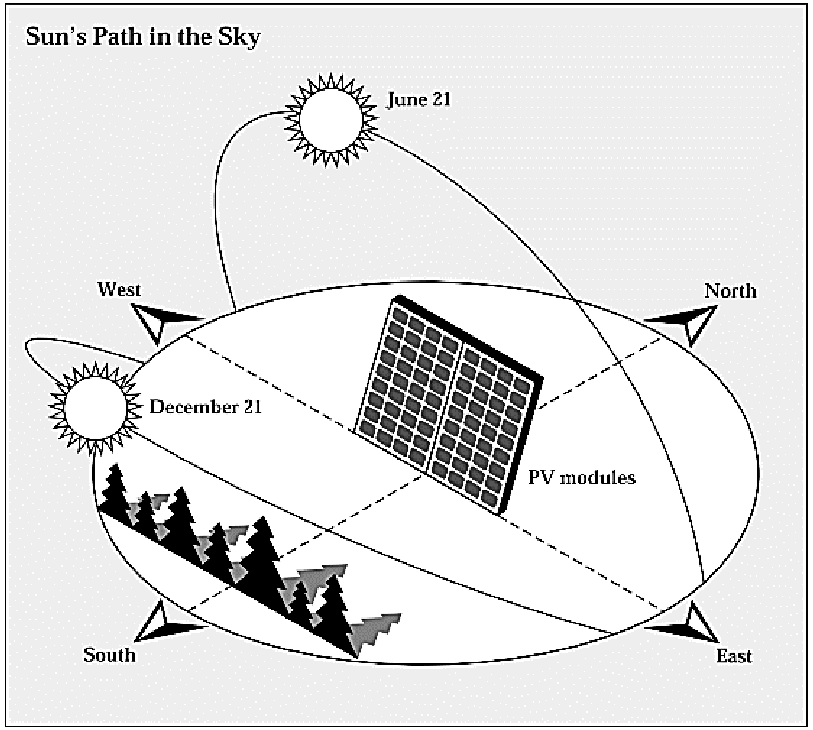
Solar Panels
Principles and Sizing

The Impact of Tilting Solar Panels on Solar Irradiance

- If we tilt our solar panels towards the sun, it means we can capture more of the sun's energy to convert into electricity. Often the angle of this tilt is determined for you by the angle of an existing roof. However, for every location there are optimal angles at which to mount your solar array, in order to capture as much solar energy as possible. Figures for Cairo in Egypt. For each month in the year we highlight on the best position.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flat	3.16	3.88	5.05	6.14	**6.96**	**7.65**	**7.30**	**6.82**	5.77	4.44	3.36	2.95
Upright	3.72	3.62	3.40	2.74	2.18	1.94	2.04	2.54	3.33	3.80	3.72	3.75
45 deg	**4.44**	**4.76**	5.28	5.45	5.28	5.39	5.31	5.60	5.71	**5.23**	**4.55**	4.33
60 deg	4.18	4.64	**5.41**	5.89	6.04	6.35	6.18	6.22	5.96	5.17	4.32	**4.04**
75 deg	3.79	4.39	5.37	**6.18**	6.66	7.18	6.90	6.69	**6.03**	4.95	3.97	3.61

