Solar Energy for a Decarbonised Future - Knowledge Transfer for Environmental Education and Awareness (SolAware)


https://solware.uomosul.edu.iq/

Summer Training 2023-2024

Session 5: An overview on solar panel and Energy Storage

A Project Funded by the British Council Between University of Mosul & Teesside university on Research Environment

This Session is divided into two parts:

An overview on solar panel(Part1)

Energy Storage - Battery(Part 2)

An overview on solar panel

Learning objective

This lecture is to learn about PV module, their connection, IV characteristic curves, and Maximum power point tracking.

☐ **An overview of solar panel.**

☐ **Module connection – series and parallel.**

☐ **Understanding IV curve. (very important)**

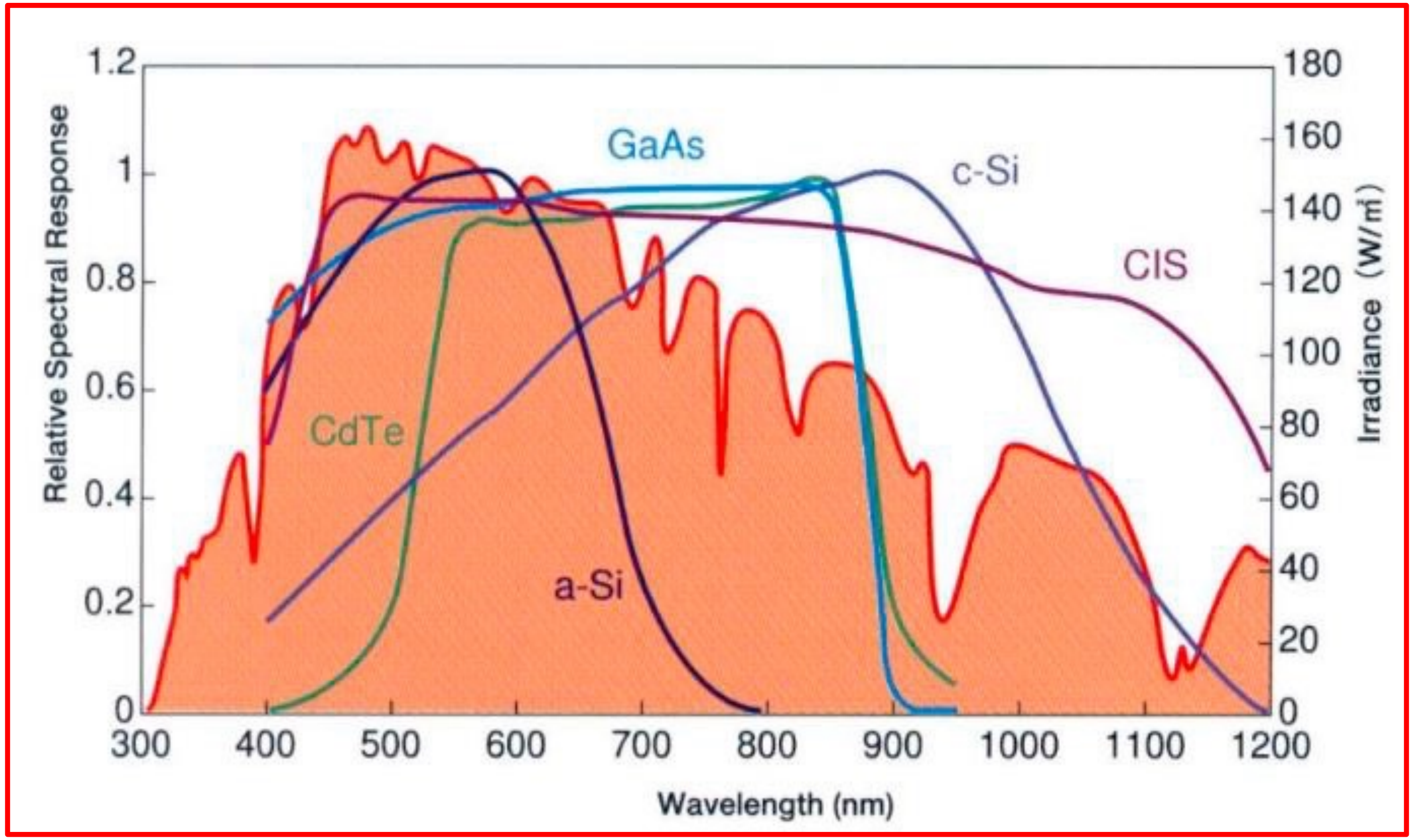
☐ **Bypass diode and blocking diode.**

