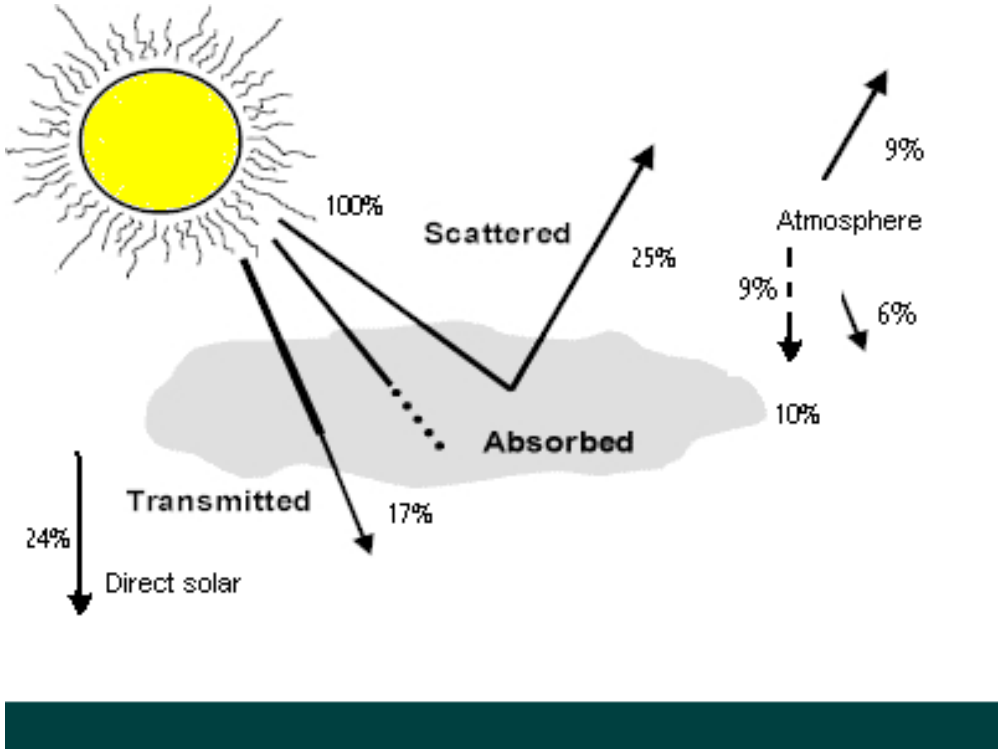
2) manufacturing-technology improvements

3) economies of scale

Indian PV Scenario

- The cumulative installed grid connected solar power capacity is 7.5 GW and a total of 100,000 MW is expected by 2022.
- Gujarat 3rd highest followed by Rajasthan & Tamilnadu.

Usable solar energy…



- The surface receives about 47% of the total solar energy that reaches the Earth. Only this amount is usable.

- Photovoltaic cells are capable of directly converting sunlight into electricity.
- As there are no moving parts, their wear & tear is less, however they are exposed to the weather conditions.
- Average lifespan is about 20 years.

Available Cell Technologies

- Single-crystal or Mono-crystalline Silicon
- Polycrystalline or Multi-crystalline Silicon
- Thin film
  - Ex. Amorphous silicon or Cadmium Telluride

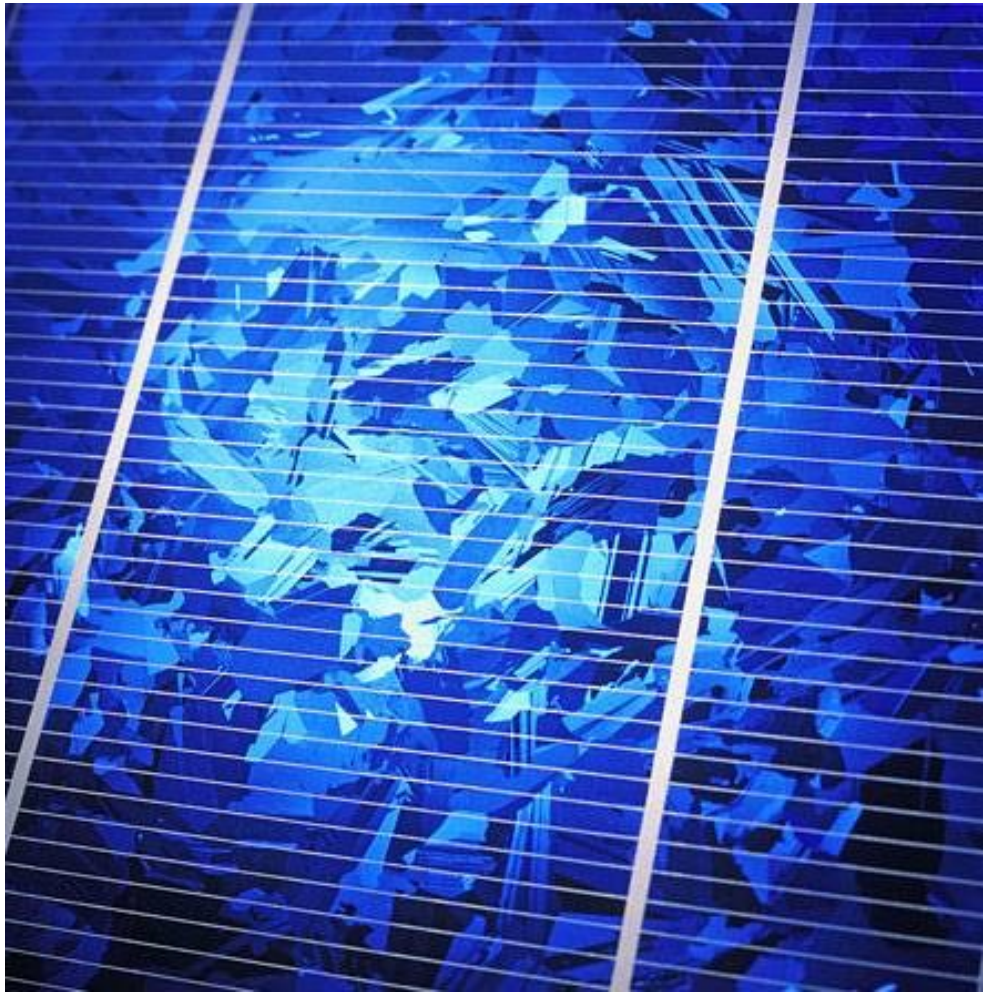
Monocrystalline Silicon Modules

- Most efficient commercially available module (11% - 18%)
- But expensive.



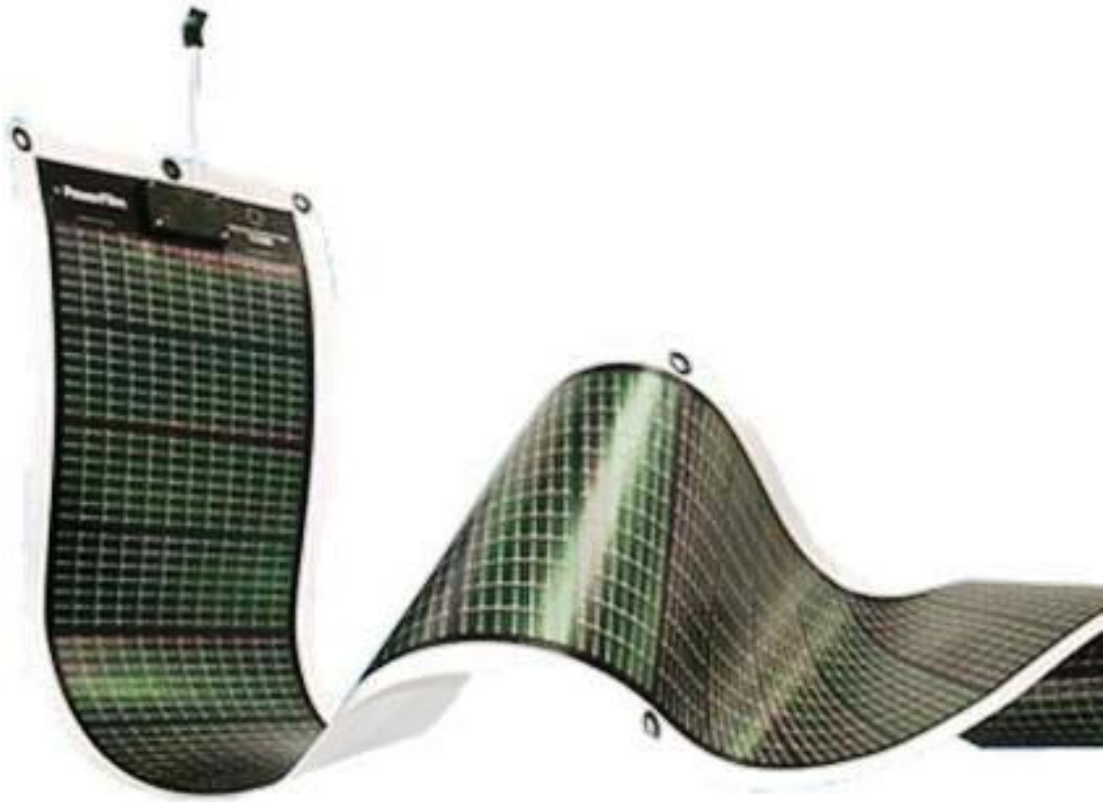
Polycrystalline Silicon Modules

- Less expensive to make than single crystalline modules
- Cells slightly less efficient than a single crystalline (10% - 12%).

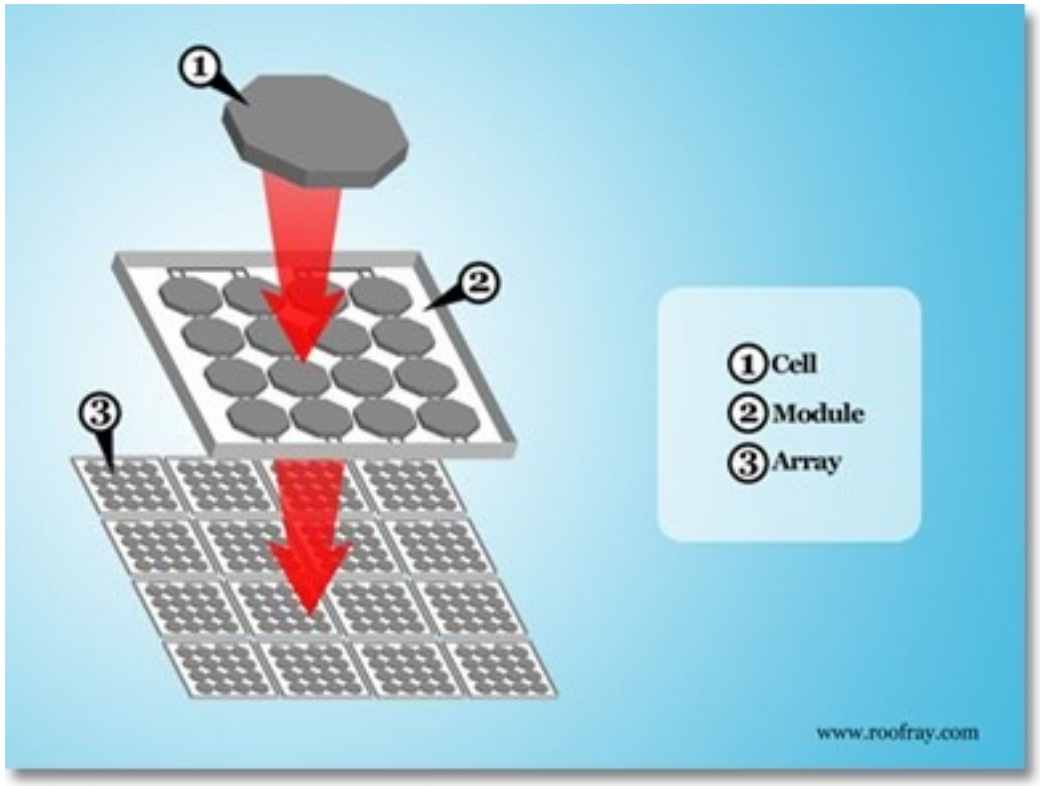


Amorphous Thin Film

- Most inexpensive technology to produce
- Efficiency = 6 – 8 %
- Can be deposited on flexible substrates
- Better performance in low light conditions that with crystalline modules