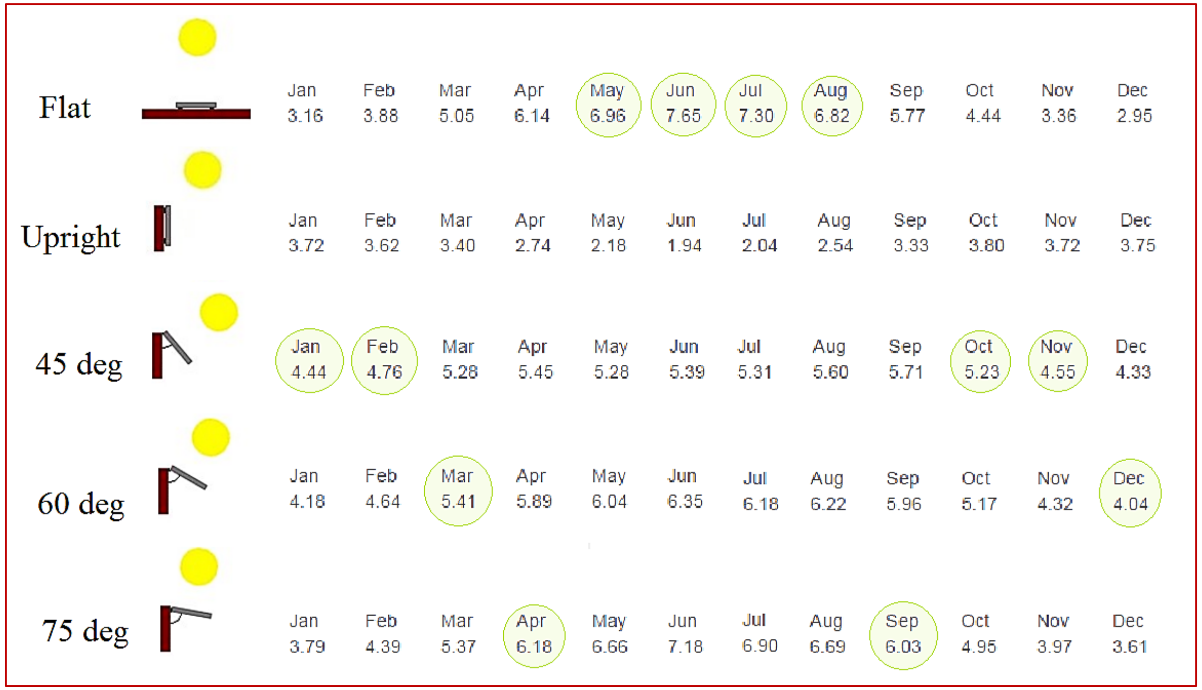


The sun's noontime height above the horizon changes seasonally. This is important to consider when siting and positioning a PV array.

Optimum Fixed Year-round Setting For PV Panels

- To calculate the optimum tilt of your solar panels all-year, you can use the relation:

Optimum Fixed Year-round Setting = 90° – (your latitudeخط العرض)



	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average Irradiance
Flat	3.16	3.88	5.05	6.14	6.96	7.65	7.3	6.82	5.77	4.44	3.36	2.95	**5.29**
Upright	3.72	3.62	3.4	2.74	2.18	1.94	2.04	2.54	3.33	3.8	3.72	3.75	**3.07**
45 deg	4.44	4.76	5.28	5.45	5.28	5.39	5.31	5.6	5.71	5.23	4.55	4.33	**5.11**
60 deg	4.18	4.64	5.41	5.89	6.04	6.35	6.18	6.22	5.96	5.17	4.32	4.04	**5.37**
75 deg	3.79	4.39	5.37	6.18	6.66	7.18	6.9	6.69	6.03	4.95	3.97	3.61	**5.48**

- Table of average says the best position is 75°. But the above equation says the best position is 60°. **(so optimum position is obtained using the above equation)**

- **Cairo in Egypt** has a latitude of 30.2º: Optimum Year Setting = 90° – 30.2° = 59.8° ≈ 60°
- This does not mean that you will get the maximum power output every single month, instead it means that across the whole year, this tilt will give you the best compromise, generating electricity all the year round.

Getting the best from solar panels at different times of the year

- Optimum Winter Setting = 90° – (your latitudeخط العرض) – 15.6°
- Optimum Summer Setting = 90° – (your latitudeخط العرض) + 15.6°

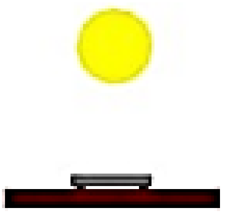
انقلاب شتوي		اعتدال خريفي		انقلاب صيفي		اعتدال ربيعي		زمان
ديسمبر		سبتمبر		يونيو		مارس		شهر
ساعة	يوم	ساعة	يوم	ساعة	يوم	ساعة	يوم	سنة
10:44	21	14:21	22	22:34	20	04:30	20	**2016**
16:28	21	20:02	22	04:24	21	10:28	20	**2017**
22:23	21	01:54	23	10:07	21	16:15	20	**2018**
04:19	22	07:50	23	15:54	21	21:58	20	**2019**
10:02	21	13:31	22	21:44	20	03:50	20	**2020**

Using solar irradiance : How much energy a solar panel will generate

- To calculate how much power (energy) a solar panel will give us per day, multiply the monthly solar irradiance figure by the stated wattage of the panel:

Solar Irradiance × Panel Wattage = Watt-hours/day

- Assuming we have a 20-watt solar panel, mounted flat on the ground, here are the calculations for Cairo in Egypt in December and June:

Flat	December	June
	**2.95** hr/day X **20** W = **59** Whr/day	**7.65** hr/day X **20** W = **153** Whr/day

Holiday Home as Example in London in United Kingdom

- Using our holiday home as an example (Needed wattage for home 695Wh/day) and then *divide* this number by the worst month on our irradiance chart for each tilt. It is worth doing this based on mounting the solar panel at different angles, to see how the performances compare:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FLAT												
	0.75	1.37	2.31	3.57	4.59	4.86	4.82	4.20	2.81	1.69	0.92	0.60
UPRIGHT												
	1.20	1.80	2.18	2.58	2.70	2.62	2.71	2.80	2.47	2.07	1.43	1.01
BEST ALL YEAR ROUND PERFORMANCE – 38° TILT												
	1.27	2.04	2.76	3.67	4.17	4.20	4.25	4.16	3.26	2.41	1.53	1.05
BEST WINTER PERFORMANCE – 23° TILT												
	1.30	2.03	2.62	3.34	3.66	3.69	3.76	3.73	3.06	2.37	1.56	1.08
BEST SUMMER PERFORMANCE – 53° TILT												
	1.19	1.95	2.77	3.84	4.52	4.63	4.66	4.41	3.31	2.33	1.43	0.97
ADJUSTING THE TILT THROUGHOUT THE YEAR FOR OPTIMAL PERFORMANCE												
	1.30	2.05	2.78	3.86	4.70	4.91	4.90	4.46	3.31	2.41	1.56	1.08
	22° tilt	30° tilt	38° tilt	46° tilt	54° tilt	62° tilt	54° tilt	46° tilt	38° tilt	30° tilt	22° tilt	14° tilt

Note: All angles are given in degrees from vertical and are location specific.

Flat	695 ÷ 0.6 = 1159 watts	If we have our solar panels laid flat, we would need a 1,159-watt solar array to power our home in December.
Upright	695 ÷ 1.01 = 688 watts	If we mount the solar panels vertically against a wall, we could generate the same amount of power with a 688-watt solar array.
38° angle Best year-round tilt	695 ÷ 1.05 = 661 watts	Angled towards the equator, we could generate the same amount of power with a 661-watt solar array.
23° angle Best winter tilt	695 ÷ 1.08 = 643 watts	With the optimum winter tilt, we can us a 643-watt solar array.
53° angle Best summer tilt	695 ÷ 0.97 = 716 watts	Angled towards the summer sun, we would require a 716-watt solar array to provide power in December
Tilt adjusted each month	695 ÷ 1.08 = 643 watts	With the tilt of the solar panel adjusted each month, we can use a 643-watt solar array, the same as the best winter tilt settings.

This chart tells us to feed our holiday home by the needed wattage 695Wh/day over all the year, you need a PV module of 1159W.

Solar Panel and Shade

- The biggest negative impact on solar energy production is shade. Even if only a very small amount of your solar array is in shade, your whole system can have a very big effect.
- Depending on the exact circumstances, even if only 5% of a photovoltaic solar panel is in shade, it is possible to lose 50–80% of power production from your entire solar array.

Solar array power point efficiencies

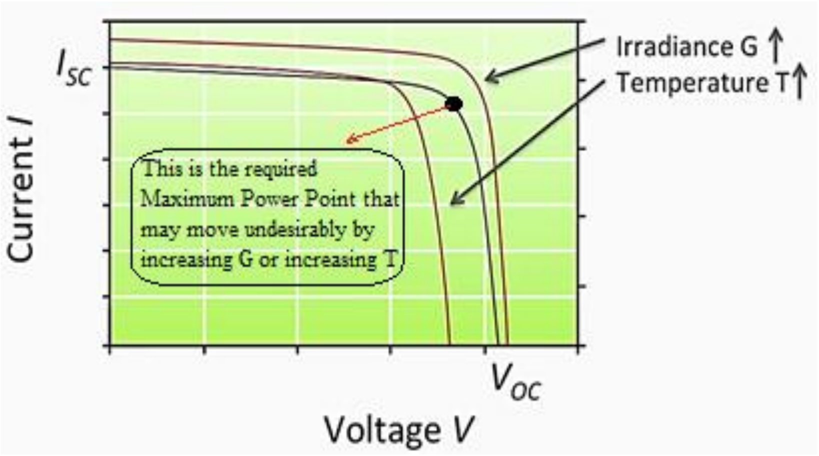
- Now we know the theoretical size (Wattage) of our solar panels. However, we have not taken into account the efficiencies of the controller or inverter that handles them.
- Solar panels are rated on their 'peak power output' or 'W_p'. The panel voltage can go up and down quite significantly, depending on irradiance and temperature.
- For solar panel rated 150W_p, 12-volt. You will deduce that: on IV curve, below the maximum power point (V_{mp}, I_{mp}) the panel voltage is less than 12-volt but above that point the panel voltage is greater than 12-volt.