☐ **Equivalent circuit model.**

☐ **Find shunt and series resistance for IV curve.**

An overview on solar panel

❖ ***What do you know about the figure below?***

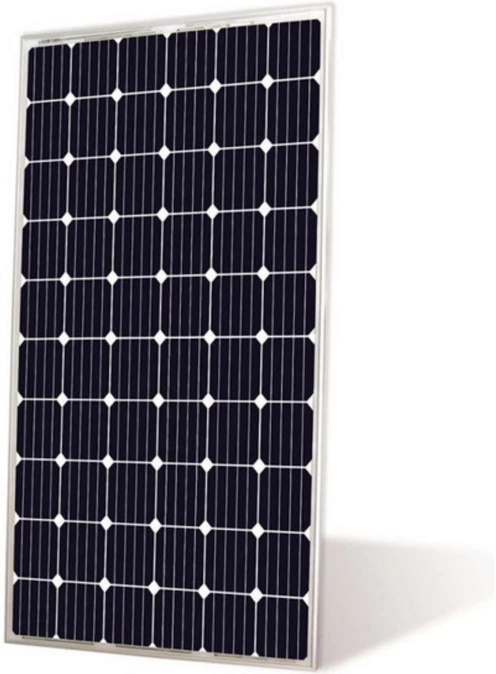


- ❖ The advantage of CIGS over a-SI is in a fact, that CIGS produces more energy in the morning as well as later in the evening.
- ❖ Solar panels are affected by heat. CIGS delivers high yields – ***<u>even in desert environments</u>***

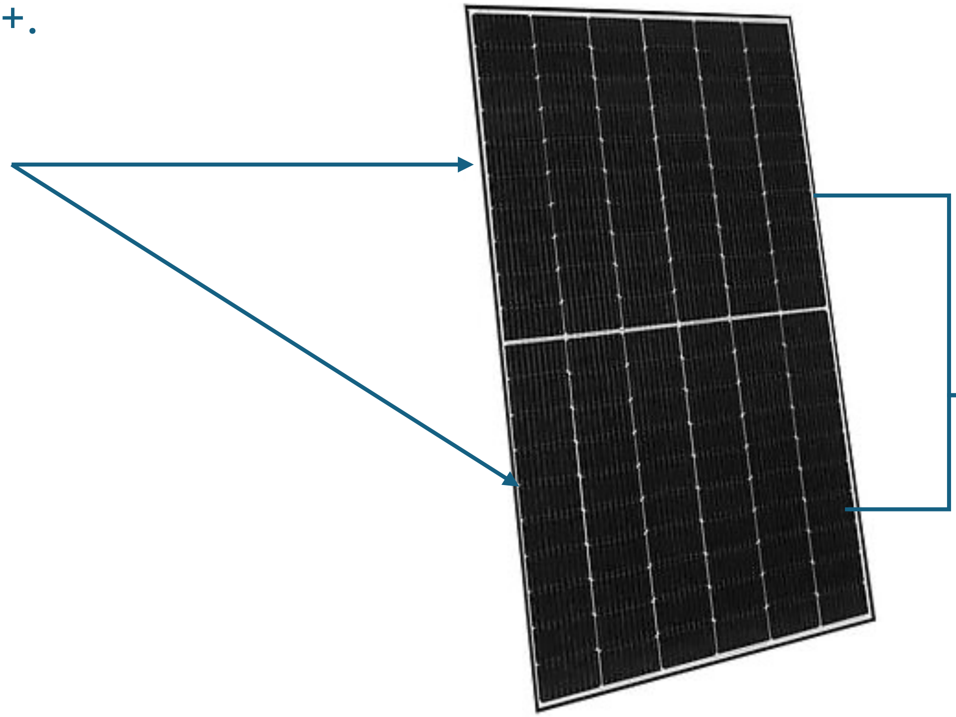
An overview on solar panel

Standard Module Design

- Most commonly 60 cells in 6 (rows) by 10 (column) configuration.
- The cells are connected in series. V per cell around 0.5V.
- Other common cells – 48, 54 and 72.
- Emerging module – half cell.
  - 120 half-cut cells.
  - Parallel connection of serial strings
- Power range from 100W to 700W+.