Photovoltaic Array



Technology to capture the solar energy

- Photovoltaic – Concentrating or Non-concentrating
- Concentrating Solar Power (CSP) - (also called solar thermal electric) are power plants that produce electricity from steam created from a fluid heated by the sun's energy

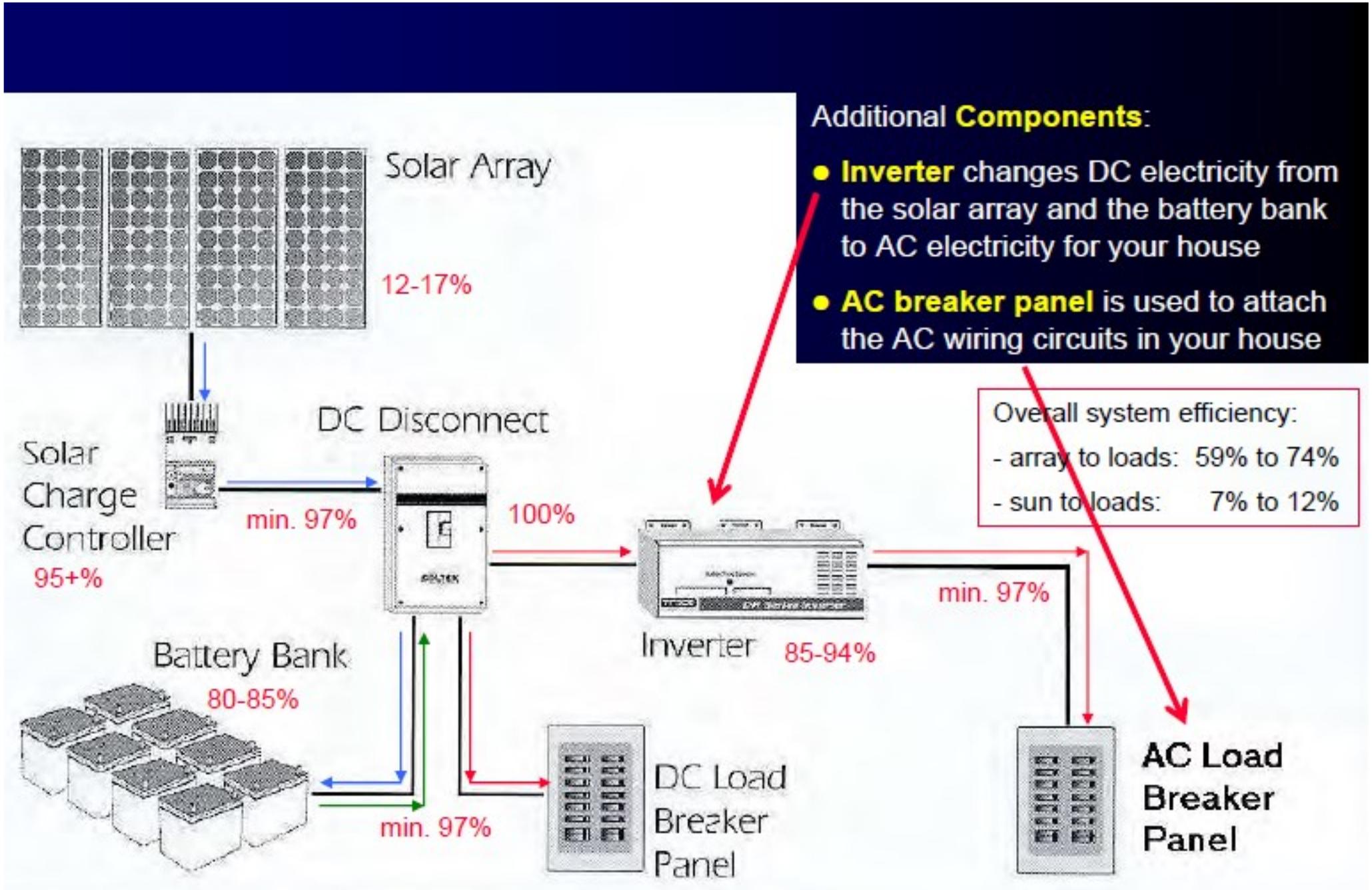
- Photovoltaic or PV – (also called solar cells) are semiconductor devices that directly convert sunlight into electricity.
- This technology has flexibility to be used for remote home power; village power; and large grid-connected systems.
- The physics of PV was first discovered in the 1800s, but was utilized with the advent of silicon semiconductor materials during the 1950s.
- Initially development of PV was for satellite usage in the early 1960s and the need to generate power to operate their sensors and communication devices in space.

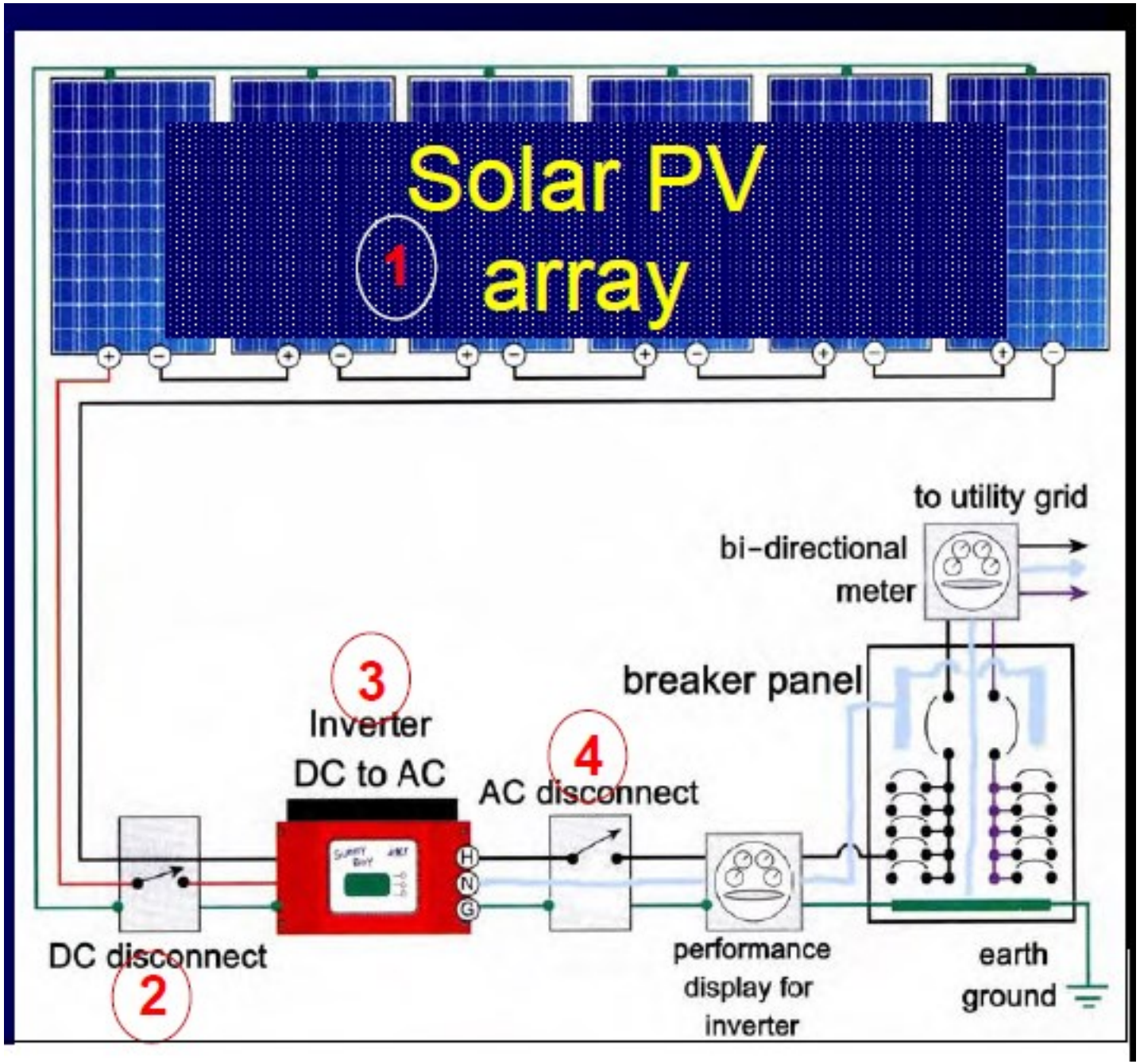
- Due to oil crisis during the late 1970s, countries like US, Europe, and Japanese plunged for the production of terrestrial solar PV power.
- This led to subsequent development of PV power industry.
- Initially the PV power plants were used to suffice electricity needs at remote locations, for e.g. powering a remote village, mountain-top radio transmitters, etc.
- But now with the need of the day their penetration in overall electric market has increased.

- Solar energy comes in two forms
  - Diffuse (skylight)
  - Direct (beam sunlight)
- Photovoltaic (PV) can use both.
- Most PV is the flat-panel kind that can receive solar energy both directly from the sun and indirectly from scattered (diffuse) light.
- By far the largest contributor on a clear day is the direct beam part, but on overcast and cloudy days the diffuse sunlight increases and the direct beam sunlight is reduced.
- Concentrating Solar Power (CSP) can use only the direct & hence it is must to track the sun.

Types of PV system

- Stand alone PV system
- Grid connected/tied PV system


Additional Components:
• Inverter changes DC electricity from the solar array and the battery bank to AC electricity for your house
• AC breaker panel is used to attach the AC wiring circuits in your house
Overall system efficiency:
- array to loads: 59% to 74%
- sun to loads: 7% to 12%
Solar Array
12-17%
Solar Charge Controller
95+%
DC Disconnect
min. 97%
100%
Inverter
85-94%
min. 97%
Battery Bank
80-85%
min. 97%
DC Load Breaker Panel
AC Load Breaker Panel


Solar PV
1
array
to utility grid
bi-directional
meter
breaker panel
3
Inverter
DC to AC
4
AC disconnect
H
N
G
DC disconnect
2
performance
display for
inverter
earth
ground

PV performance ratio

- It is the number of hours for which PV system operates effectively at its rated capacity in order to generate its energy.
- Energy per year/rated generating capacity = (KWh/year)/KW = hours/year.
- Thus, if rated operating hours are 1000 hours/year and if 5000 KWh is the electricity requirement per year, then we need 5 KW PV array.
- Say PV module efficiency is 10 – 12 % and if the incident energy is 1000 W/m^2 , then array output will be 100 W/m^2 - 120 W/m^2 .
- Hence, area requirement for 5 KW PV array will be 41 – 50 m^2 .