Solar array power point efficiencies …

- This swing in voltage gets much higher if you have multiple solar panels connected together in series – or if you are using a higher-voltage solar panel. It is common for a solar array with fifteen or twenty panels connected in series to have voltage swings of several hundred volts when a cloud obscures the sun for a few seconds!. Managing this voltage swing can be done in one of two ways.
- ***The cheap and simple method*** is to cut the voltage down to a setting that the solar panel can easily maintain. For instance, a solar panel rated at 12 volts will usually maintain a voltage level of at least 14 volts during daylight hours. A charge controller or inverter that cuts the voltage down to this level will then always be able to use this power (i.e., high voltage and less current then the power obtained is less than the peak). The disadvantage of this approach is that, as you cut the voltage, the wattage drops with it, meaning you can lose a significant amount of energy. This method can reduce the efficiency of a solar array by around 25%.

Solar array power point efficiencies …

- ***A better solution*** is to use controllers and inverters that incorporate Maximum Power Point Tracking (MPPT). Maximum power point tracking adjusts the voltage from the solar array to provide the correct voltage for the batteries or for the inverter in order to remove this inefficiency. Maximum power point trackers are typically 90–95% efficient.
- You only need an MPPT inverter, where you are powering the inverter directly from the solar panels. You do not require an MPPT inverter if you are planning to run the inverter through a battery bank.
- MPPT is an algorithm that included in charge controllers used for producing maximum available power from PV module under certain conditions, because Maximum Power Point varies with (increasing solar irradiance, or increasing ambient temperature and solar cell temperature).
- The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage).



Solar array power point efficiencies …

- To take into account power point efficiencies, you need to divide your calculation by 0.9 if you plan to use a MPPT controller or inverter, and by 0.75 if you plan to use a non-MPPT controller or inverter:

Flat	695 ÷ 0.6 = 1159 watts	If we have our solar panels laid flat, we would need a 1,159-watt solar array to power our home in December.
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Tilt adjusted each month	695 ÷ 1.08 = 643 watts	With the tilt of the solar panel adjusted each month, we can use a 643-watt solar array, the same as the best winter tilt settings.

Non MPPT controller/inverter calculation	MPPT controller/inverter calculation
1159Watts ÷ 0.75 = 1545Watt 1545 Watts solar panels	1159 Watts ÷ 0.90 = 1288 Watts 1288 Watts solar panel
688 Watts ÷ 0.75 = 917 Watts 917 Watts solar panels	688 Watts ÷ 0.90 = 764 Watts 764 Watts solar panel

and soon

Effect of Temperature on the solar panel

- Solar PV systems can often generate more electricity on a day with a cool wind and a hazy ضبابية sun *than* when the sun is blazing ملتهبة and the temperature is high.
- At a cooler temperature, the solar panel will generate more electricity, whilst at a warmer temperature the same solar panel will generate less.
- Solar panel manufacturers provide information to show the effects of temperature on their panels. Called *a temperature coefficient of power rating*, it is shown as a percentage of total power reduction per 1°C increase in temperature.

Effect of Temperature on the solar panel …

- Typically, this figure shows *a temperature coefficient of power rating* 0.5% for a 100W solar panel, which means that for every 1°C increase in temperature, you will lose 0.5% efficiency from your solar array and vice versa.

	5°c/ 41°F	15°c/ 59°F	25°c/ 77°F	35°c/ 95°F	45°c/ 113°F	55°c/ 131°F	65°c/ 149°F	75°c/ 167°F	85°c/ 185°F
Panel output for a 100W solar panel	110W	105W	100W	95W	90W	85W	80W	75W	70W
Percentage gain/loss	10%	5%	0%	-5%	-10%	-15%	-20%	-25%	-30%

Effect of Temperature on the solar panel …

- *For a roof-top installation*, if the average air temperature at a particular time of year is 25°C/77°F or above, multiply this temperature in Celsius by 1.4 in order to get a likely solar panel temperature. *For a pole-mounted installation*, multiply your air temperature by 1.2 in order to calculate the likely solar panel temperature. Then increase your wattage requirements by the percentage loss shown in the temperature coefficient of power rating shown on your solar panels, in order to work out the wattage you need your solar panels to generate.

