Thursday, 9/21/23

PV Modules and Arrays, Typical Construction

Consider the figure below:

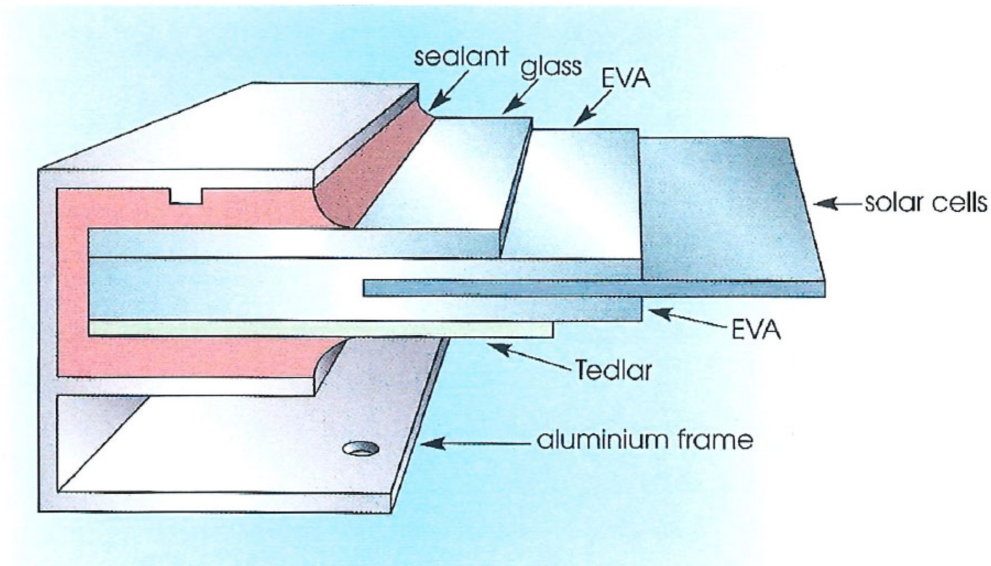


Figure 3.2 Typical construction of a conventional PV module.

a. Rigid Crystalline Si PV Cells

The PV cells are cushioned by airtight encapsulation in a layer of transparent ethyl vinyl acetate (EVA):

So that the cell survives handling,

Airtight to keep moisture out.

The top cover is a layer of "tempered glass."

Tempered glass is strengthened compared to normal glass.

This top cover glass layer might have an antireflection coating (ARC) applied to it.

The Tedlar layer serves as a barrier to moisture and chemical attack.

Tedlar is a lightweight synthetic polymer.

The Tedlar layer is under the backside EVA layer.

The glass-EVA-PV-EVA-Tedlar assembly is fitted into a slotted aluminum frame and fixed in place with a sealant.

b. Rigid Thin Film PV Cells

Rigid thin film PV cells are deposited directly onto glass.

c. Flexible Thin Film PV Cells

For flexible PV cells, many module/array options exist.

Including fabrication on a roll of plastic film.

Consider the figure below:

Figure 3.3 Innovative design: an example from Japan (IEA-PVPS).

Electrically Connecting PV Cells and Modules

For typical large power applications, two connection architectures are used:

(1) PV powered DC systems with battery storage

Typically, 12 V rechargeable batteries are used.

Approximately 18 V is suitable for charging 12 V rechargeable batteries.

Connecting 36 PV cells in series is often used for this:

V_{oc}: approximately 20 V

V_{mpp}: approximately 17 V

(2) AC grid connected PV systems:

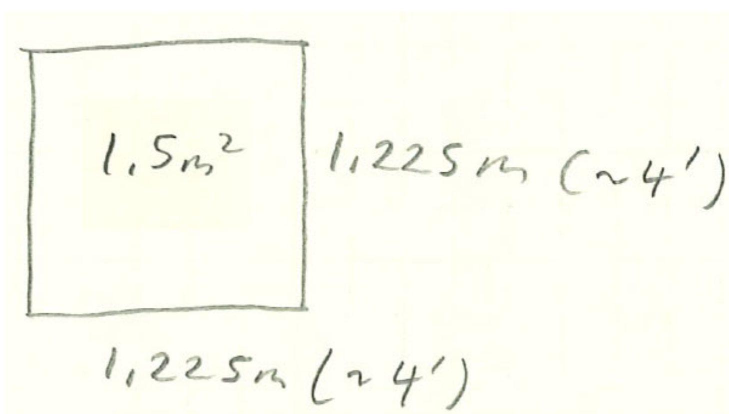
A higher DC voltage is desired to achieve higher DC-AC conversion efficiency.

72 SC Si PV cells in series yields a V_{mpp} of approximately 35 V.

72 SC Si PV cells take about 1.5m^2 of real estate:

Yields up to about 200 W_p.

Consider this:



So, 1.5 m^2 is about 16 ft^2:

Yielding 12.5 W/ft^2 peak.

Consider a standard 2000 ft^2 roof with 1000 ft^2 facing south:

This could yield about 12.5 kW peak.

If, on average, peak performance is achieved 6 hours per day:

This yields 75 kWH of energy per day.

Let's assume we get this much energy out of the system for an average of 200 days per year, yielding 15,000 kWH per year.

With Alabama Power, residential users pay $14.50 plus $0.124384 per kWH for the first 1000 kWh per month. Above 1000 kWH, the fee is $0.126913 per kWH (June-September) or $0.112384 per kWH (October-May). So, 15,000 kWH would cost you $1915.67 in the summer or $1712.26 in the winter, if you purchased this amount of electricity from Alabama Power at these rates.

However, if you sold all of this energy back to Alabama Power at their stated rate of $0.0744 per kWH (peak hours, June through September, Time of Day Rate Option, and minus the $0.97 monthly fee):

Alabama Power would pay you $1115.03.

Electrically Connecting "Real" PV Cells into a Module

a. Connecting cells to form a module

"Real" PV cells are *NOT* identical!

This is due to manufacturing differences, localized damage, partial shading of the module/array, etc.

Therefore, the module's output is limited by the PV cell with the lowest output:

i.e. the "weakest link in the chain."

This resulting power loss is called Mismatch Loss:

(1) Mismatch loss from manufacturing tolerances: usually small and of little concern.

(2) Mismatch loss from partial shading: potentially problematic and should be avoided.

(3) Mismatch loss from a bad PV cell: very bad!

A bad PV cell acts as a load if it cannot produce current (the reverse biased pn junction is in reverse breakdown).

This cell now consumes power and dissipates it as heat, which can further damage the array (solder joint melting, etc.). This is known as Hot-Spot Formation.

Consider the drawing below:

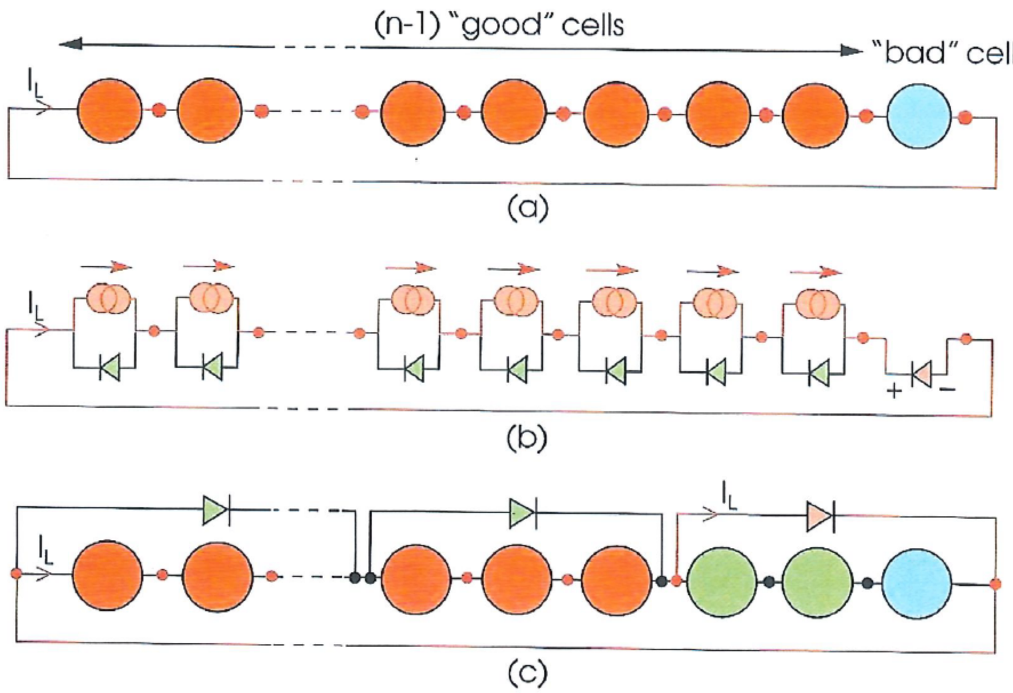


Figure 3.4 (a) A string of cells including one 'bad' cell; (b) equivalent circuit; (c) addition of bypass diodes.

In (a) above: with the series chain of connected PV cells, the full voltage of the series connected good cells is across the reverse biased bad cell.

This leads to reverse breakdown of the bad cell's pn junction, leading to hot spot formation.

In (b) above, the circuit model for the series chain in (a) is shown.

In (c) above, bypass diodes have been added to small groups of PV cells to prevent hot spots from occurring due to bad cells. If a cell is bad, the current is shunted around that group of PV cells through the bypass diode.

There is a tradeoff though: the bypass diode will take out all good cells in the group with one bad cell.

Typically, one bypass diode is used for every 10 or fewer PV cells.

b. Modules as Units

PV modules are also characterized by V_{oc}, I_{sc}, and P_{mpp}.

Modules can be connected in series and parallel too, as shown below:

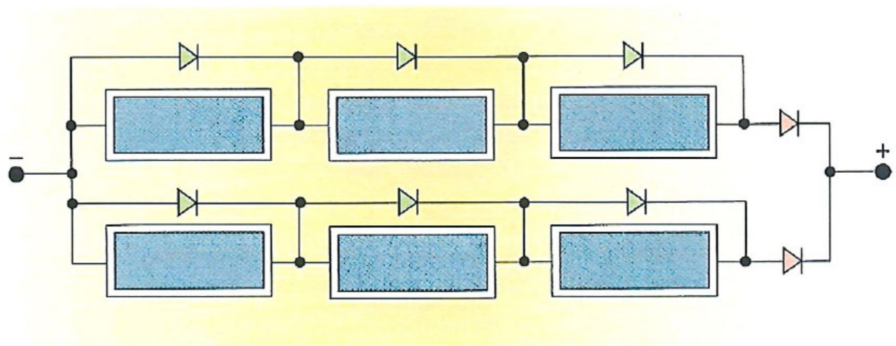


Figure 3.5 An array of 6 modules.

Bypass diodes are also added to module assemblies: one per module.

Diodes in series with modules are called <u>Blocking Diodes</u>:

These diodes ensure that current only flows <u>out</u> of the modules.

They are typically used with battery charging PV systems to prevent batteries from discharging through the modules at night.

They will introduce a small voltage drop due to their turn-on voltage:

~ 0.2 V – Schottky diodes

~ 0.7 V – Si pn junction diodes

Bypass and blocking diodes might be included in the PV module.

PV modules have specifications similar to PV cells.

Typical PV module specification from the textbook, p. 86:

■ Nominal power	180 W_p
■ Open-circuit voltage	43.8 V
■ Short-circuit current	5.50 A
■ Voltage at maximum power	35.8 V
■ Current at maximum power	5.03 A
■ Power reduction per °C	0.45%
■ Voltage reduction per °C	0.33%
■ Length	1600 mm
■ Width	804 mm
■ Weight	18 kg
■ Efficiency	14.0%

The textbook lists some "average module efficiencies: under standard conditions on p. 85:

SC Si: 18%
MC Si: 17%
CIS: 15%
CdTe: 16.5%
a-Si: <10%

Note: SC Si and MC Si PV tend to lose their efficiency advantage in weak or diffuse light, or in high temperatures.

