Reference:

[1] https://eosweb.larc.nasa.gov "A renewable energy resource web site developed by NASA" about Surface meteorology and Solar energy resource. (release 6.0)

[2] http://www.pucsl.gov.lk/english/wp-content/uploads/2013/03/Electricity-Tariff-2013-Proposal-by-CEB-Main-tables.pdf "A Retail Tariff Proposal for 2013 Ceylon Electricity Board March" published by Public Utility Commission Sri Lanka.

[3] www.homerenergy.com Hybrid Optimization Modeling Software for micro grid and distributed generation power system design and renewable energy integration

[4] http://homerenergy.com/HOMER_2.html HOMER 2 is the current commercial version of HOMER developed by National Renewable Energy Laboratory with new power system components.

[5] http://www.retscreen.net RETScreen is a Clean Energy Project Analysis Software developed and maintained by the Government of Canada through Natural Resources Canada's CanmetENERGY research centre.

[6] http://www.pvsyst.com PVSyst is a photovotic PVsyst software is a tool that allows its user to accurately analyze different configurations and to evaluate the results and identify the best solution.

APPENDIX A

Solar Energy

Using solar power as an energy source started as early as 7th century B.C. as magnifying glasses were started to use for concentrating sun's rays to make fire and for burning ants. In 3rd century B.C., Greeks and Romans used burning mirrors to light torches for religious purposes. In 1839, French scientist Edmond Becquerel discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution. The electricity generation of this system increased when exposed to light. In 1883, the first solar cell was built by Charles Fritt, by coating the semiconductor selenium with an extremely thin layer of gold to form junctions which are around 1% efficient. In 1954, Daryl Chapin, Calvin Fuller, and Gerald Pearson developed the silicon photovoltaic (PV) cell at Bell Telephone Laboratories with 4% efficiency and later achieved 11% efficiency [16].

Efficiencies around 40% is developed by some solar PV array manufacturers, and National Renewable Energy Laboratory (NREL) accepted that the 40.8% is the maximum tested efficiency for a solar PV panel [13]. Manufacturing those high efficiency solar photovoltaic modules in industrial level for mass applications is not economically viable and generally, at industrial level, 10% to 19% efficiency ranges are more popular.

There are three types of solar PV cell depending on the crystal type used to manufacture the cell, namely, mono crystalline, polycrystalline and amorphous.

Physics

PV cells can be modeled as a current source in parallel with a diode [14]. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in below figure.

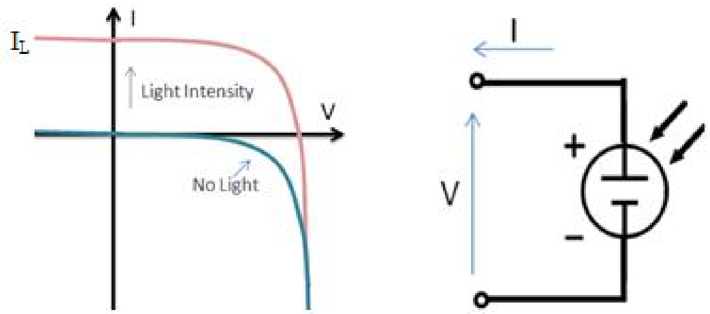


Figure 4: I-V curve of a PV cell and equivalent electrical diagram

In an ideal cell, the total current I is equal to the current I_ℓ generated by the photoelectric effect minus the diode current I_D, according to the equation:

$$I = I_l - I_D = I_l - I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

Where,

I_0 - Saturation current of the diode

q - Elementary charge 1.6×10^{-19} Coulombs

k - Constant of value 1.38×10^{-23} J/K

T - Cell temperature in Kelvin

V - Measured cell voltage that is either produced (power quadrant) or applied (voltage bias).

By expanding the equation, circuit model shown in Figure 3.6 and the following associated equation can be obtained.

$$I = I_l - I_0\left(e^{\frac{q(V+IR_S)}{nKT}} - 1\right) - \frac{V + IR_S}{R_{SH}}$$

Where,

n - Diode ideality factor (typically between 1 and 2)

R_S - series resistances.