Working out dimensions

- There are two main technologies of solar panels on the market, *amorphous* and *crystalline*.
- For the purposes of working out how much space you are going to need to fit the solar panels, you need to know that a $1m^2$ amorphous solar panel generates in the region of 60Watts, whilst a $1m^2$ crystalline solar panel generates in the region of 160Watts.
- If you are planning to do the physical installation yourself, a solar electric system consisting of solar array, controller and battery costs around $5.60 US per watt, +/– 15%.

Example 2

- For our holiday home installation, we need 320Watts of solar electricity if we tilt the solar panels upright the sun, or 456Watts if we mount the panels flat.
- Assume: a 1m² amorphous solar panel generates in the region of 60Watts, whilst a 1m² crystalline solar panel generates in the region of 160Watts.
- Assume: solar system budget around ($5.6 US) per watt
- Determine:
  - (a) Area required to fix amorphous solar panel for upright mounting. [5⅓m²]
  - (b) Area required to fix amorphous solar panel for flat mounting. [7.6m²]
  - (c) Area required to fix crystalline solar panel for upright mounting. [2m²]
  - (d) Area required to fix crystalline solar panel for flat mounting. [2.85m²]
  - (e) Budget required for solar system for upright mounting. [$1,792 US]
  - (f) Budget required for solar system for flat mounting. [$2,553.6 US]

Roof-mounting

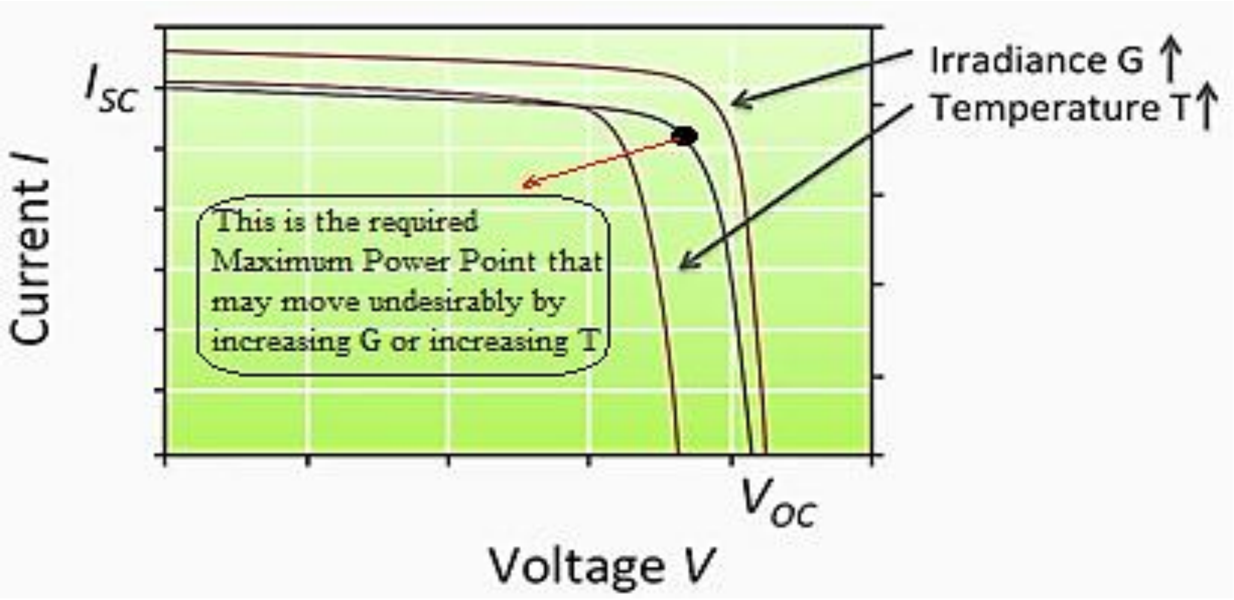
- A typical 4kW_p grid-tie system, made up of sixteen 250W_p solar panels can often weigh in the region of 360kg.
- Check the structure of the roof. Ensure that it is strong enough to take the solar array and what fixings you will need. There are so many different roof designs. If you are not certain about the suitability of your roof, ask a builder to assess your roof for you.