PV modules also perform similarly to PV cells when the insolation varies:

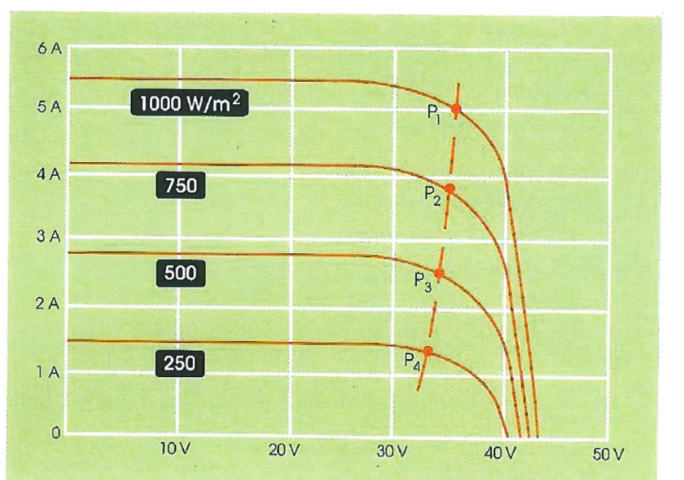


Figure 3.6 *I–V* characteristics of a typical monocrystalline silicon module rated at 180 W_p.

Here is a comparison of various PV technology modules, from the textbook p. 88.

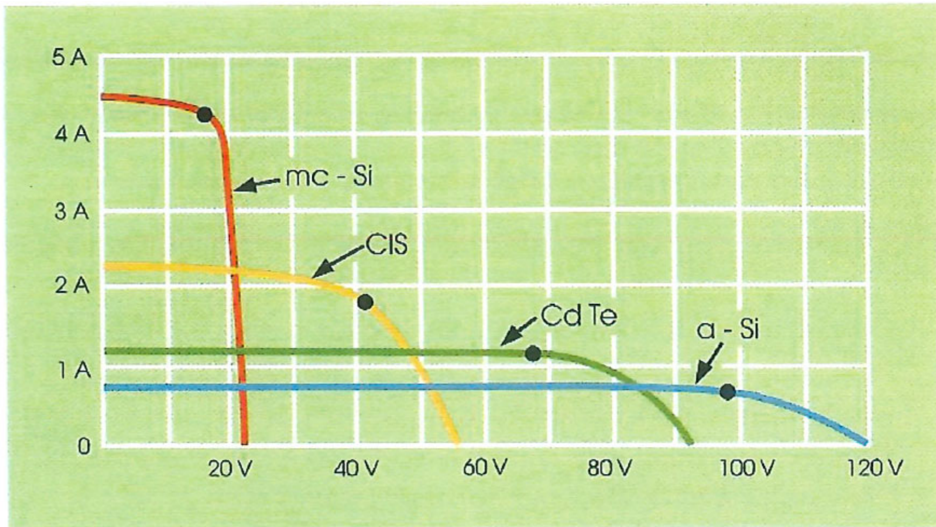


Figure 3.7 *I–V* characteristics in strong sunlight (1000 W/m^2) of four 75 W_p modules.