R_{SH} - Shunt resistance

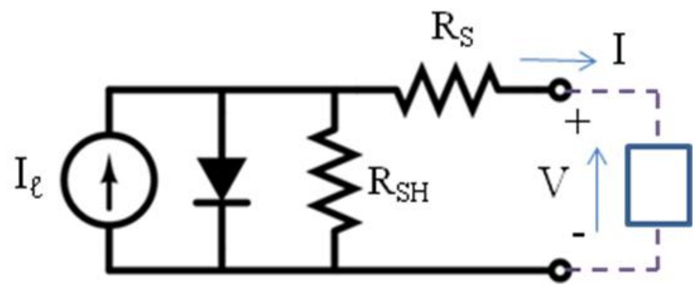


Figure 5: Simplified Equivalent Circuit Model for a Photovoltaic Cell

I-V curve of an illuminated PV cell has the shape shown in Figure 3.7, as the voltage across the measuring load is swept from zero to V_{OC}, and many performance parameters for the cell can be determined from this data.

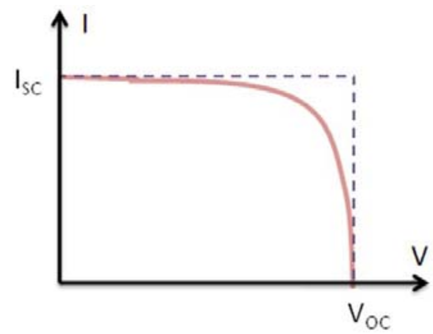


Figure 6: Illuminated I-V Sweep Curve

Important electrical characteristics of a solar PV panel are given below.

- Nominal power (P_{MAX} measured in Watts), Maximum power point voltage (V_{MPP}), Maximum power point current (I_{MPP}) - The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation P=IV. At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively.

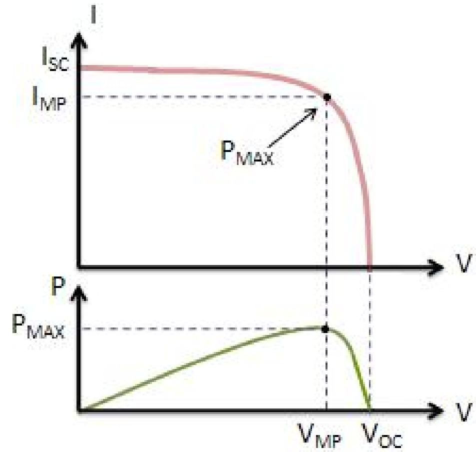


Figure 7: Maximum Power for an I-V Sweep

- Open circuit voltage (V_{OC} measured in Volts) - The open circuit voltage (V_{OC}) occurs when there is no current passing through the cell.

$$V \text{ (at } I=0) = V_{OC}$$

  V_{OC} is also the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant.

$$V_{OC}= V_{MAX} \text{ for forward-bias power quadrant}$$

- Short circuit current (I_{SC} measured in Ampere) - The short circuit current I_{SC} corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0.

$$I \text{ (at } V=0) = I_{SC}$$

  I_{SC} occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation.

$$I_{SC} = I_{MAX} = I_{\ell} \text{ for forward-bias power quadrant}$$

- Module efficiency (%) - Efficiency is the ratio of the electrical power output P_{out}, compared to the solar power input, P_{in}, into the PV cell. P_{out} can be taken to be P_{MAX} since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

$$\eta = \frac{P_{out}}{P_{in}}$$

Solar PV module performance is generally rated under standard test conditions, which are given below.

- Solar Irradiance of 1000 W/m^2
- Sun angle
- Module temperature of 25^{0}C
- I-V Operating (load matching for maximum power)

The crystals used to make PV cells, like all semiconductors, are sensitive to temperature. Figure 3.9 depicts the effect of temperature on an I-V curve. When a PV cell is exposed to higher temperatures, I_{SC} increases slightly, while V_{OC} decreases more significantly.

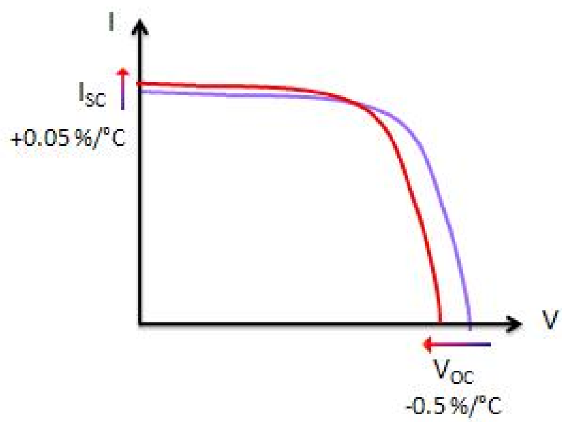


Figure 8: Temperature Effect on I-V Curve

For a specified set of ambient conditions, higher temperatures result in a decrease in the maximum power output P_{MAX}.