60 cells
6 x 10

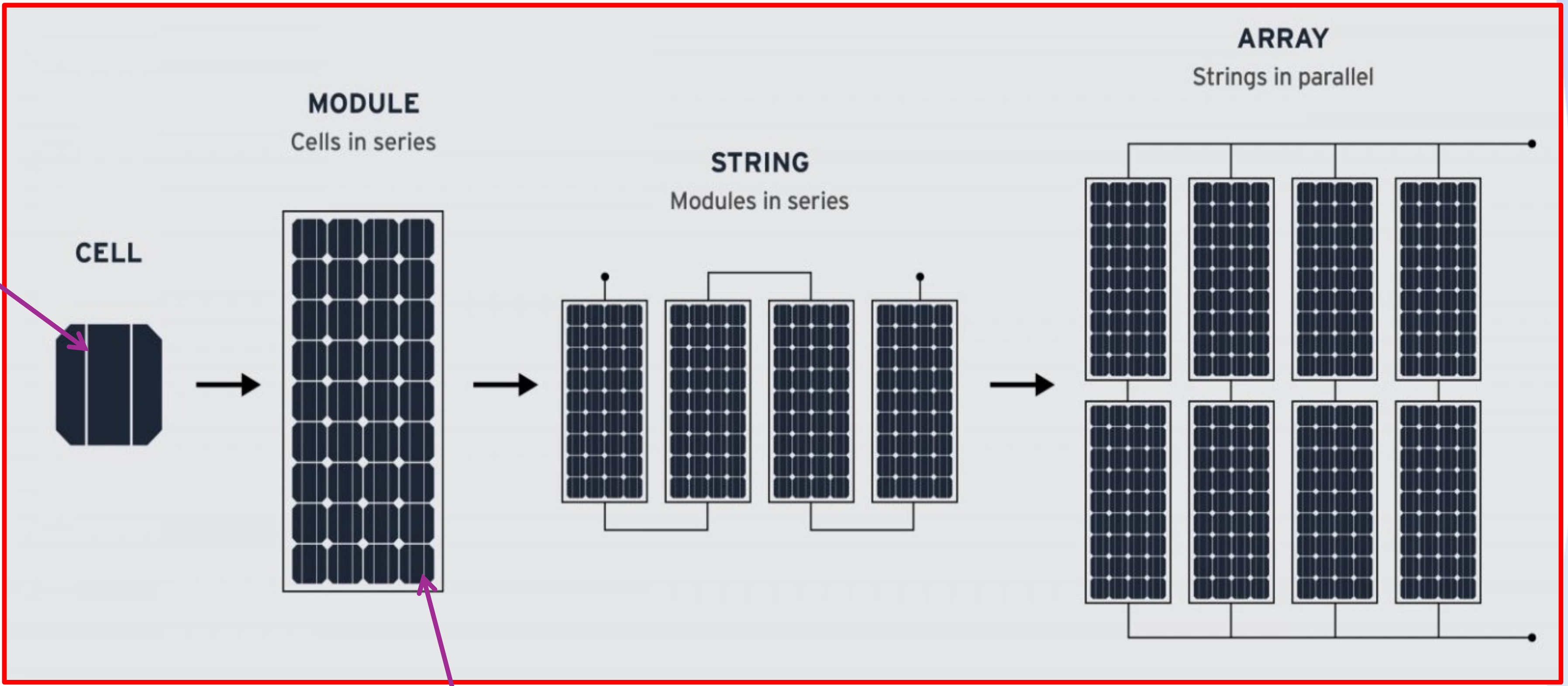


2 x 60 cells

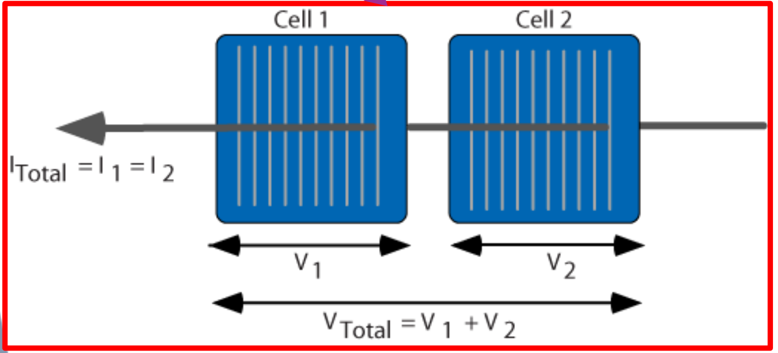
Parallel connection

An Overview of Solar Panel

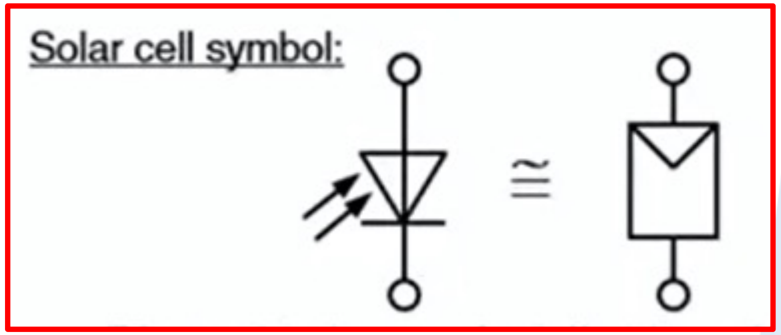
A single cell has V_{oc} = 0.5 to 0.6V at STC.



Cells are connected in series to achieve usable voltage.



Cells are connected in series to form a module.


Solar cell symbol:

An overview on solar panel

Solar cell parameters

I_{SC} = Short circuit current (Maximum Current)

- **Short-Circuit Current (Isc):** The current through the solar cell when the voltage across the cell is zero.

V_{OC} = Open circuit voltage (Maximum Voltage)

