

Renewable Energy and Distributed Generations

Lecture 10

Grid-Connected Solar Energy Conversion System

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Lecture learning outcomes:

At the end of this lecture, you will be able to:

- i. Understand the grid connect solar conversion system(WECs)
- ii. Know the advantage of Grid-Connected solar PV system
- iii. Understand the operating principles and basic components of Grid-connected solar PV system
- iv. Know the controlling of Grid connected solar PV system

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- 1. Introduction**
- 2. Grid-connected PV system**
- 3. Operation of Grid-Connected PV System**
- 4. Grid-connected PV System Modeling**

Summary

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1. Introduction

- Grid-connected PV systems are solar PV systems that are connected to the grid.
- As a result, the PV system harvests solar energy, connects to the grid, and meets the needs of various household appliances.
- The system supplies energy to both residential and commercial loads. The bidirectional energy meter then feeds any excess power generated back into the grid.
- Fig. 1& 2 shows the basic grid-connected photovoltaic system.

2. Grid-Connected PV System(G-CPVs)

- The utility power grid and the grid-connected system are intended to work in tandem for :
 - commercial
 - industrial, and residential purposes
 - Private and governmental development
- It is typically used for commercial and residential applications to balance the average yearly energy expenses.
- The PV system array can be installed in many locations, such as an open area or on top of a roof.

G-CPVs

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- There are typically two types of grid-connected small, medium-scale to large systems that are used.
- Systems shown in Figs. 1 and 2 that are integrated with and without batteries to the grid.
- Figure 1 and 2 shows the systems with energy storage and those that are connected to the utility power grid but do not have battery bucking capacity
- It typically consists of:
 - solar panels
 - inverter
 - a charge controller
 - a monitoring system, and
 - electrical distribution panel.