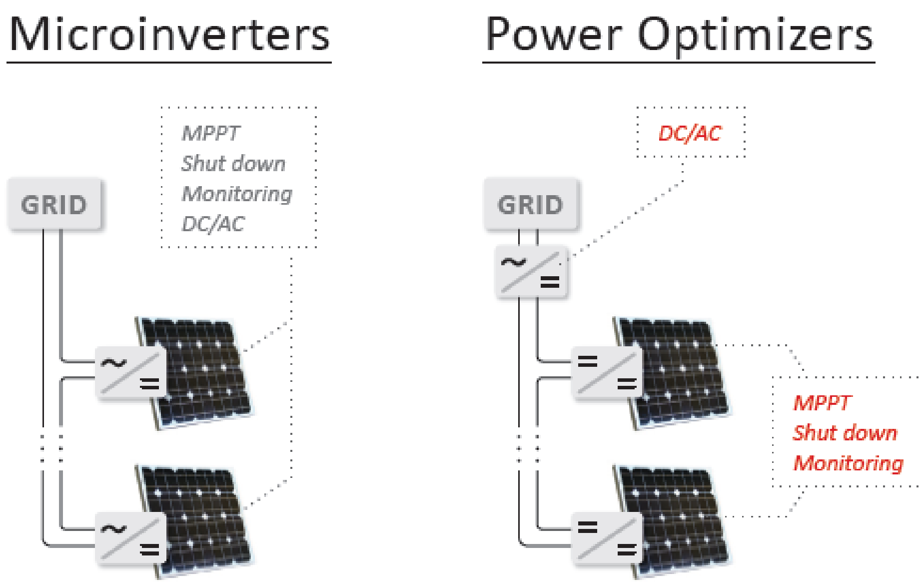
Shading on solar panels results uneven current flows through the circuits and diodes are included to avoid overheating of cells in case of partial shading. Since cell heating reduces the operating efficiency it is desirable to minimize the heating. Very few modules incorporate any design features to decrease temperature, and it is a good practice to provide good ventilation behind the module.

APPENDIX B

A comparison of Micro inverters & Power Optimizers

Module level electronics overcome the shortcomings of traditional inverters and enable maximum power, module level monitoring, flexible design and enhanced safety.

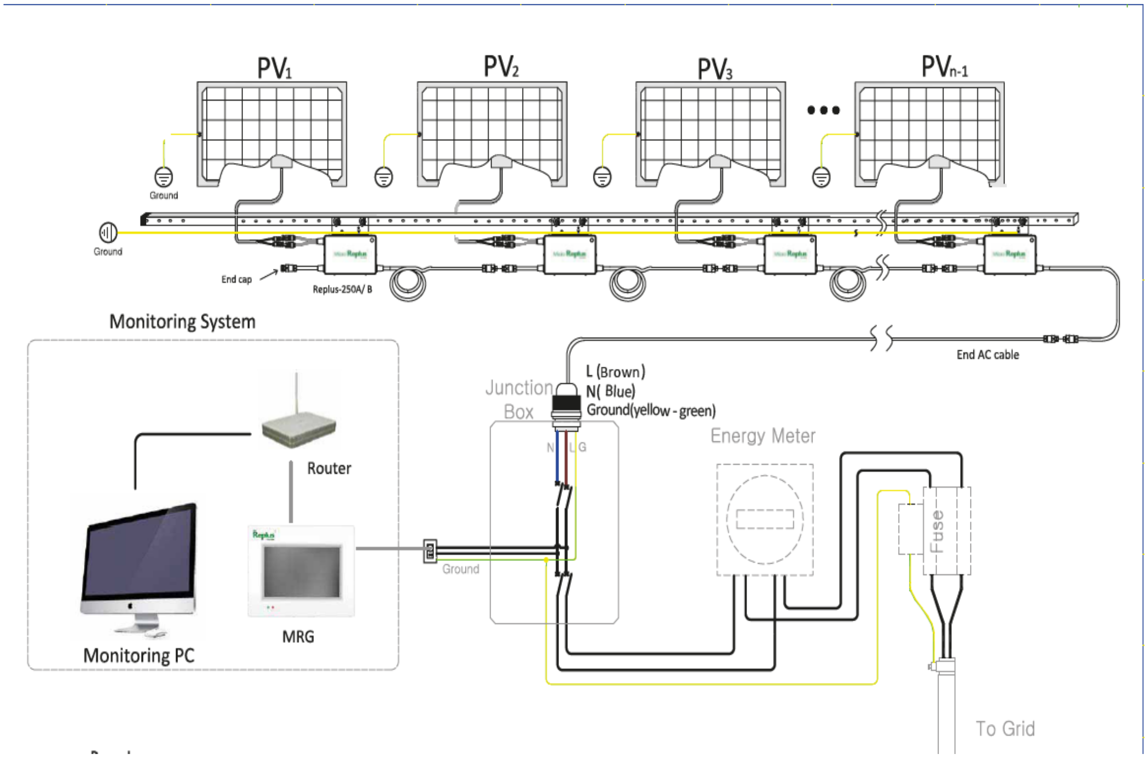
However, there is no need to add an inverter to every module if DC power optimizers can achieve all these benefits at lower cost, higher efficiency and higher reliability.