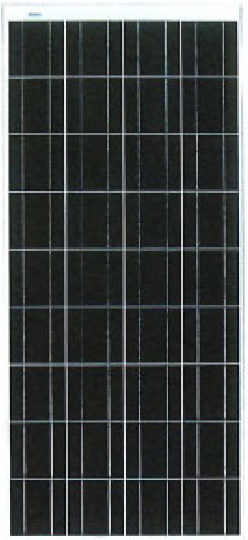
Here is an example commercial PV module specification:

Example commercial PV module specification:

CELL TYPE	**156*156mm POLYCRYSTALLINE SOLAR CELL**	
ITEM	**HS100-12P**	**HS120-12P**
Maximum Power (Wp)	**100 W**	**120 W**
Maximum Power Voltage (Vm)	**17.1 V**	**17.2 V**
Maximum Power Current (Im)	**5.9 A**	**6.4 A**
Open circuit Voltage (Voc)	**21.6 V**	**21.6 V**
Short circuit Current (Iso)	**6.42 A**	**7.13 A**
Length*Width*Depth (mm)	**1482*676*35**	
Weight (kg)	**12**	
Number of cells	**36**	
Maximum system voltage	**1000 VDC**	
Output tolerance	**+/-5%**	
FF	**>= 72%**	
Standard test conditions	**STC: AM 1.5, 1000w/m2, Module Temperature 25°C**	

http://www.hebesolar.com/manufacturers-100-watt-solar-panels.html

Consider an actual PV module data sheet, on the next two pages.



140W and 150W Photovoltaic modules 140J and 150J

This line of modules is the direct result of over three decades of design, manufacturing and use. Attending to every detail in the design and manufacture of our products, our process controls and testing methods have optimized module life and electrical energy production.

Ameresco Solar's off-grid module line offers the following features and benefits:

► Built to last

From mountaintops to off-shore platforms, on weather stations in the bitter cold of Antarctica and on telephone signal repeaters in the hot Australian outback, the technology has been proven in the harshest environments.

► Accessible junction box for off-grid connections

J-type junction box has accessible terminals for easier module interconnections in off-grid applications, and it allows fitting cable glands for various sections.

► Thick, durable scratch resistant back sheet

The thick back sheet provides extra insulation and increased resistance to protect your module against rough handling. Made of white polyester, it ensures longer term performance and increased energy production.

► High reliability

Cell interconnections and diode placement use well-established industry practice and are field-proven to provide excellent reliability.

► Quality and certifications

ISO 9001 — ISO 9001 factory certification ensures that our manufacturing facilities use proven manufacturing and quality control processes.

Certified to IEC 61215 and 61730

Certified to UL1703 and ULC1703
Certified for use in Class 1, Division 2 Hazardous locations

CE — Conforms with European Directive 2006/95/EC

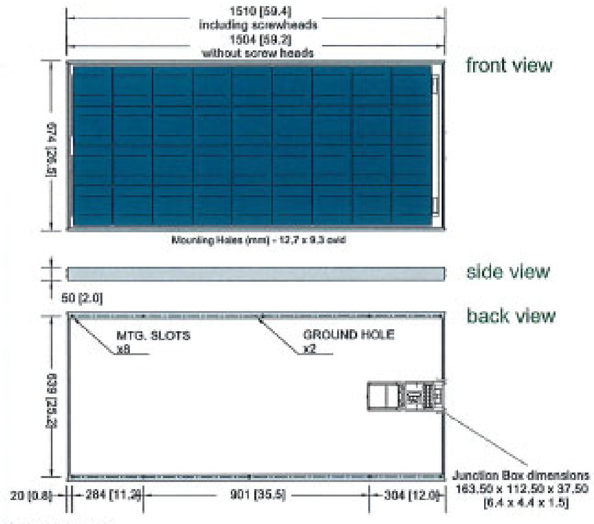
Photographs are intended to portray typical module appearance, actual module appearance may vary.