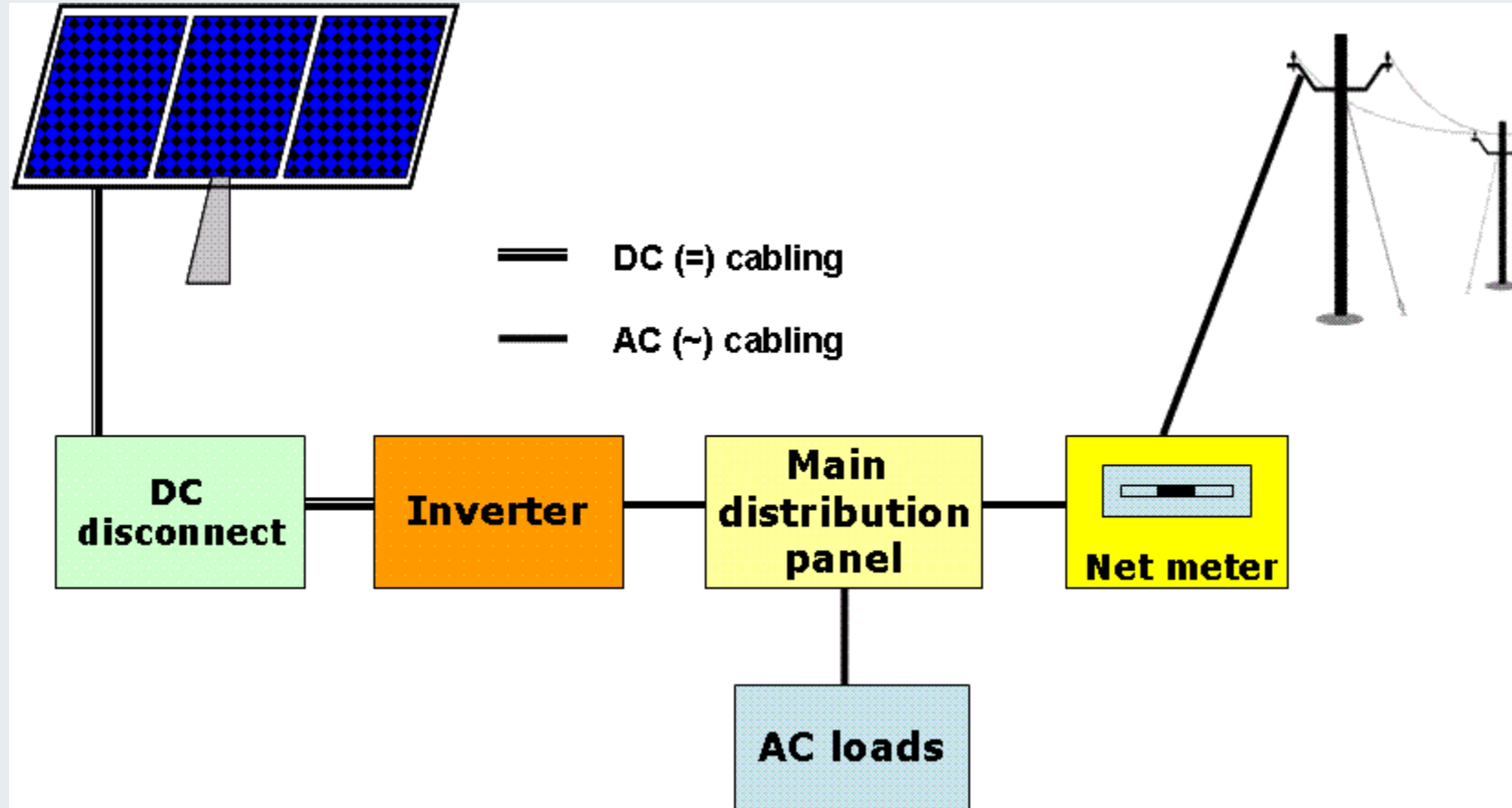


Figure 1: Grid connected system without battery backups[1].