- **Open-Circuit Voltage (Voc): The maximum voltage available from a solar cell, measured when the circuit is open and no current is flowing.**

P_{MP} = Maximum Power point.

- **Maximum Power Point (Pmax):** The point on the current-voltage (I-V) curve where the product of current and voltage is maximum, indicating the highest power output.

Fill Factor (FF)

- **Fill Factor (FF):** A measure of the quality of the solar cell, defined as the ratio of the maximum power output to the product of Voc and Isc.

Cell efficiency

I_{MP} = Current at maximum power.

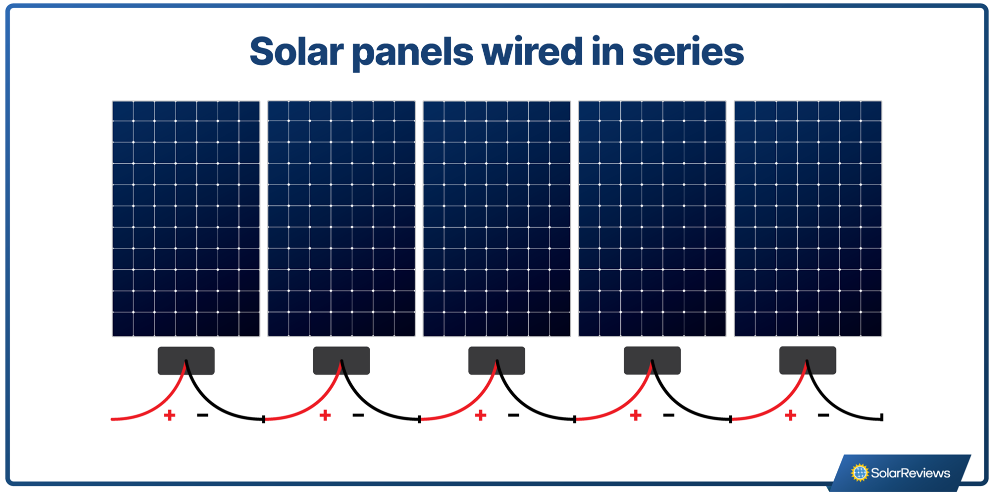
V_{MP} = Voltage at maximum power.