Basic Mounting Options

- Fixed
  - Roof, ground, pole
- Integrated
- Tracking
  - Pole (active & passive)









Passive Vs. Active

Active:

- Motors & gears controlled by sensors follow the sun throughout the day



Passive Vs. Active

Passive:

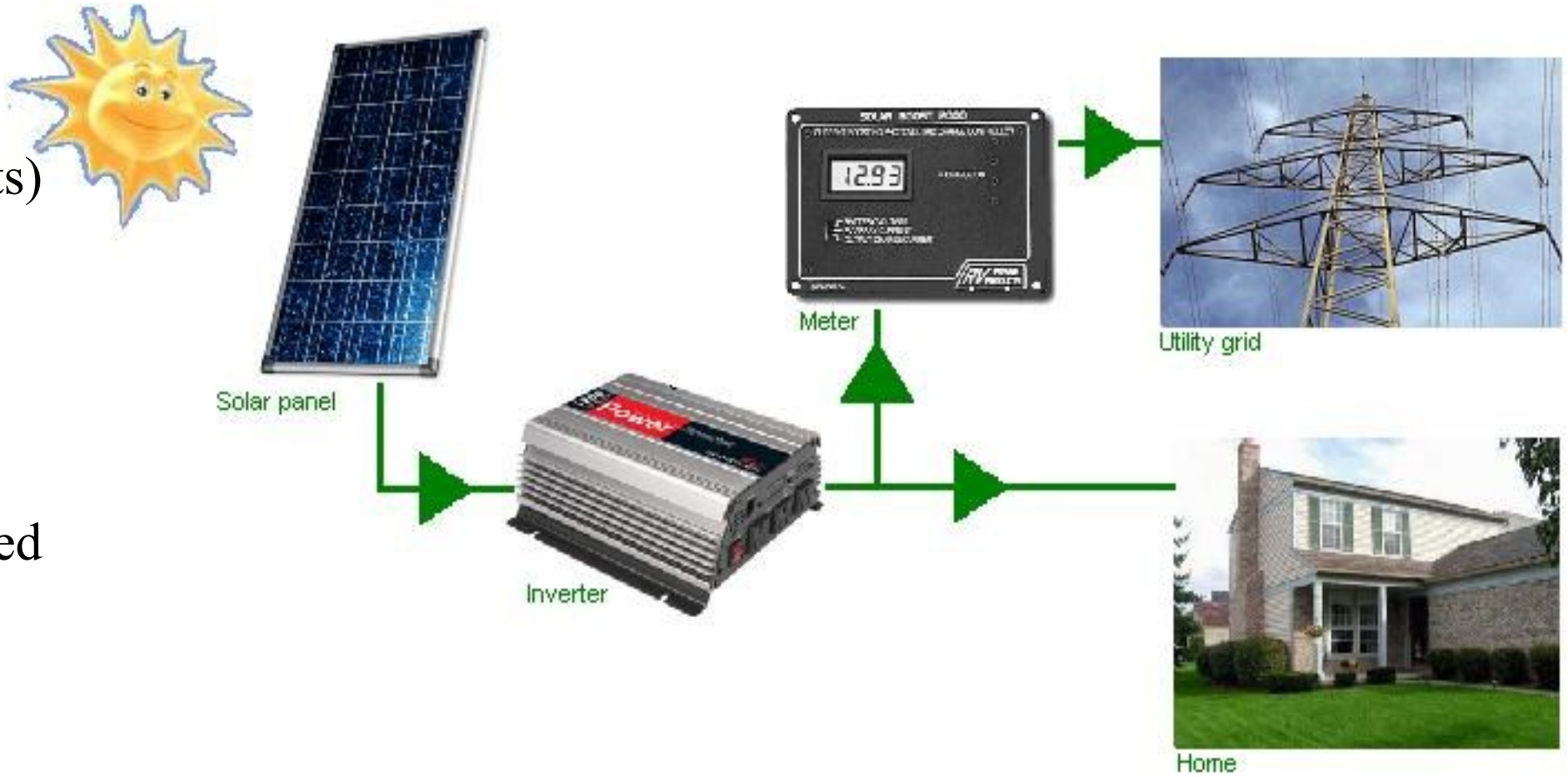
- Have no motors, controls, or gears
- Uses a low boiling point gas fluid, with change in weight depending on temperature the frame is moved.
- Non precise tracking



Grid-Tied System

Grid-Tied System

- Advantages
  - Easy to install (less components)
  - Go green
- Disadvantages
  - Uncertainty based on weather conditions



Power Electronics role in PV system

- Development of power electronic technology has played a vital role in penetration of all renewable energy based power generation systems.
- Development in semiconducting technology with evolution of devices having fast switching as well as high power handling capability .
- Availability of fast computing devices like DSPs, have led to development of grid integration of PV systems.

Power Electronics in PV

- Battery charge controllers
- Maximum power point trackers
- Voltage changers
- Solar Inverters

Battery Charge Controller

- Prevents battery overcharge
- Blocks reverse current

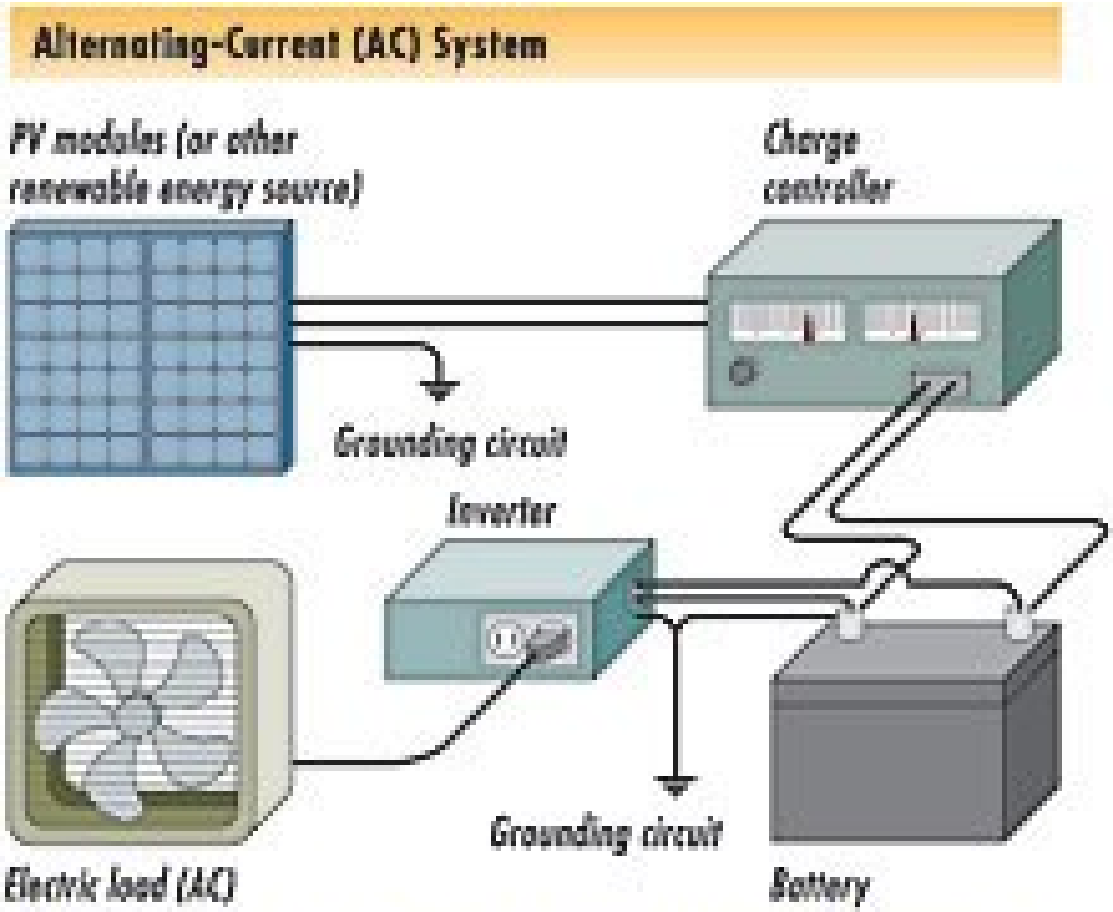


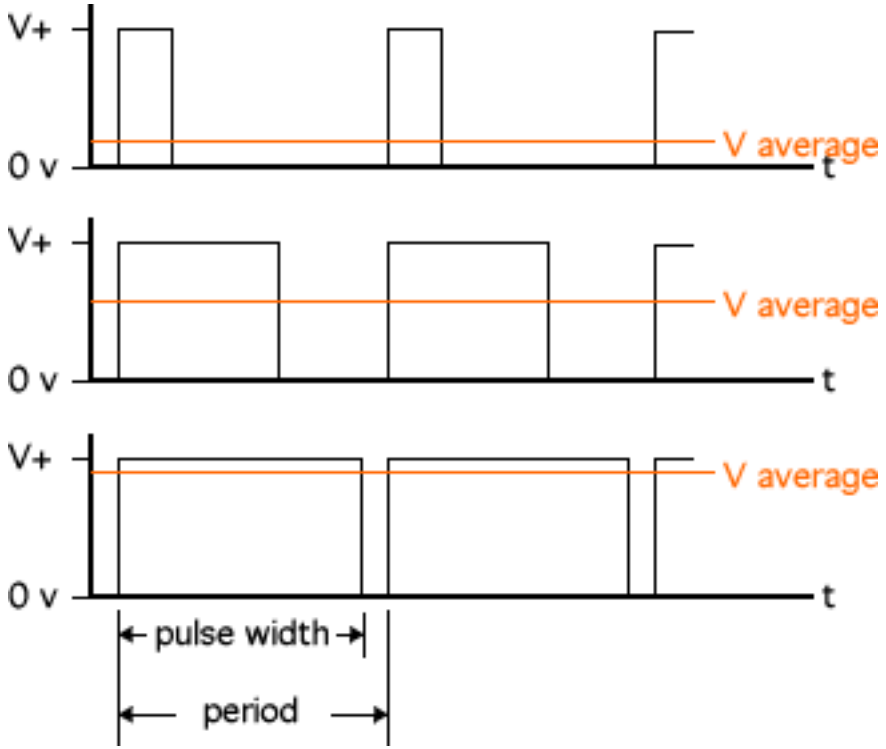
Diagram of a typical AC, battery-based system.