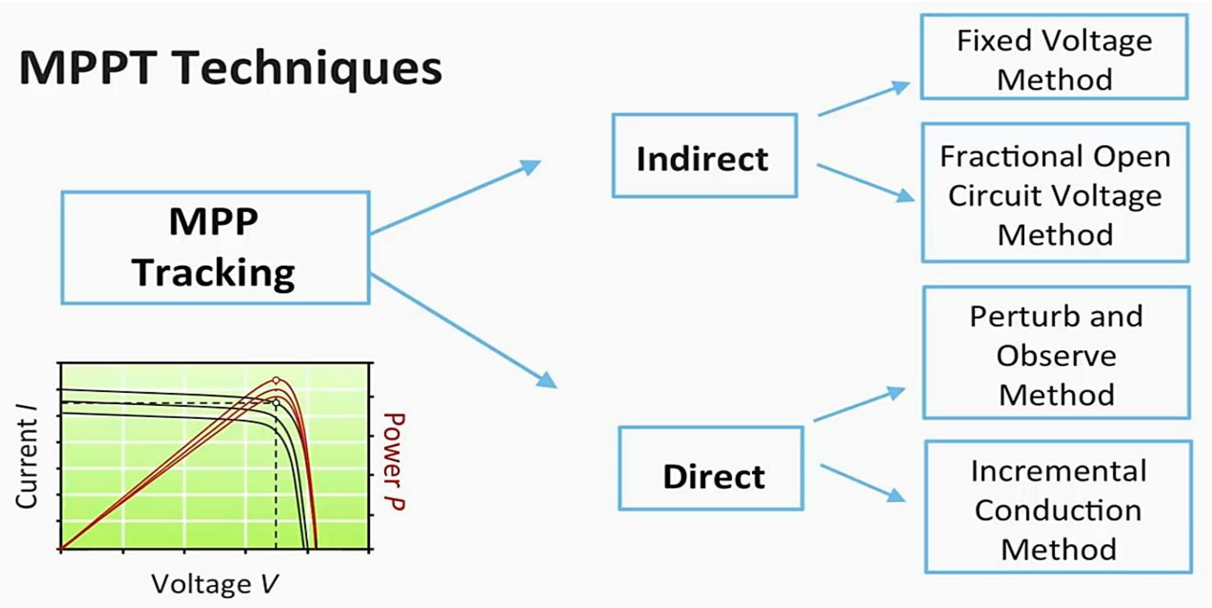
What is MPPT & How Can Maintain It ?

- MPPT: Maximum Power Point Tracking is an algorithm that included in charge controllers used for producing maximum available power from PV module under certain conditions.

- Maximum Power Point (the dark point on the intermediate curve): this value my move undesirably by increasing solar irradiance, or by increasing ambient & solar cell temperature). So, we apply MPPT by different techniques to maintain the maximum point of the PV module

- MPPT see the second figure.





References

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- Michael Baxwell_Solar Electricity Handbook 2017 Edition.pdf.
- http://www.solarelectricityhandbook.com
- PV I V characteristics part1 Isc Voc.mp4
- PV I V characteristics part2 Effects of Iph T.mp4
- PV I V characteristics part3 Effects of Rs Rsh a.mp4
- Modeling and Simulation of Photovoltaic Module Considering an Ideal Solar Cell.pdf
- Sedra & Smith_Microelectronic Circuits_6th Edition.pdf (pages in pdf: 173-178)
- MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell.pdf
- 7.3 – MPPT.mp4
- How to operate MPPT solar charge controller.mp4
- Basics of Maximum Power Point Tracking (MPPT) Solar Charge Controller.pdf
- Mppt.Zip

Recommendations

- We need slides talk about:

  1- Comparison between crystalline and amorphous solar panels.

  2- MPPT explain.

  3- A brief explain about PV cell Modelling.

  4- The Four Configurations for Solar Power …. From reference_Solar Electricity Handbook 2017 Edition.pdf

Recommendation

- *Recommended Videos and References:*

1- PV I V characteristics part1 Isc Voc.wmp

2- PV I V characteristics part2 Effects of Iph T.wmp

3- PV I V characteristics part3 Effects of Rs Rsh a.wmp

4- Modeling and Simulation of Photovoltaic Module Considering an Ideal Solar Cell.pdf

5- Sedra & Smith_Microelectronic Circuits_6th Edition.pdf (pages in pdf: 173-178)

6- MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell.pdf