Parameters are measured at STC

Electrical Property of solar module

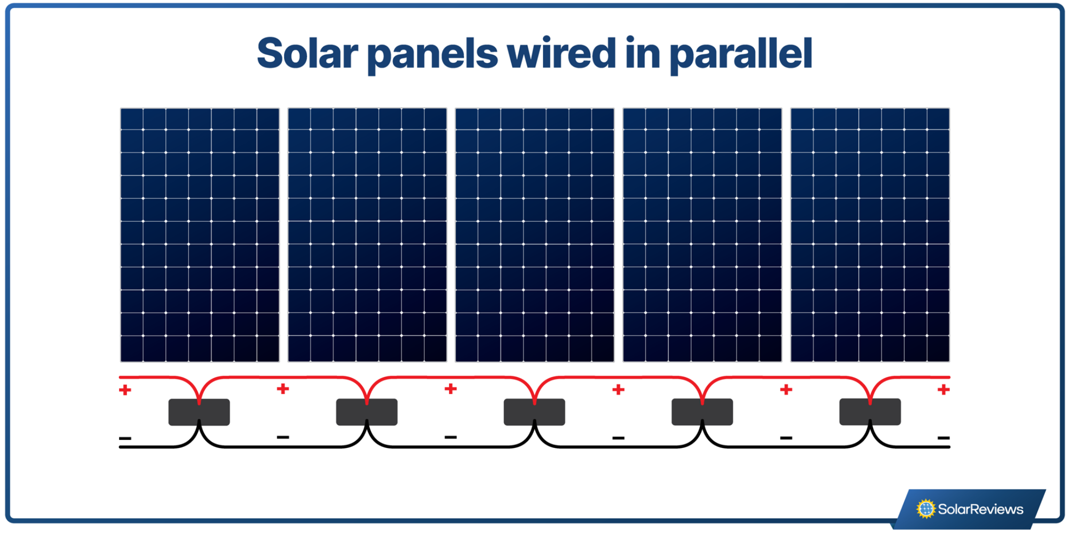
Module connection

- ○ Series Connection
- ○ Parallel Connection



Solar panels wired in series

- In series, Σ of the module voltage V.
- Current, I, stays the same.
- Limits the current.
- Shading can limit the current.