- Types:

➢ One and Two Stage Charge Controllers

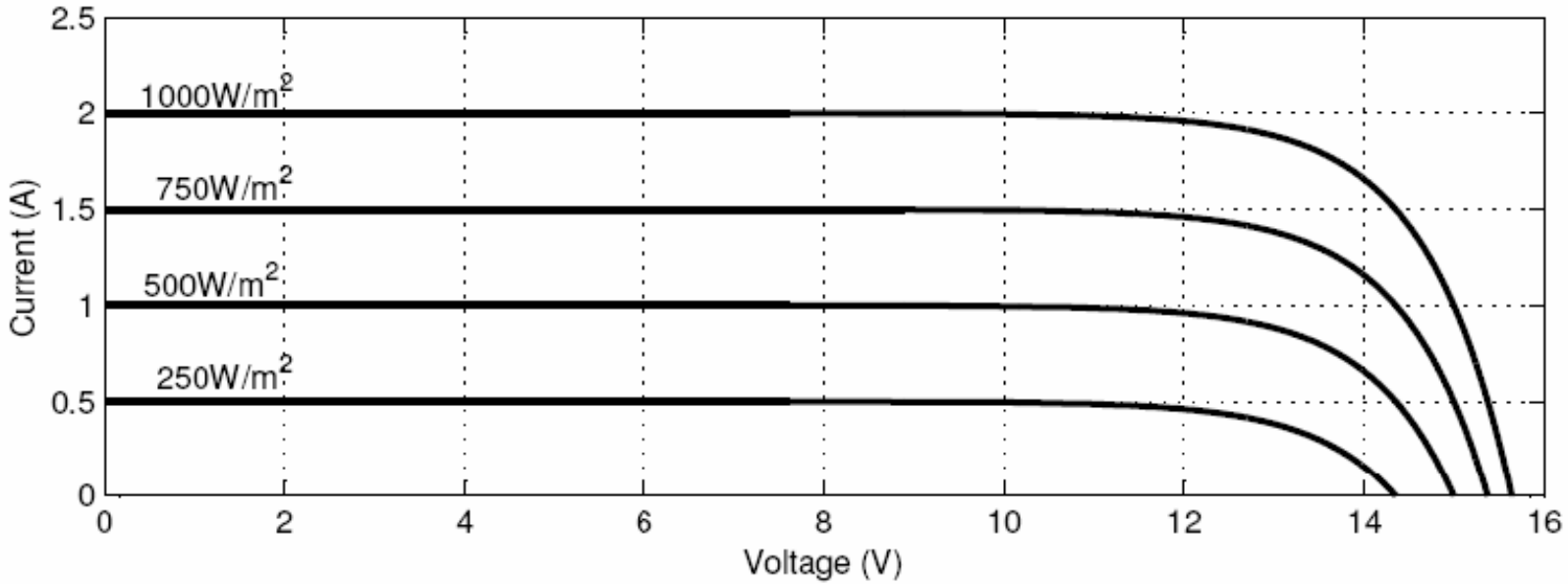
Operate by switching current fully on/off (1 stage) or by reducing current in two steps (2 stage)

➢ Pulse-Width Modulation (PWM) Controllers

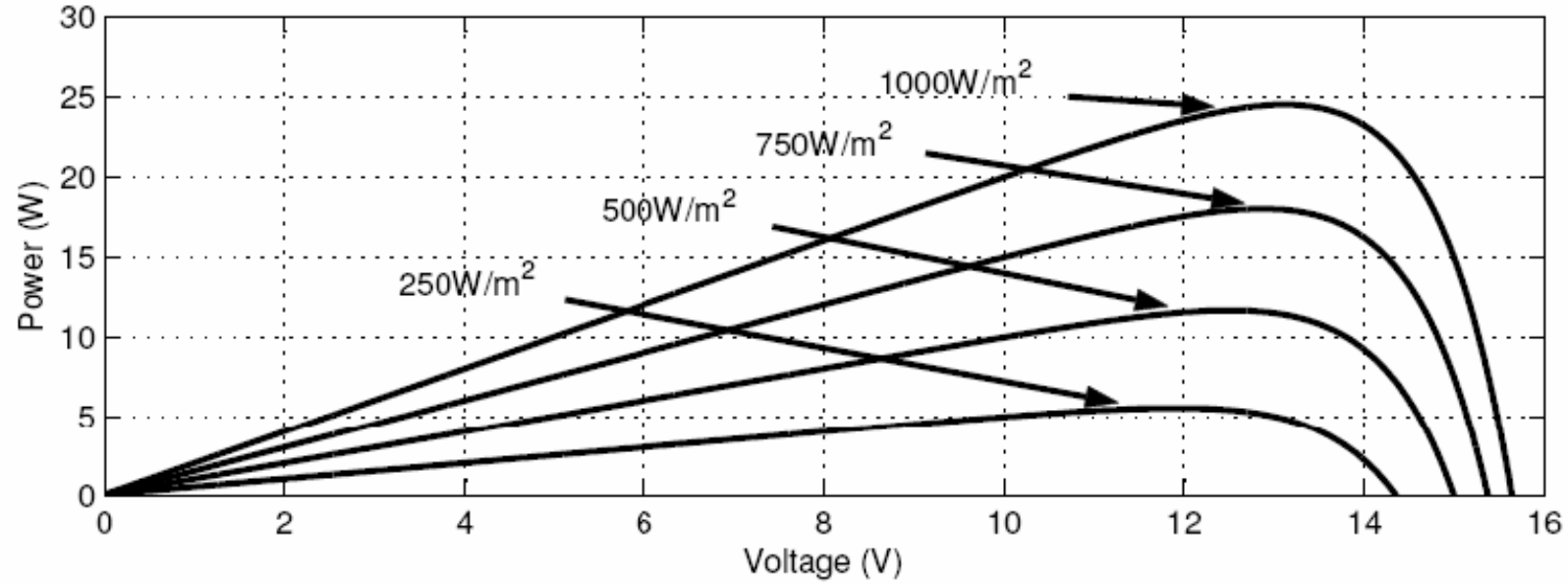


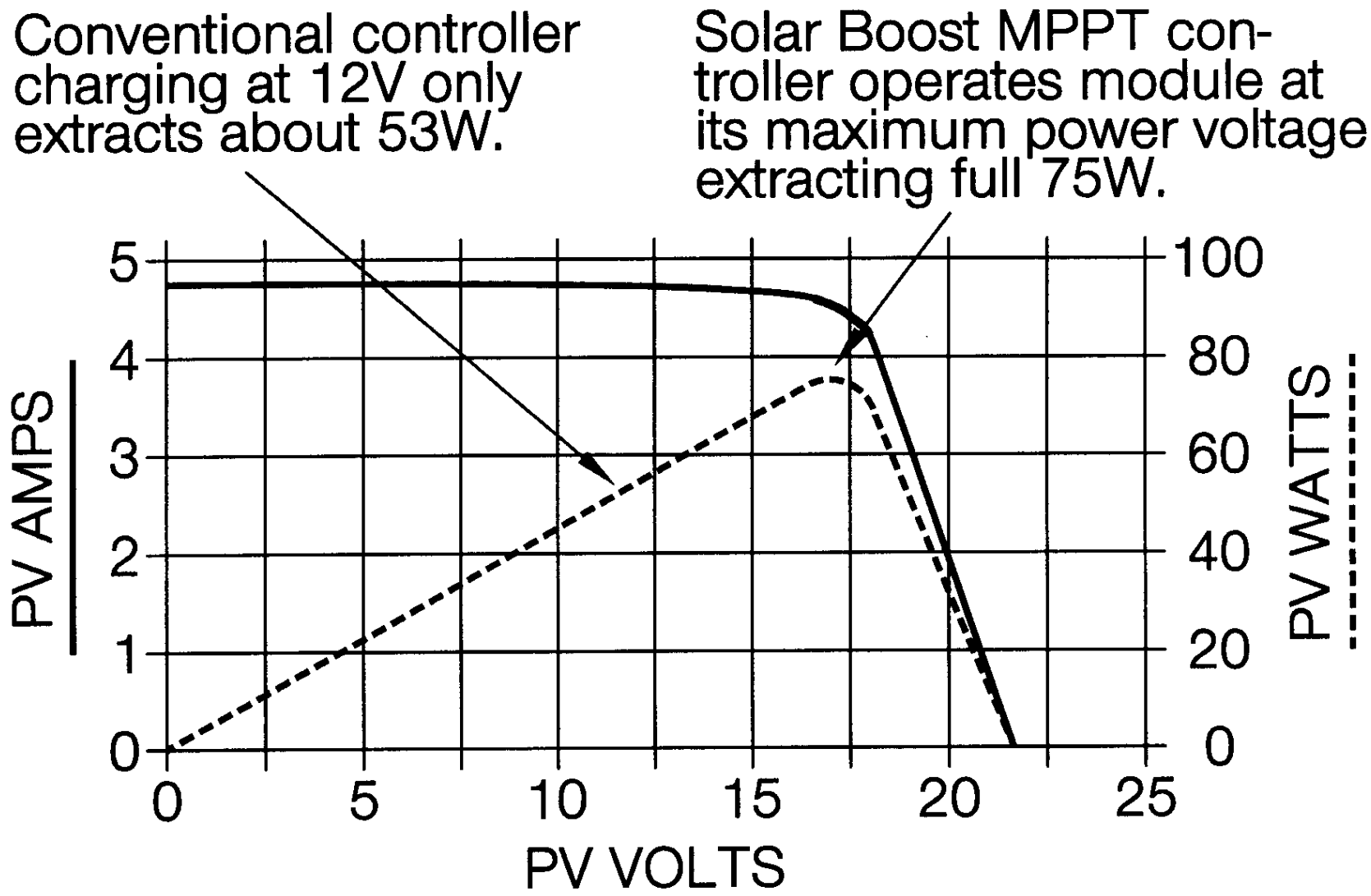
Maximum Power Point Tracking (MPPT)

- Power output of PV module varies with change in direction of sun, changes in solar insolation level and with varying temperature.
- There exists a peak power corresponding to a particular voltage and current.
- Since the module efficiency is low it is desirable to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and insolation conditions.



I-V and P-V plots under varying insolation conition.



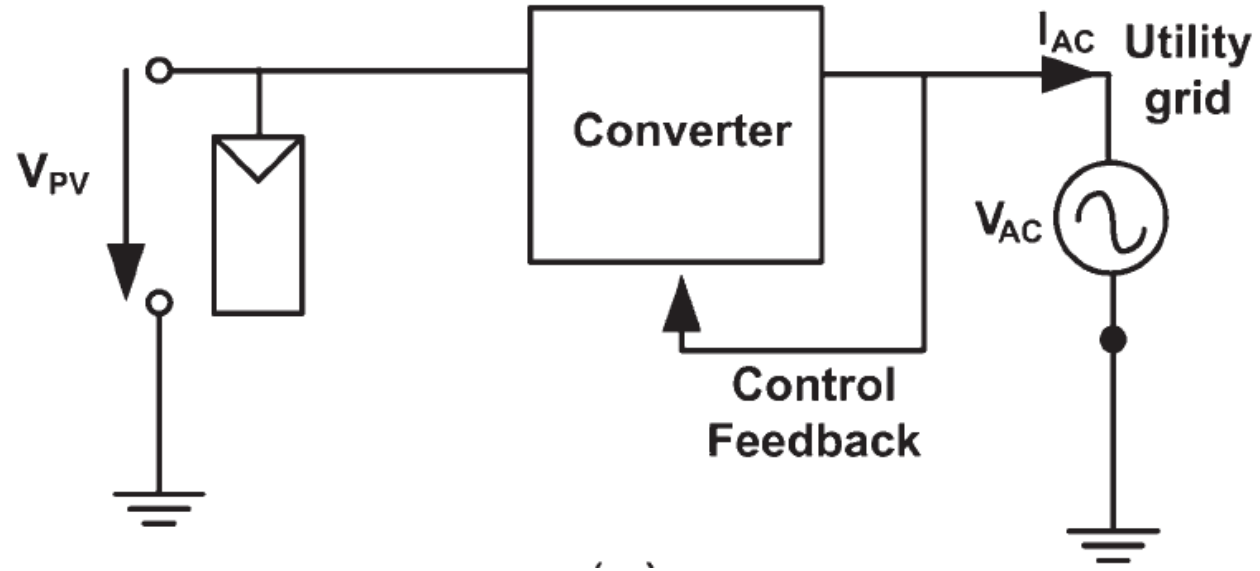

Conventional controller charging at 12V only extracts about 53W.
Solar Boost MPPT controller operates module at its maximum power voltage extracting full 75W.
PV AMPS
PV WATTS
PV VOLTS
0
1
2
3
4
5
0
20
40
60
80
100
0
5
10
15
20
25

MPPT....