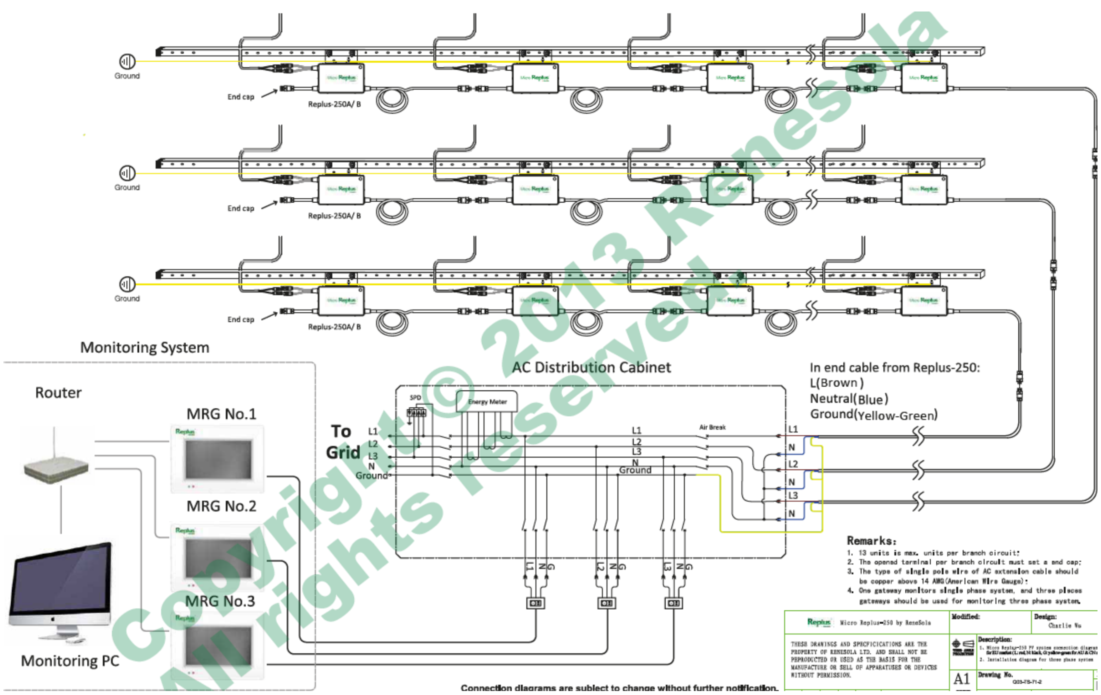
The comparision with respect to Micro Inverters Vs Solar Edge Power Optimizers are discusse below with respect to the Israel manufacture Solar Edge.

Benefits	Micro inverters	Power Optimizers	Details
Cost per Watt	Higher	Lower - 20-50% cheaper	Micro inverters cost includes trunk cables and gateways. Solar Edge system cost includes inverter, built-in module-level monitoring and 25 year warranty for inverters and power optimizers.
Scalability	Not scalable	Scalable	The cost/watt of a Solar Edge system decreases as installation size increases
Added Energy	Lower	Higher	Power optimizers have higher efficiency (99.5%) than micro inverters. Reduced efficiency of micro inverters increases heat dissipation. which enhances module degradation. Micro inverters have a higher minimum voltage than power optimizers: Less shading tolerance Late wake up leading to fewer production hour
Compatibility	Limited	Broad	Micro inverters have a limited AC output power (e.g. no support for 72-cell modules) When connected to higher capacity modules, the excess DC power is lost. E.g. in a 6kW installation of 260W modules, only 5kW AC power will be produced
Reliability	Lower	Higher	Micro inverters have much higher part count leading to increased failure rate. Some micro inverters work with electrolytic capacitors which have short life time. Micro inverters create higher temperatures

A connection diagram of single phase Grid tie micro inverter system for Net Metering is shown below.