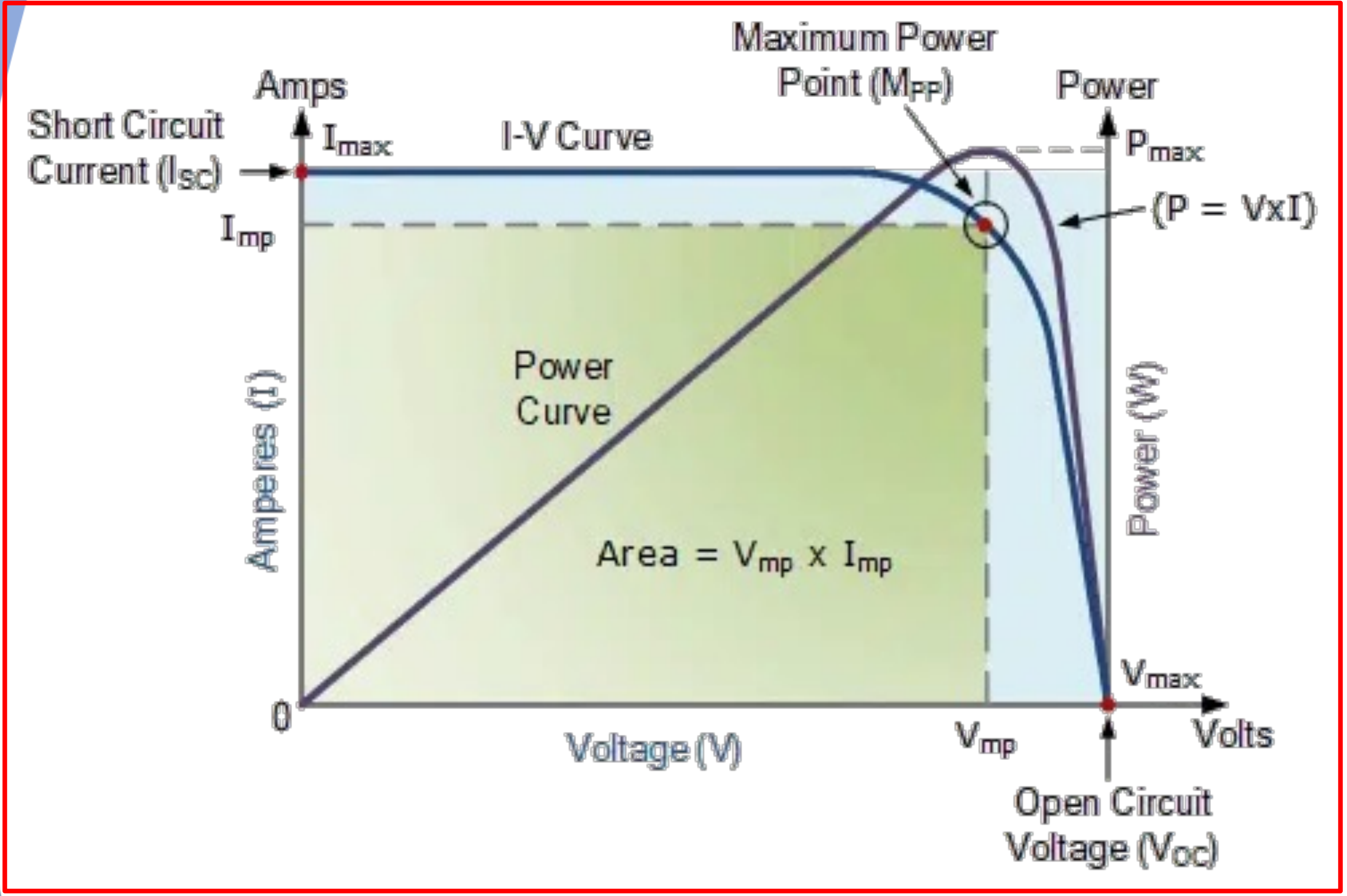


Solar panels wired in parallel

- In series, Σ of the module current I.
- High current.
- Voltage, V, stays the same.

An Overview of Solar Panel

- Understanding IV curve



Efficiency, $\eta = \frac{P\max(W)}{A\ x\ S}$,

A = Area of the module

S = Solar irradiance = 1000W/m^2

Fill Factor, $= \frac{P\max(W)}{Voc\ x\ Isc}$

- Fill factor is used to characterised the performance of the PV module. It indicates how well A PN junction was made in a PV cell. Higher FF is desirable.

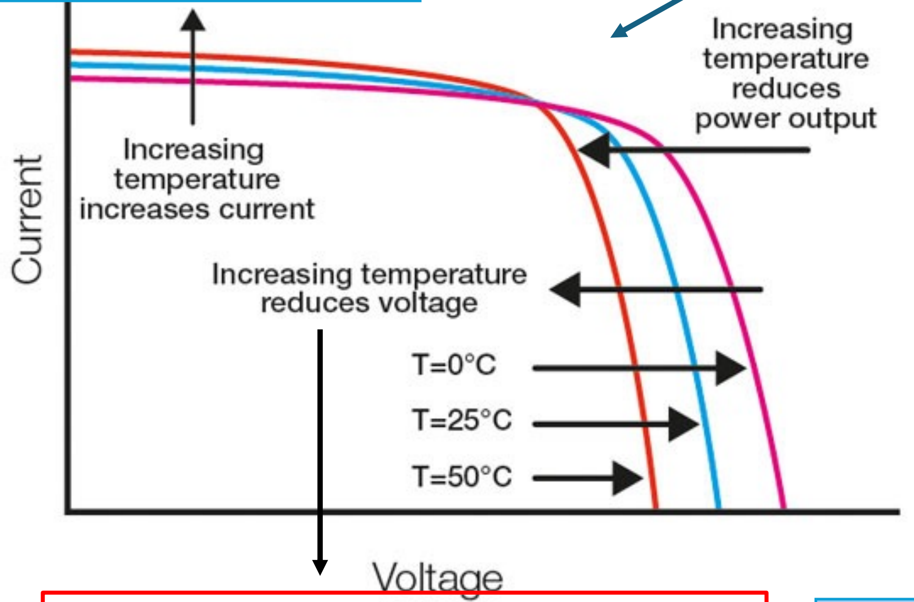
Efficiency, $\eta = \frac{FF\ X\ Voc\ X\ Isc}{A\ x\ S}$