Electrical characteristics

140J / 150J

	[1] STC 1000W/m²	[2] NOCT 800W/m²
Maximum power (P_{max})	140W / 150W	101W / 108W
Voltage at P_{max} (V_{mpp})	17.5V / 18.1V	15.6V / 16.2V
Current at P_{max} (I_{mpp})	8.0A / 8.3A	6.5A / 6.7A
Short circuit current (I_{sc})	8.2A / 8.5A	6.6A / 6.9A
Open circuit voltage (V_{oc})	22.0V / 22.2V	20.0V / 20.2V
Module efficiency	13.7% / 14.6%	
Tolerance (P_{max})	+10% / -5%	
Nominal voltage	12V	
Efficiency reduction at 200W/m²	<5% reduction efficiency 13.0% / 13.8%	
Limiting reverse current	8.2A / 8.5A	
Temperature coefficient of I_{sc}	0.105%/°C	
Temperature coefficient of V_{oc}	-0.360%/°C	
Temperature coefficient of (P_{max})	-0.45%/°C	
[3] NOCT	47±2°C	
Maximum series fuse rating	20A	
Application class (according to IEC 61730:2007)	Class C	
Maximum system voltage	600V (U.S. NEC) / 1000V (IEC 61730:2007)	

1: Values at Standard Test Conditions (STC): 1000W/m² irradiance, AM1.5 solar spectrum and 25°C module temperature
2: Values at 800W/m² irradiance, Nominal Operation Cell Temperature (NOCT) and AM1.5 solar spectrum
3: Nominal Operation Cell Temperature: Module operation temperature at 800W/m² irradiance, 20°C air temperature, 1m/s wind speed

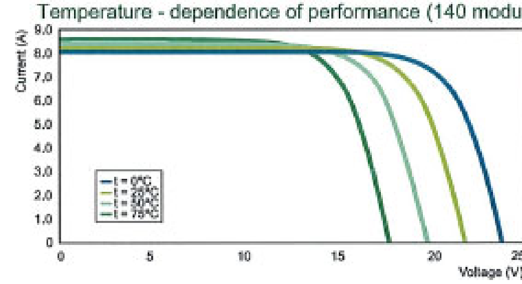


Mechanical characteristics

Solar cells	36 crystalline 6" silicon cells (156 x 156mm) in series
Front cover	High transmission 3.2mm (1/8th in) glass
Encapsulant	EVA
Back cover	White polyester
Frame	Silver anodized aluminum
Junction box	IP65 with 4 terminal screw connection block; accepts PG 13.5, M20 13mm (½") conduit, or cable fittings accepting 6-12mm diameter cable. Terminals accept 2.5-10mm² (8-14 AWG) wire
Dimensions	1510 x 674 x 50mm / 59.4 x 26.5 x 2in
Weight	12kg / 26.5lbs

All dimensional tolerances within ±1% unless otherwise stated.

Temperature - dependence of performance (140 module)



Warranty*

- Free from defects in materials and workmanship for 2 years
- 90% min. power output over 12 years
- Optional 25 years available

* Refer to warranty document for terms and conditions.

Certification

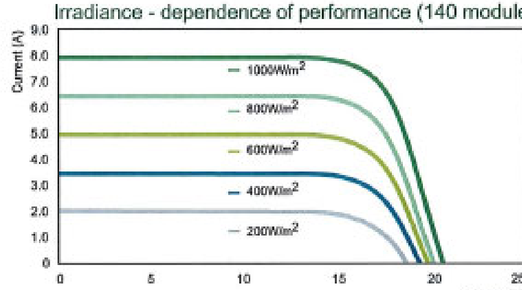
Certified according to the extended version of the IEC 61215 (ed.2), EN 61215:2005-08 (Crystalline silicon terrestrial photovoltaic modules - Design qualification and type approval).

Certified according to IEC 61730-1 and IEC 61730-2 (ed.1), EN 61730-1:2007-05 and EN 61730-2:2007-05. (Photovoltaic module safety qualification, requirements for construction and testing).

d to UL 1703 & ULC ORD-C1703 Standard for Safety by Intertek ETL. Class C Fire Rating.

Approved by Intertek ETL according to FM 3611, Dec 2004, and according to CAN/CSA C22.2 No. 213-M1987, 1st Edition, Reaffirmed 2004, for use in a Class I, Division 2, Group A, B, C, D Hazardous (Classified) Location.

Irradiance - dependence of performance (140 module)



For more information, call 855-43-SOLAR or visit www.amerescosolar.com.