<http://dx.doi.org/10.21474/IJAR01/3423>

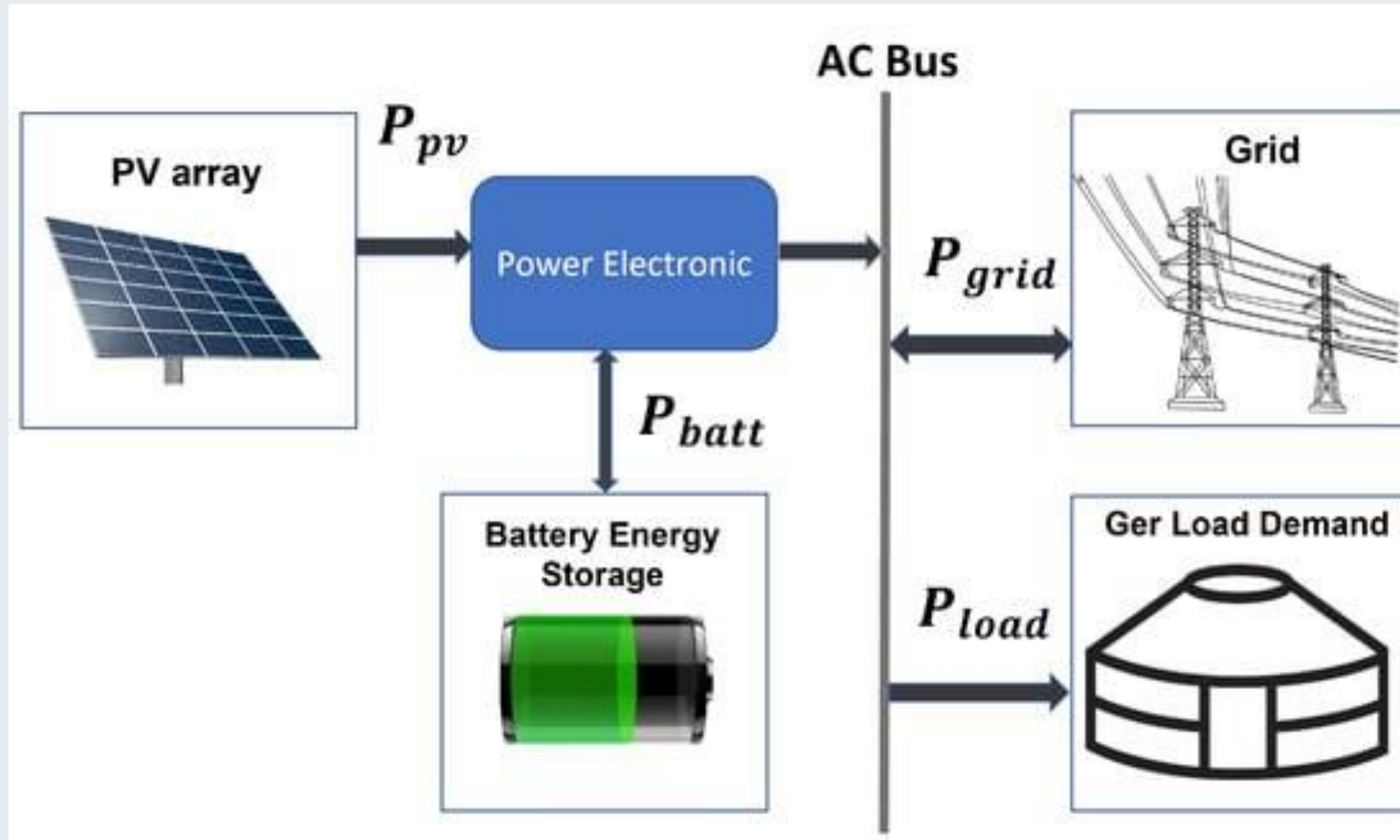


Figure 2: Grid connected system with battery backups[2].

Source: <https://www.mdpi.com/1996-1073/15/5/1892>

2.1 Advantage

- A grid connected PV system has many benefits. Some of them are as follows:
- Reduced maintenance cost.
- Reducing the cost of energy billing and easy for installation
- Environmentally friendly and carbon emissions free.
- Majority of grid connected models of PV system do not need additional batteries like off-grid system that reduces battery cost
- It can be installed in vacant roof space without requiring any additional land.
- It's quite reliable.
- It can be used in commercial establishments, industrial units, and educational institutions.

2.2 Disadvantages

- It cannot work without a grid.
- If the grid fails, the system is not working.
- The initial installation cost maybe high.
- If the system is modeled without a battery backup it will not provide electricity during power outages
- Needs skilled personnel for maintenance, control and synchronization

3. Operation of Grid-Connected PV System(O-GC-PVs)

- Grid-connected photovoltaic (PV) energy is one of the fastest growing and most promising renewable energy sources in the world.
- In fact, it has increased over 10 times in the last two years alone.
- Although, the core of a PV system is the PV cell (also known as a *PV generator*), **power electronics p**
lays a fundamental role as an enabling technology for an efficient PV system control and interface to t
ransfer the generated power to the grid.
- An overview of a generic power converter interface for grid-connected PV systems is shown in Fig. 3