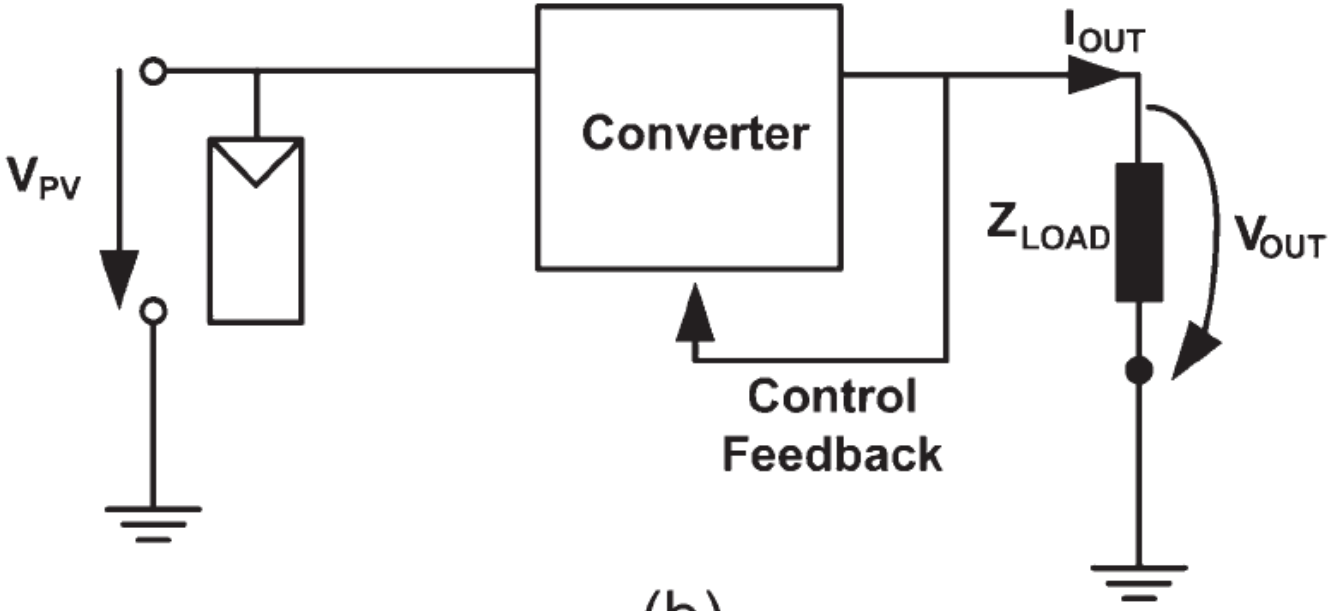
- A MPPT, or maximum power point tracker is an electronic DC to DC converter (step up/step down) that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.
- A high efficiency DC-to-DC power converter converts the module voltage at the controller input to battery voltage at the output.
- Maximum power point tracking is used to ensure that the panel output is always achieved at the maximum power point.
- Using MPPT significantly increases the output from the solar power plant.

PV inverters

- PV Inverters need to maintain synchronism between the PV source and the grid.
- PV Inverters must be able to detect an islanding situation and take appropriate measures in order to protect persons and equipment.
- PV inverter should be capable for
  - Grid integration of PV cells
  - PV cells as isolated power supplies



Grid connected

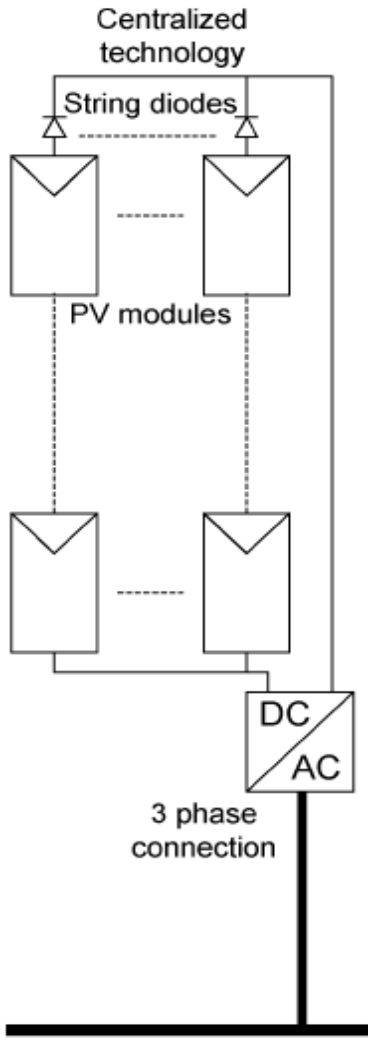


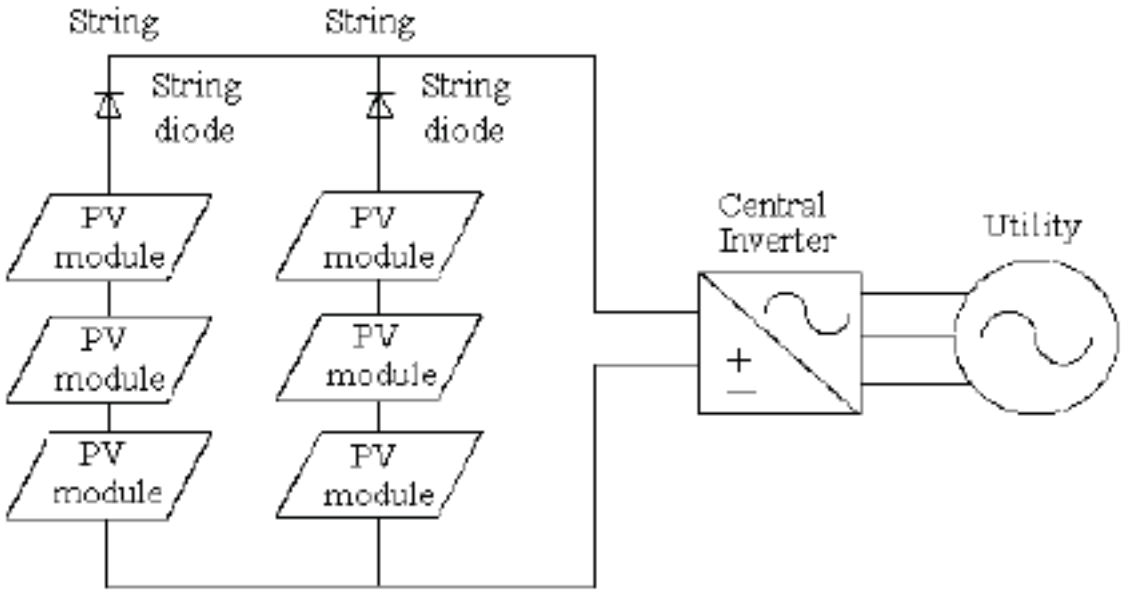
Stand-alone

Topologies of PV inverters

- Centralized Inverters
- String Inverters
- Multi-string Inverters
- AC modules & AC cell technology

Centralized Inverters





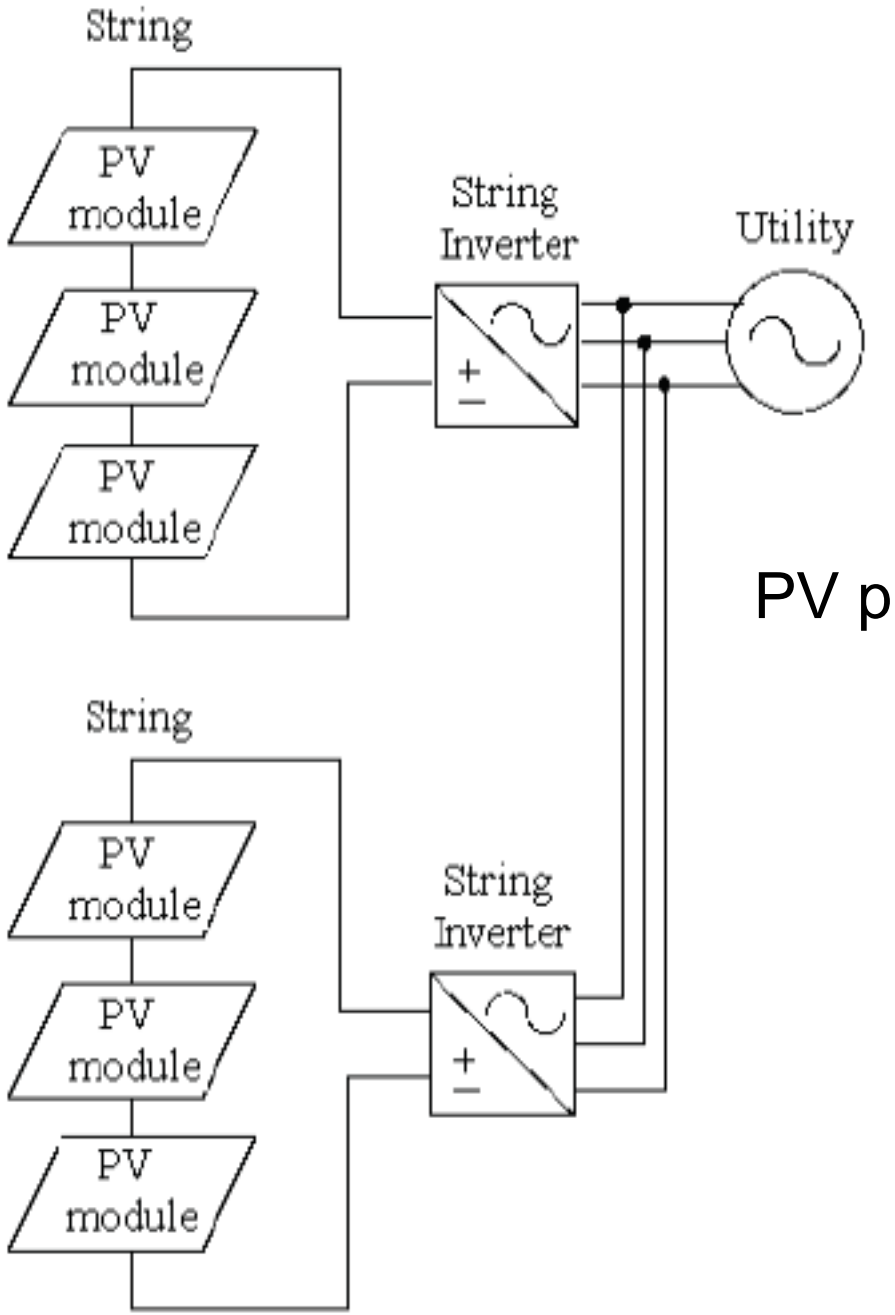
PV plant layout with central inverter

- PV modules are connected in series and/or parallel and connected to a centralized inverter.
- The main advantage is less power conditioning system has the lowest cost due to the presence of one inverter only; it is also characterized by a high conversion efficiency of the inverter.
- Disadvantage

  - Configuration can cause high power losses due to the possible mismatch between the PV modules and/or strings

  - High risk factor because of outage of single inverter.

String Inverters



PV plant layout with an inverter for each PV string

- A number of PV modules are connected in series in the form of a single string.
- These strings are directly interconnected through the utility with one inverter per string.
- Advantage:

    - Maximum power point tracker for each string. Useful when mismatching conditions occur.