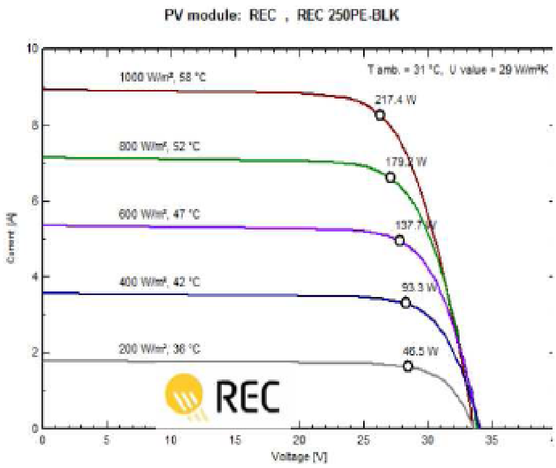


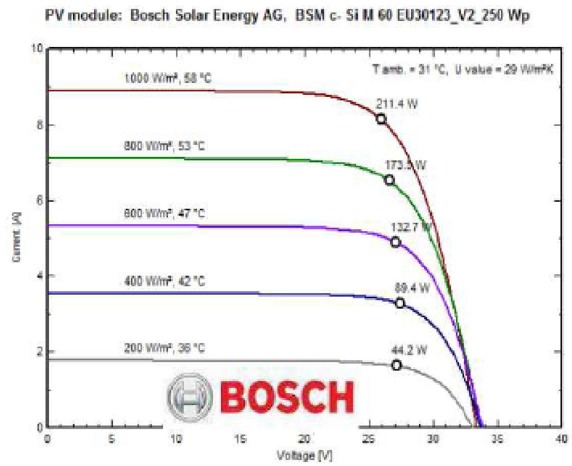
A connection diagram of three phase Grid tie micro inverter system for Net Metering is shown below.

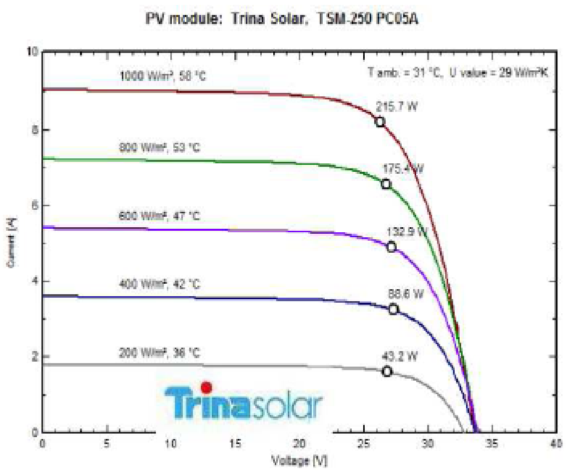


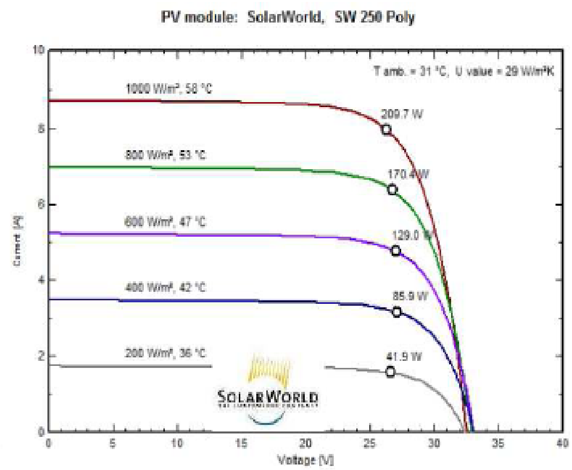
Comparison of characteristics of some leading solar modules.

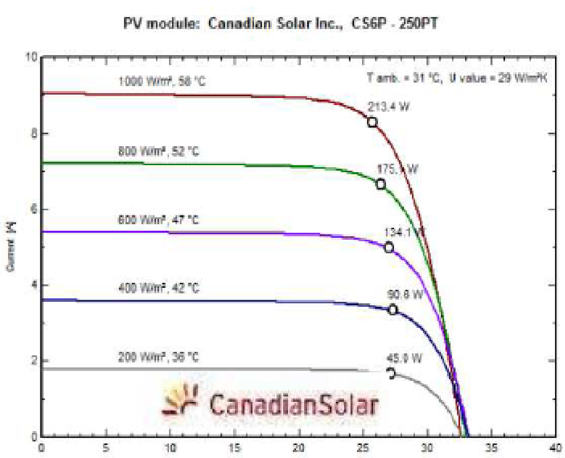
Source : Data Sheet & PVSyst PAN File.