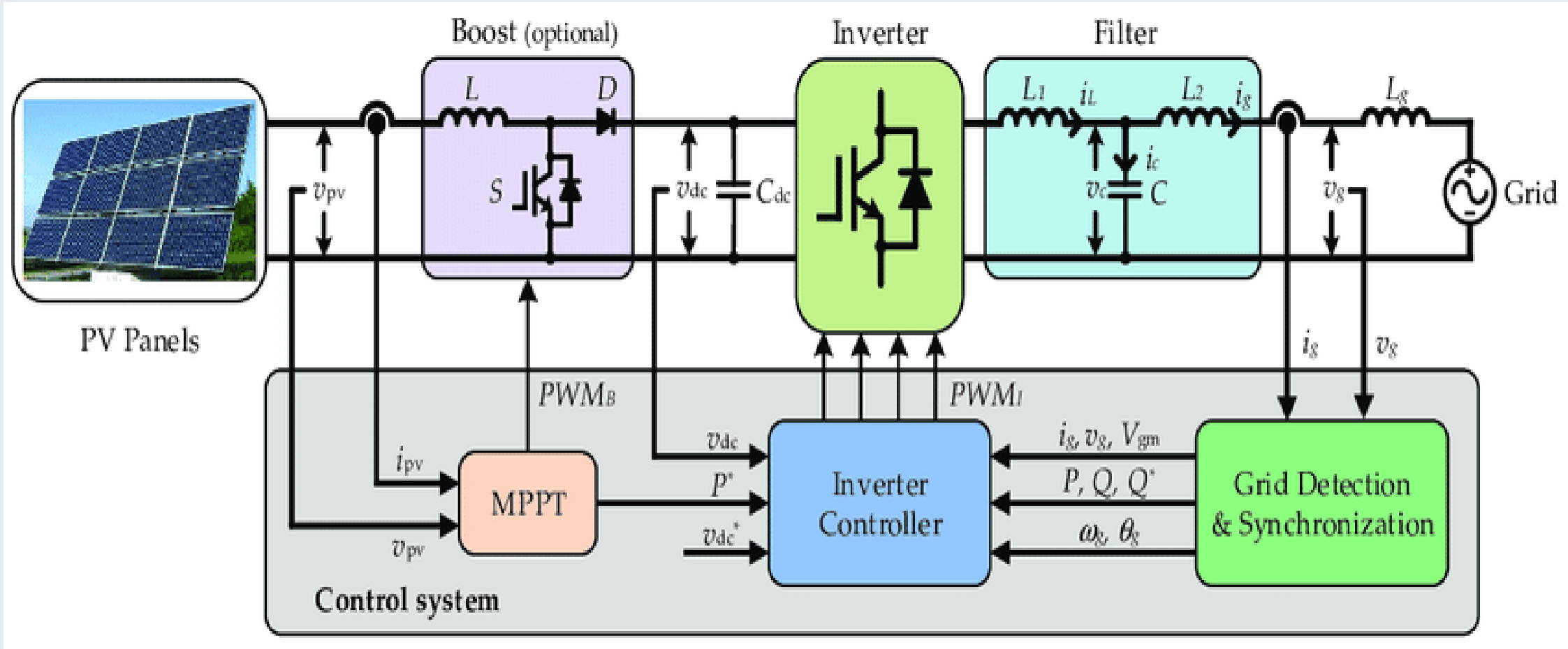


Figure 3: Overview of a generic grid-connected PV energy conversion system[3].

Source: <https://www.mdpi.com/2076-3417/7/4/315>

- The functions of the power converter stage of a PV system include is the backbone of SECs
- It comprises the maximum power point tracking (MPPT), DC-to-AC power conversion, grid synchronization, grid code compliance of power quality, active and reactive power control and anti-islanding detection.
- Figure 3 comprises the PV generation system, which can be:
 - a single module,
 - a string of series-connected modules, or
 - an array of parallel-connected strings.

- The PV system is followed by a filters, a passive input filter, which is a capacitor that is used to decouple the input voltage and current from the subsequent power stages
- The filter reduces the current and voltage ripple
- It also control the reactive power at the PV side.
- The DC–DC stage, which is generally used to perform the MPPT of the PV system
- Thus, the boost converter elevate its output voltage and in some occasions also provide galvanic isolation using DC–DC converters with high-frequency (HF) transformers
- It also controls the reactive power and makes the DC-link voltage constant

- The DC–DC stage is connected through a DC link to the grid-tied DC–AC converter, referred as the PV inverter.
- In PV systems where no DC–DC stage is used, the input filter is equivalent to the DC-link capacitor as shown in Fig.3
- The AC filter provides the harmonic mitigation and assists the converter–grid interface control.
- The grid-tied converter also includes a grid monitoring and interaction unit, with circuit breaker and fuse to disconnect the system when required, such as during the night, grid faults, or islanding operation.

O-GC-PVs

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- The **feedback for the control system is** composed of **several current and voltage sensors at** the PV input side for:
 - MPPT, DC-link stage or for DC-link voltage control and
 - grid side for grid synchronization and active/reactive power control.