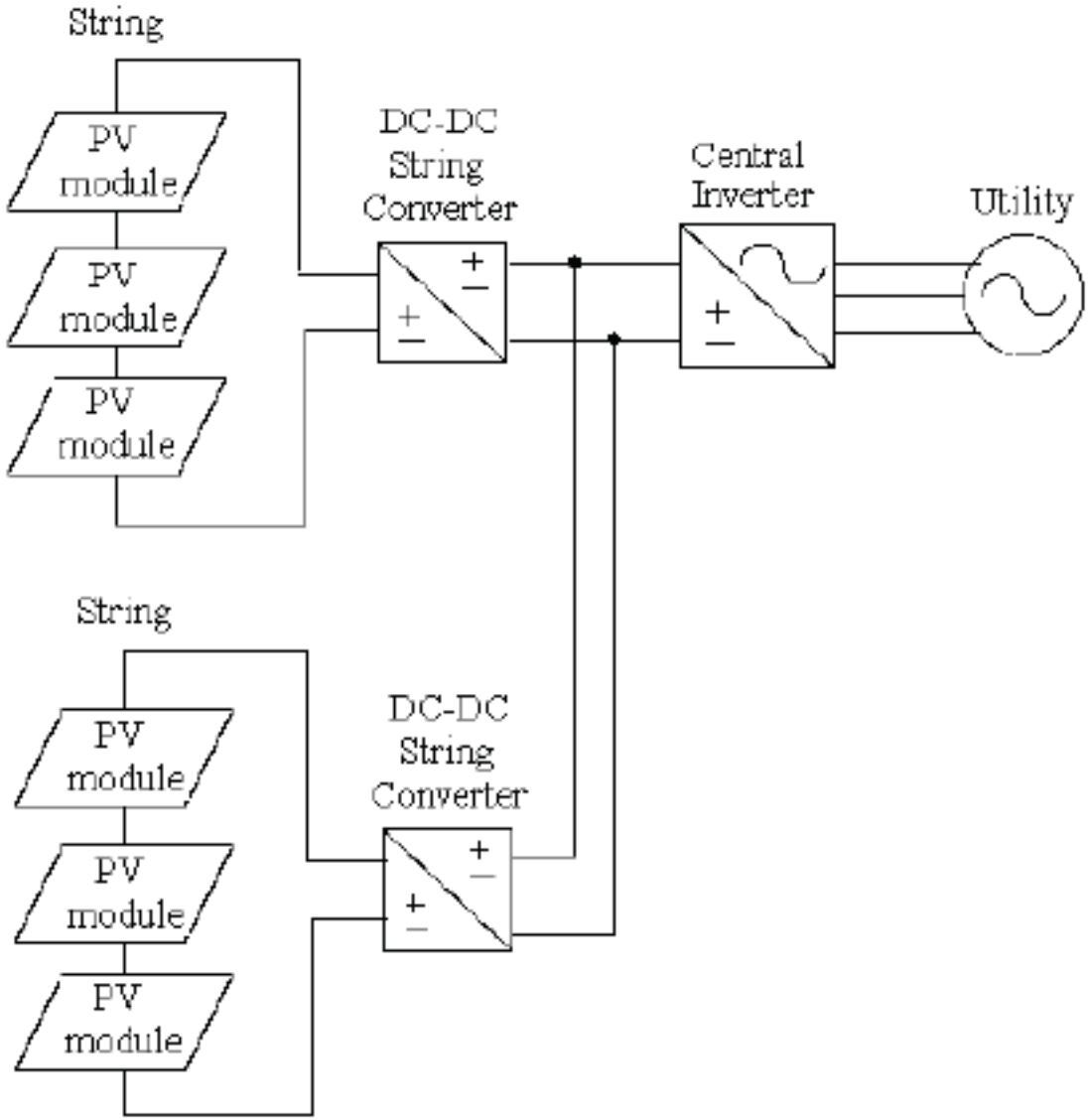
    - The input voltage coming from the PV strings may be high enough to avoid the need for voltage amplification.

- Disadvantage:

    - Increased cost because of additional inverters

Multi-string Inverter

- As the cost of the PV modules is still rather expensive, voltage amplification can be added together with the string inverter in order to allow for fewer modules to be connected to the inverter.
- This led to development of Multistring inverters.
- Several strings are interfaced with their own DC – DC converter for voltage boosting and, then, they are connected to a common DC bus.
- A common DC-AC inverter is then used for utility interfacing.


String
PV module
PV module
PV module
DC-DC String Converter
Central Inverter
Utility
String
PV module
PV module
PV module
DC-DC String Converter

AC module

- Here each PV module has its own inverter.
- Advantages :

  - Easy to add modules because each module has its own DC-AC inverter and the connection to the utility is easier

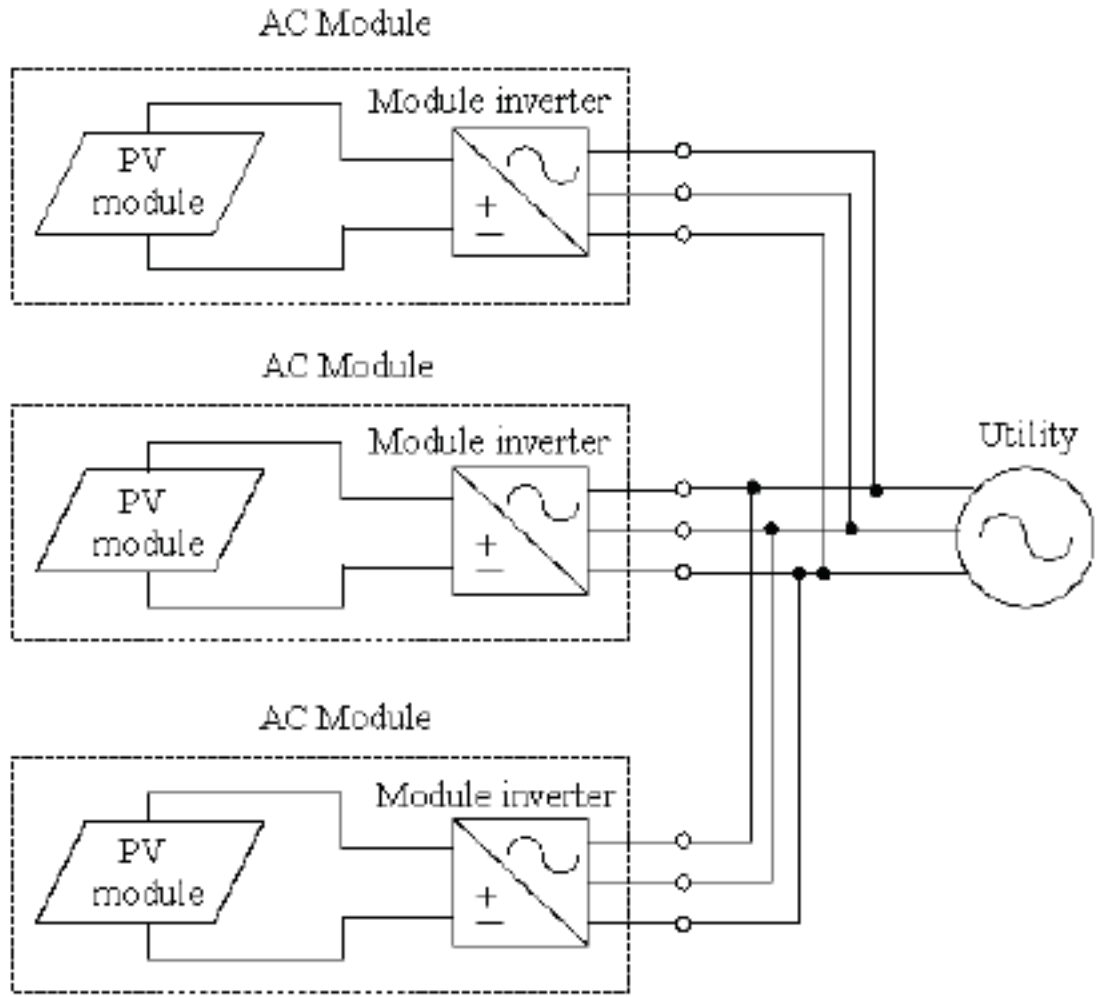
  - Improvement in system reliability because there is no single-point failure for the system.

  - Lower power losses of the system due to the reduced mismatch among the modules

- Disadvantages:

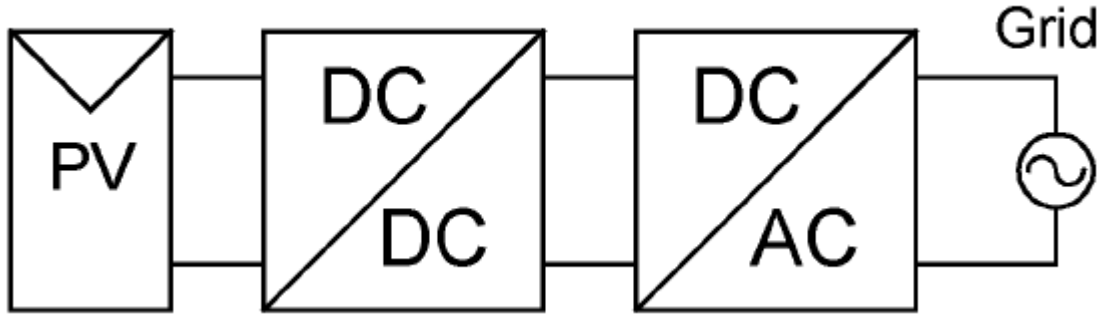
  - costly than the conventional PV systems because of the increased number of inverters.

- The power electronics are typically mounted outside together with the PV panel and need to be designed to operate in an outdoor environment.


AC Module
Module inverter
PV
module
+
–
AC Module
Module inverter
PV
module
+
–
AC Module
Module inverter
PV
module
+
–
Utility

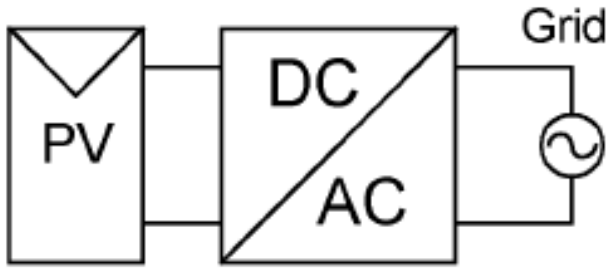
AC cell

- One large PV cell connected to a dc–ac inverter
- Very low voltage

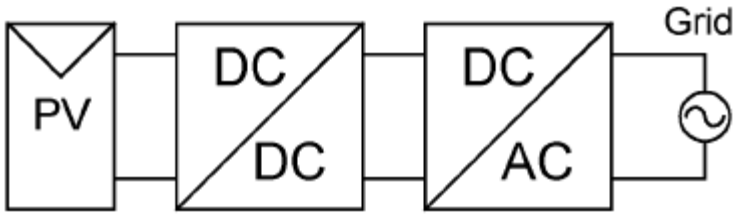


Classification of Power conditioning system

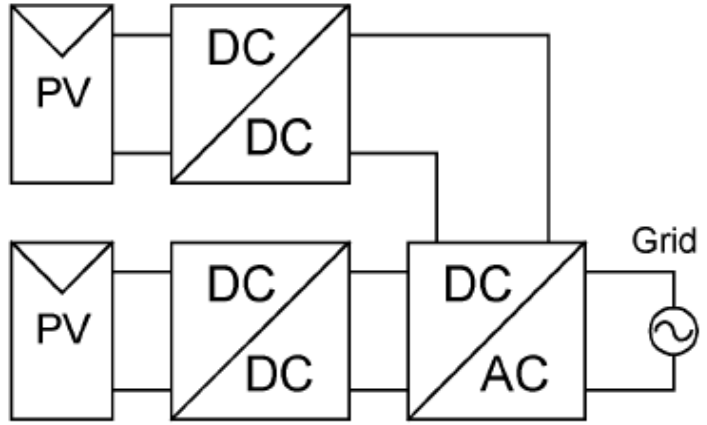
- Single-stage inverter



- Multi-stage inverter



Modules with a common dual stage inverter



Strings with their own dc/dc converter
and a common grid-connected inverter

Some of the issues related to Grid connected PV

- Problems related to energy losses caused by mismatching conditions of PV modules
- Important mismatching in working conditions of series connected modules can occur