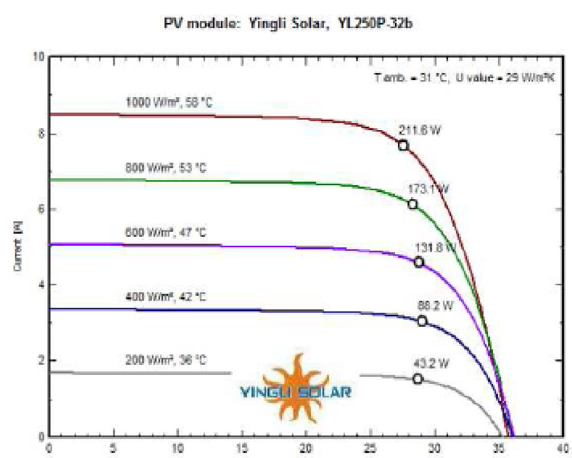






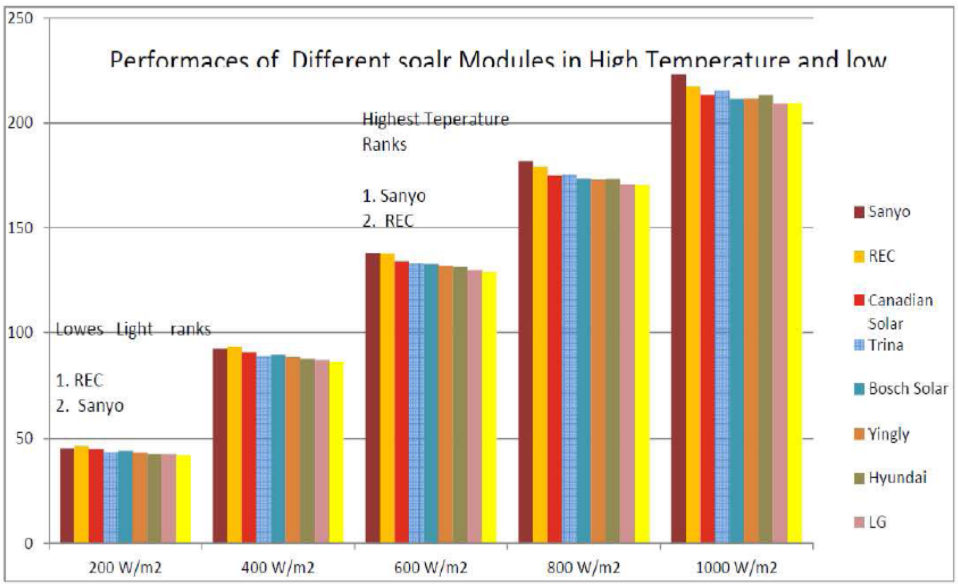






Output power in Watts at different environmental conditions

	1000 W/m2	800 W/m2	600 W/m2	400 W/m2	200 W/m2
Sanyo	223.1	181.7	138	92.3	45.4
REC	217.4	179.2	137.7	93.3	46.5
Canadian Solar	213.4	175.1	134.1	90.6	45
Trina	215.7	175.4	132.9	88.6	43.2
Bosch Solar	211.4	173.5	132.7	89.4	44.2
Yingly	211.6	173.1	131.8	88.2	43.2
Hyundai	213.3	173.3	131.2	87.4	42.6
LG	209.3	170.8	129.9	87	42.6
Solarworld	209.7	170.4	129	85.9	41.9

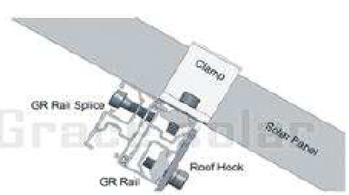


Source: PV syst- world's leading PV analysis software

Solar PV Mounting Systems.

- Standard Mounting system provides
  - Better ventilation gap and cooling effect →up to 5% more energy yield
  - Nice aesthetic appearance
  - Quick assembling and dissembling for easy maintenance
  - Low weight – less burden on structure.

Four Steps to put the tilt-in module into rail easily



Assembly drawing