The control system is further composed of :

- analog-to-digital signal converters, digital microprocessors (or equivalent) and *gate drive* units to control the semiconductor devices of the different power stages.

4. Grid-connected PV System Modeling (GC-PVM)

Electrical Model of a PV Cell

- The electrical characteristics of a PV module or cell are nonlinear and are highly dependent on solar irradiation and temperature.
- The PV cell can be electrically modeled by an equivalent circuit such as the one shown in Fig.4 with a photocurrent source in parallel with a diode, a shunt resistance R_{sh} and a series resistance R_s .
- The model in Fig.4 can be mathematically described by Eqn.1[4].

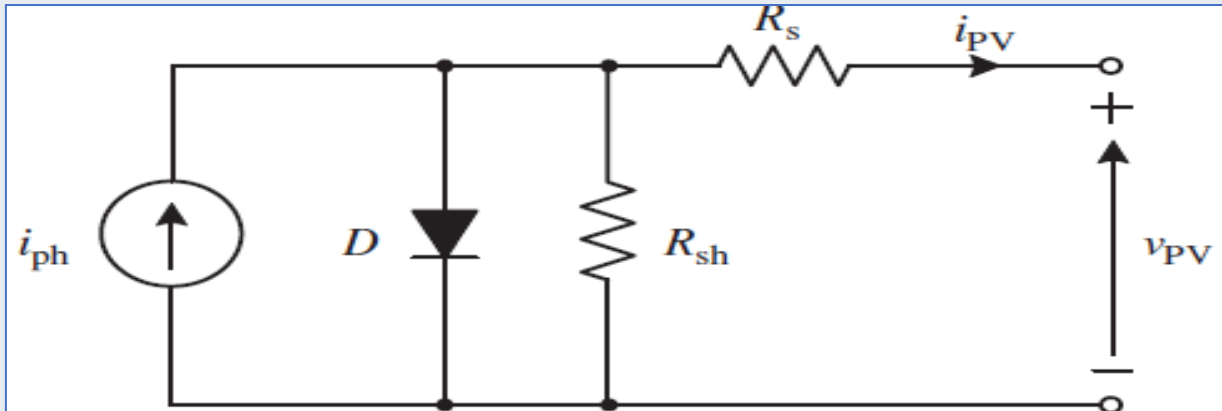


Figure 4, PV cell electrical model[5]. Source: <https://www.mdpi.com/1996-1073/16/4/2018>

Variable	Parameter
v_{PV}	Cell output voltage (V)
i_{PV}	Cell output current (A)
R_s	Cell series parasitic resistance (Ω)
R_{sh}	Cell shunt parasitic resistance (Ω)
q	Electronic charge: 1.6×10^{-19} (Coulombs)
K	Boltzmann constant: 1.38×10^{-23} (J/K)
T	Absolute temperature (K)
n	Diode ideality factor: ideally $n = 1$
i_o	Cell reverse saturation current: 10^{-12} (A/cm ²)
i_{ph}	Cell photocurrent: 35–40 mA/cm ² /Sun for Si cells

$$i_{PV} = i_L - i_0 \left[e^{\frac{q(v_{PV} + i_{PV}R_s)}{nKT}} - 1 \right] - \frac{v_{PV} + i_{PV}R_s}{R_{sh}}$$

eqn.(1)

•where i_{PV} is the output current of the PV cell, which is a function of its output voltage v_{PV} , and a number of variables.

4.1 Photovoltaic Module I–V and P–V Curves

- Typically the I-v and P-V curves represent the variation in voltage, current and hence the power with respect to temperature and solar radiations.
- Typical PV module's current–voltage ($I-V$) curves and power–voltage ($P-V$) curves are presented in Fig.5
- From the $I-V$ curves, it can be seen that the PV module **behaves as a DC current source** that remains almost constant even if the PV module is connected to different output voltage potentials.
- When the voltage across the **module gets higher, the free electrons** start recombining and do not generate current.