  - discrepancies in module parameter values caused by manufacturing tolerances

  - different module ageing effects

  - different orientations of modules

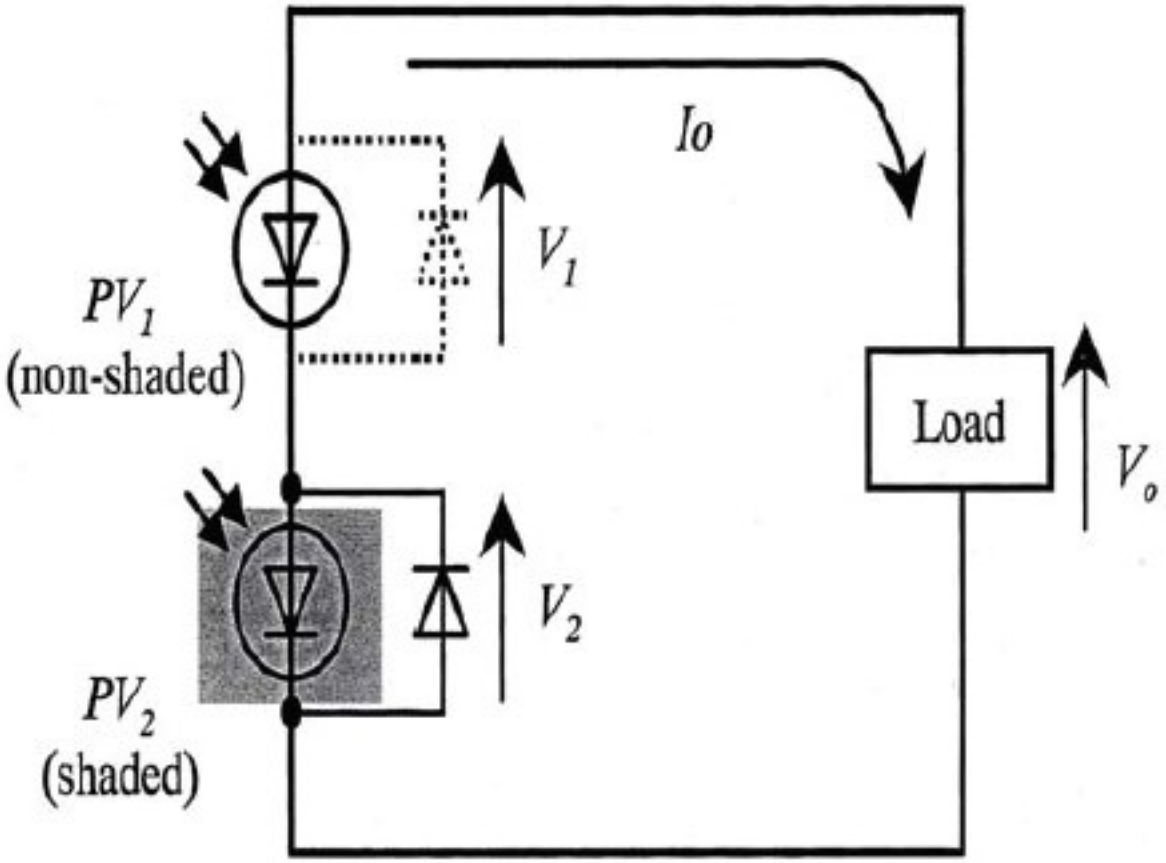
  - different solar irradiances levels of modules, caused by different shadowing effects

- The maximum current that a PV module is able to generate (the short circuit current, I_{sc}) strongly depends both on its intrinsic characteristic and on the solar irradiance intensity.
- The maximum voltage of a PV module (the open circuit voltage, V_o) only slightly depends on the solar irradiance intensity, while it substantially depends on the working temperature.
- Thus, in case of a shadowed/poorly illuminated PV module (module mismatch example) in a string, the entire string will operate at poor power level.

Solution….

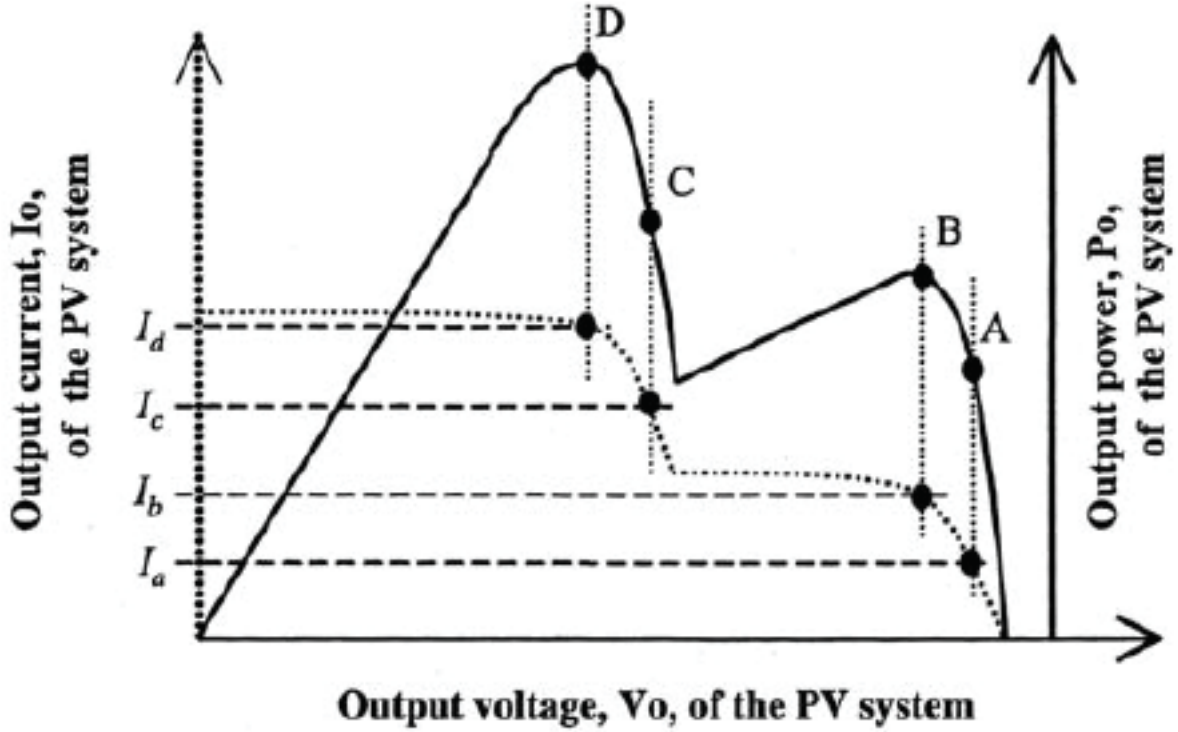
- By-pass diode

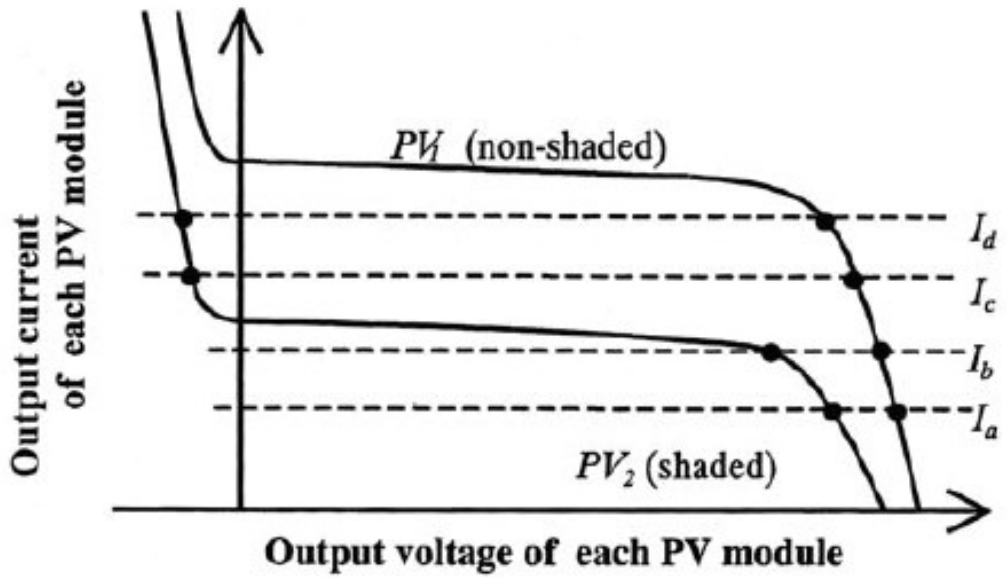
- When in a string only a module is shaded, its by-pass diode goes in the on-state
- Thus the shaded module results short circuited and the current in the string is that of non shaded modules.
- In this way, the string generated power is greater than that in case of modules with no by-pass diodes



Drawback…

- But, in case of mismatching conditions, due to module by-pass diodes, the string power versus voltage becomes a multimodal curve.





- $I_o = I_a$ (operating point A), both PV modules generate power, but neither one generates maximum power
- $I_o = I_b$ (operating point B), the shaded module PV2 generates maximum power, but the non-shaded module does not generate maximum power
- $I_o = I_c$ (operating point C), the non-shaded module generates power, but the shaded module does not generate any power, because the string current, I_o, flows through its bypass diode
- When $I_o = I_d$ (operating point D), the non-shaded module generates its maximum power, but the shaded module does not generate any power because the string current, I_o, flows through its bypass diode.
- Thus, with by-pass diodes, the power-voltage (PV) characteristic curve is a multimodal curve having a number of peaks equal to the number of the string modules.

More than one peaks … Problems !!!!!

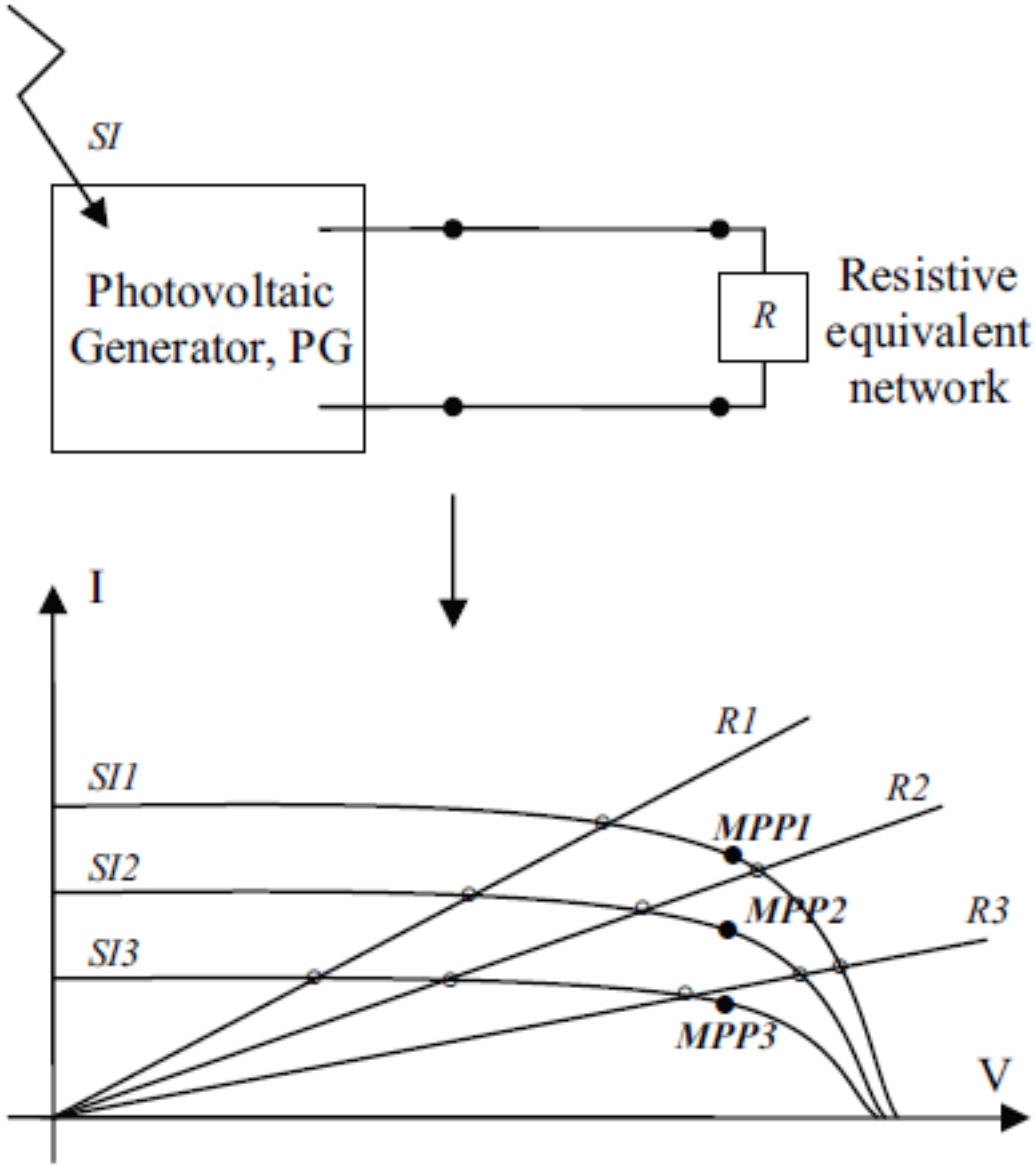
- Presence of more than one peak in the P-V characteristic of a PV string makes very difficult, for conventional MPPT techniques, the detection of the absolute maximum power point of the PV string.
- Due to presence of more local maximum points in the P-V string and/or module characteristic, instead of only one absolute maximum point, conventional inverter MPPT techniques can catch and maintain a local maximum power point instead of the absolute maximum power point.
- Thus, reducing the overall PV plant generated power.