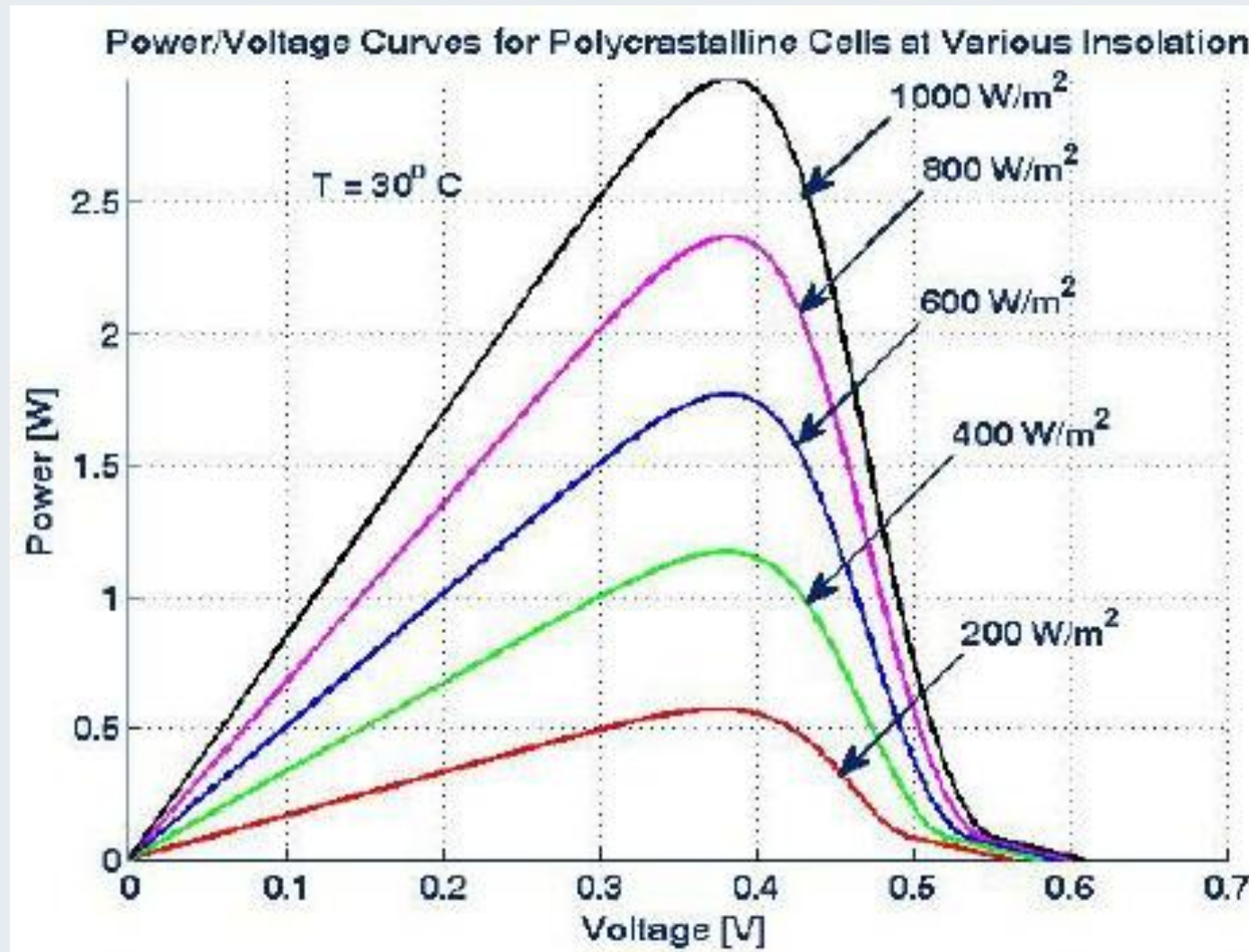


Figure 5, I-V Curves for different irradiances with constant standard temperature [6] : source : https://www.researchgate.net/figure/I-V-curves-of-solar-cell-at-various-irradiance_fig13_282755961. License: CC BY-NC-ND 4.0

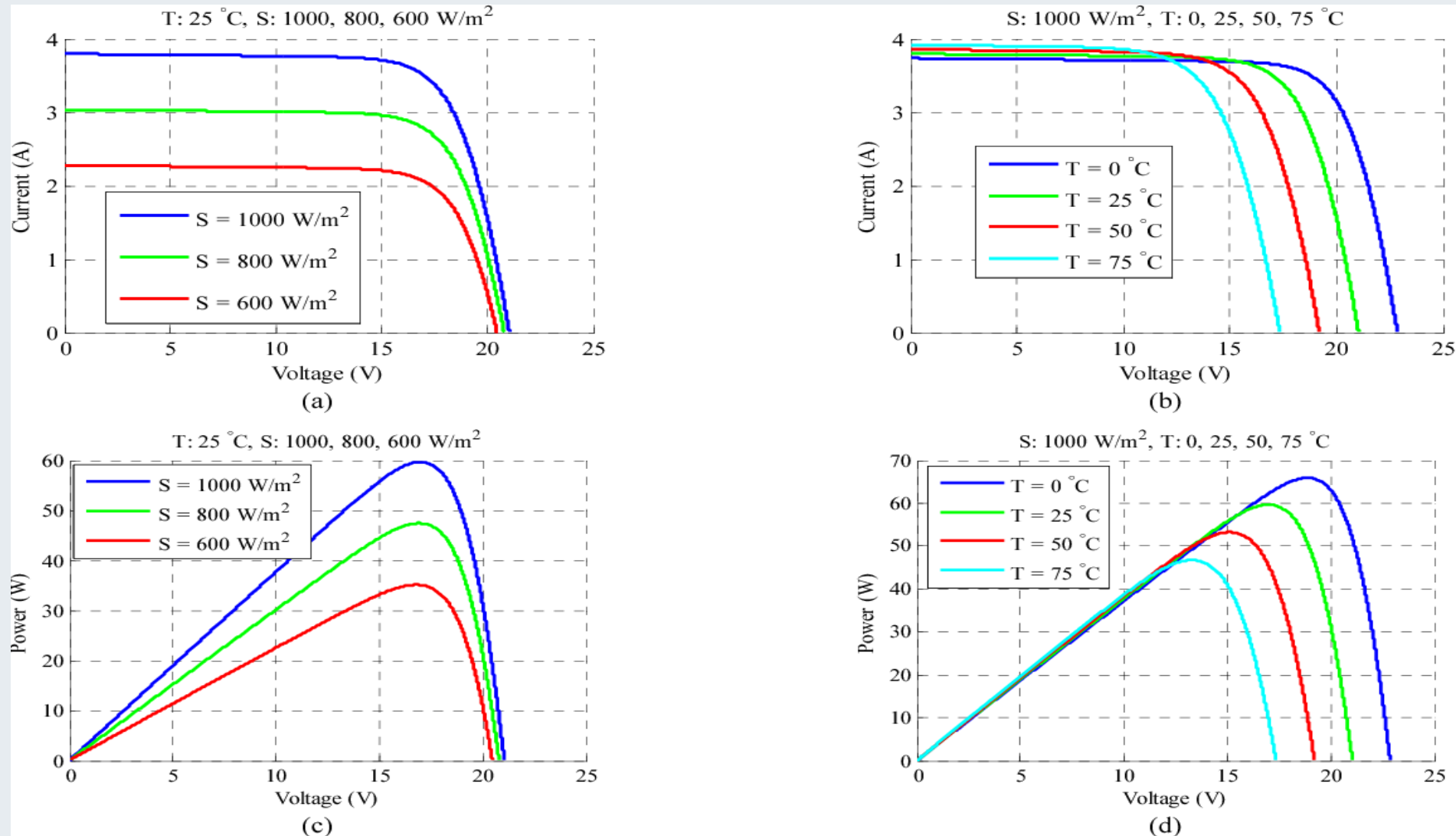


Figure 6, I-V Curves for different irradiances and temperature condition[7]