Distributed MPPT

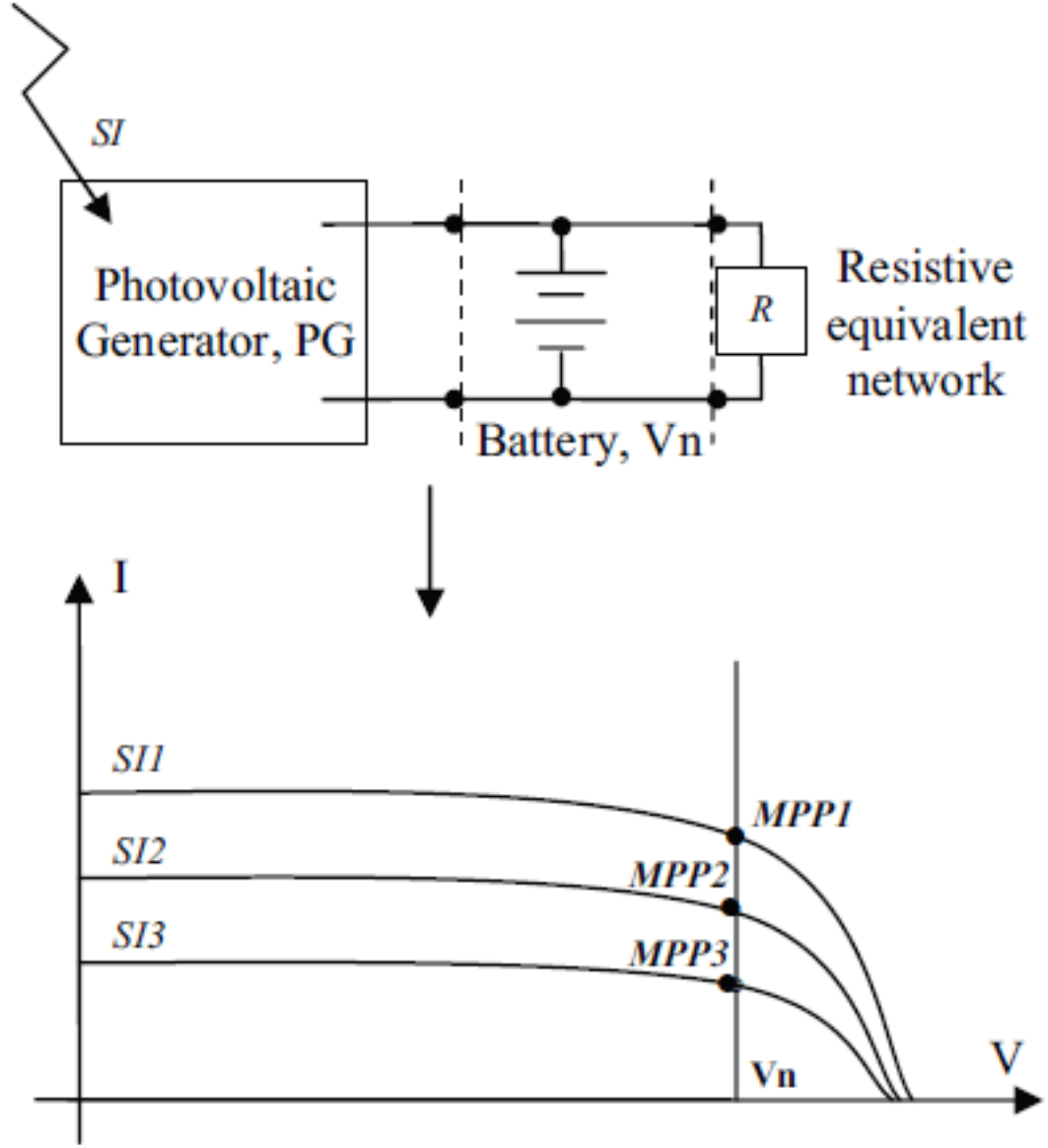
- The basic idea is use of dc/dc converter circuits to be connected in cascade to each module of a PV string, together with a centralized utility interactive inverter and have a proper coordinated control of all these converters.
- Thus, the generation point of each PV module can be independently controlled and maximized.
- Also, the P-V characteristic of a PV string results in a mono-modal characteristic with only a maximum power point to be caught by the MPPT algorithm, also in the presence of PV module mismatching conditions.
- But cost ??????????? and control complexity ?????

Passive distributed MPPT technique

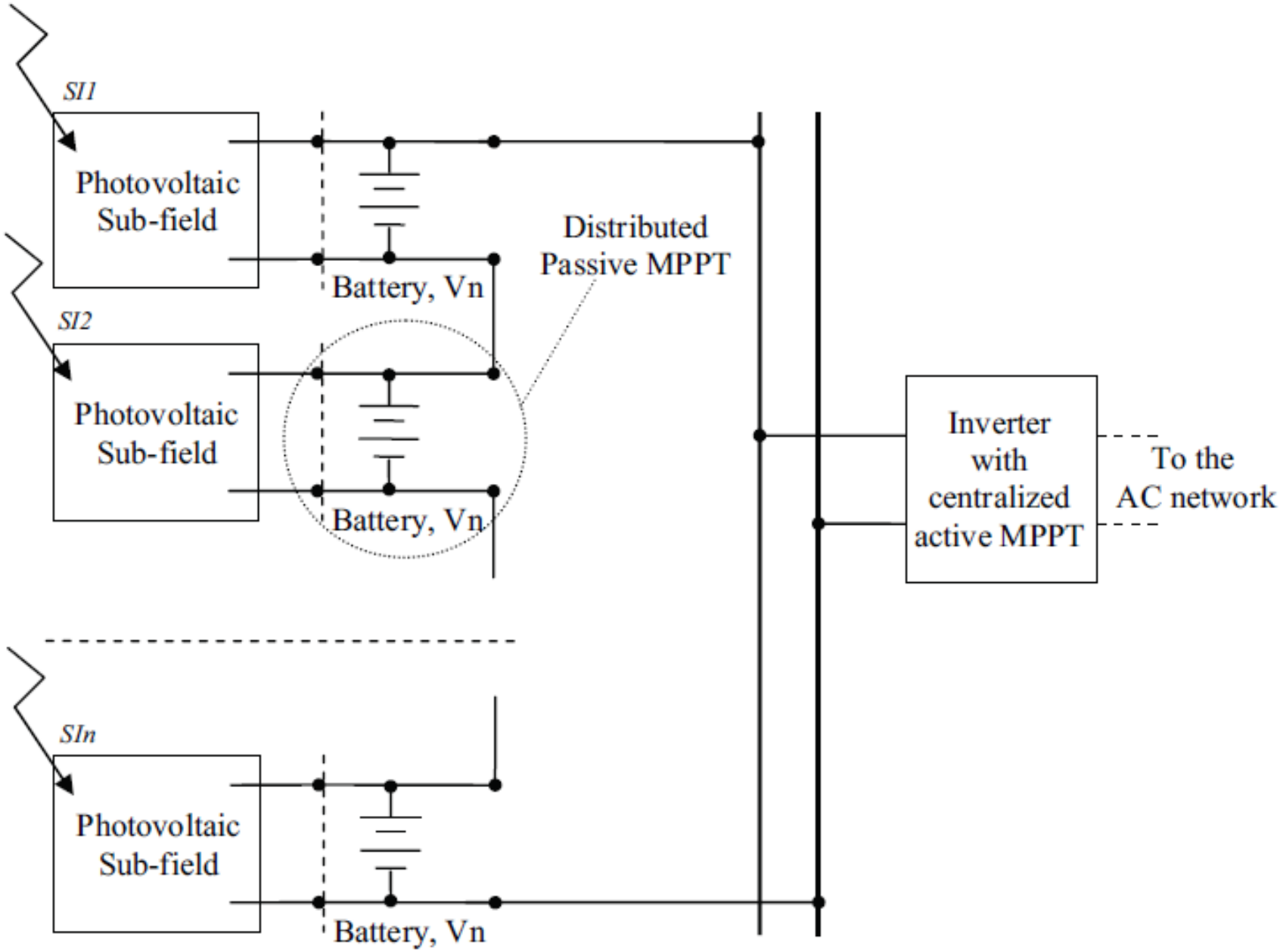
- Active MPPTs (Converter based) are complex to control.
- For different solar irradiance (SI) levels, the variation of the MPP directly involves the PV current values, while the PV voltage values remain almost constant.


SI
Photovoltaic
Generator, PG
R
Resistive
equivalent
network
I
R1
SI1
R2
MPP1
SI2
MPP2
R3
SI3
MPP3
V

- This means that a battery, if used in parallel with the PG if properly designed in its nominal voltage value and capacity, can naturally catch and maintain a PG working point very close to the MPP, for any PG solar irradiance level and for any value of the network equivalent resistance.


SI
Photovoltaic
Generator, PG
R
Resistive
equivalent
network
Battery, Vn
I
SI1
SI2
SI3
MPP1
MPP2
MPP3
Vn
V

- Due to changes in I-V characteristics of PV modules with temperature, it is obvious that battery used as passive MPPT will have lower performance as compared with commonly utilized active MPPTs.
- Hence, to overcome this issue instead of utilizing batteries in grid-connected PV systems in a centralized way and instead of active MPPTs, batteries are used in a distributed way.


SI1
Photovoltaic
Sub-field
Battery, Vn
Distributed
Passive MPPT
SI2
Photovoltaic
Sub-field
Battery, Vn
Inverter
with
centralized
active MPPT
To the
AC network
SIn
Photovoltaic
Sub-field
Battery, Vn