: source s: <https://doi.org/10.1016/j.enconman.2020.113521>

- This effect is not linear with respect to the voltage and it cuts off abruptly
- When all electrons are recombined and no current is produced, the module is operating at an open-circuit voltage v_{oc} .
- This voltage varies slightly for different levels of solar irradiation (at the same temperature), as it can be seen .
- This necessitates the voltage controlling with respect to temperature, solar radiations and other variables

- In contrast, when short circuited”
- the module produces the **largest current, short-circuit** current i_{sc} , which is very linearly dependent on the **solar irradiation**
- The **more photons, the more free electrons and more current can flow** .
- Consequently, **the $P-V$ curves** obtained by multiplying the axes of the $I-V$ curve.
- Thus, the PV module will be composed $dp/dv=0$ segment corresponding to the MPP for that given irradiation.

- The voltage at which the MPP is obtained is known as **the *maximum power voltage* v_{mp}** .
- The slopes of the $I-V$ curve can be adjusted by the **shunt resistance R_{sh}** and series resistance R_s in the PV cell model to better represent the real PV cell.
- Accordingly, the PV system voltage can be controlled easily
- As the operating conditions **of irradiation and temperature are inherently time variant**, the instantaneous v_{mp} is unknown (unless irradiation and temperature are measured, which is expensive).

- The control techniques used for such task *are known as maximum power point tracking (MPPT) methods.*
- The MPPT algorithm generates the voltage reference to be controlled by the converter.
- The same applies to PV arrays formed by parallel-connected strings.
- In these cases, the $I-V$ curve has several local MPPs and one global MPP, making it more difficult to achieve a true MPPT.

4.2 Conversion and Power Electronic Technology

- Several inverter systems convert or transform the DC into AC for grid-connected PV systems.
- Penetration of PV into the smart grid requires studies in variability and conversion technology.
- The mathematical models and probability density used to model PV behavior include Beta and Rayleigh density functions.
- The tracking method based on fuzzy/GA technologies is able to obtain enough power points for effective delivery.
- Siting and sizing of PV uses classical and computational intelligence methods that involve decisions based on real - time data.

4.3 Control of Grid-Connected PV Systems

- According to the previous sections, grid-connected PV systems can be composed of one or two power conversion stages (DC–DC and DC–AC) and different converter topologies.
- Therefore, the control system and modulation schemes depend on the topology and vary from one topology to another.
- Nevertheless, the main control objectives are *universal and include MPPT of the PV system, grid synchronization, DC-link voltage control, active and reactive power control and grid monitoring including anti-islanding detection.*

- Following the analysis of the power curves of PV modules presented before, it is clear that to maximize the energy output of a PV system, it should be operating around the MPP.
- The MPP depends on the solar irradiation and temperature of the module, which are variable in time.
- The MPP is achieved by controlling the load curve of the PV module or string, making it to intersect the $I-V$ curve where $i_{PV} \times v_{PV}$ is maximal.
- As defined before, the voltage at which this occurs is known as the *maximum power voltage* v_{mp} which should be considered as the reference voltage for the control system $v^*_{PV} = v_{mp}$.

- This voltage could be obtained through direct measurement of the solar irradiation and the module temperature, which are used to compute v_{mp} from the PV module physical model.
- However, solar irradiation sensors (pyranometers), in particular, are very expensive.
- Therefore, numerical methods based on electrical variable measurements (already needed for the converter control) are used to search for the MPP.

- Since this task is performed online and updated periodically over time, they are known as MPP tracking (MPPT) methods.
- There are several MPPT methods found in practice and in the literature that can reach up to 99% of the MPP efficiency.
- A classification of the most common MPPT methods is given.

Summary

- In conclusion, the grid-connected solar energy conversion is well discussed here.
- It is observed that the grid connected system comprises PV module, DC-DC converter, DC-Link, Inverter, switches and other grid synchronizing
- The controlling approach, specifically, MPPT is also discussed.
- In addition, the importance of controlling the temperature and solar radiation in maximum power harvesting or P-V curve is observed

References

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Thank you !