Electrical Property of solar module

- **IV curve of PV module**

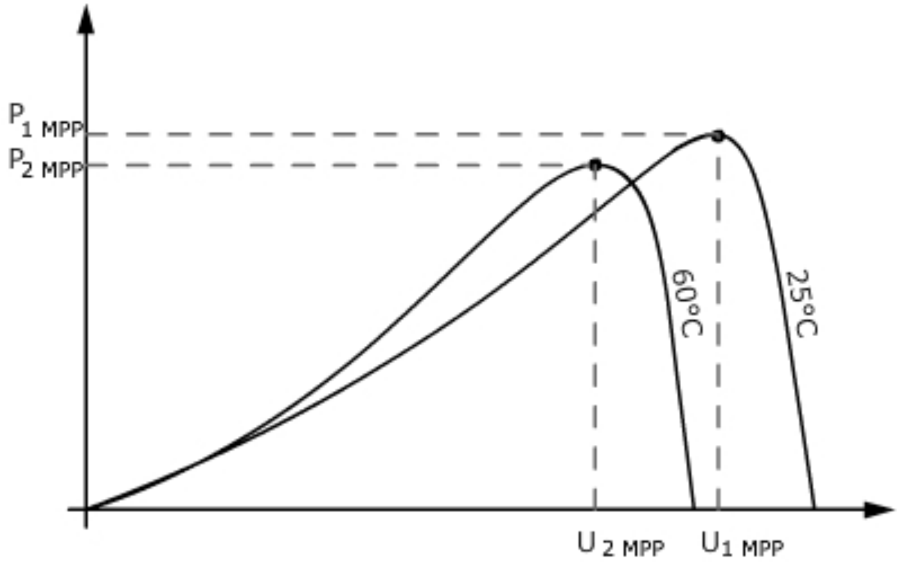
Because the increase in temperature causes more electron-hole pairs to be generated

Does any one know why?

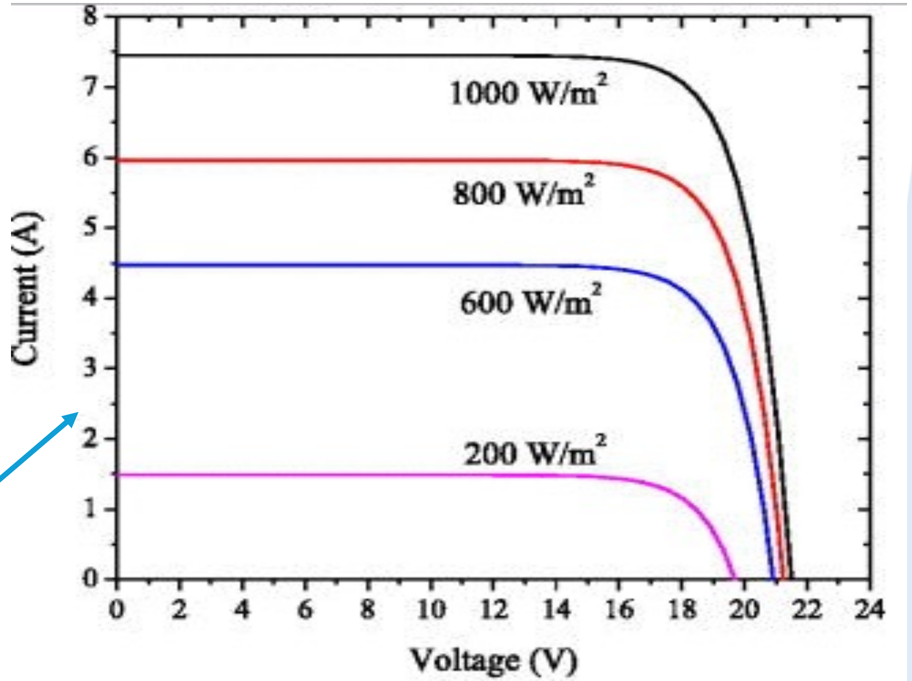


Due to the reduction of energy bandgap, and the charge carriers recombine more easily at higher temperatures

Effect of temperature to Isc and Voc



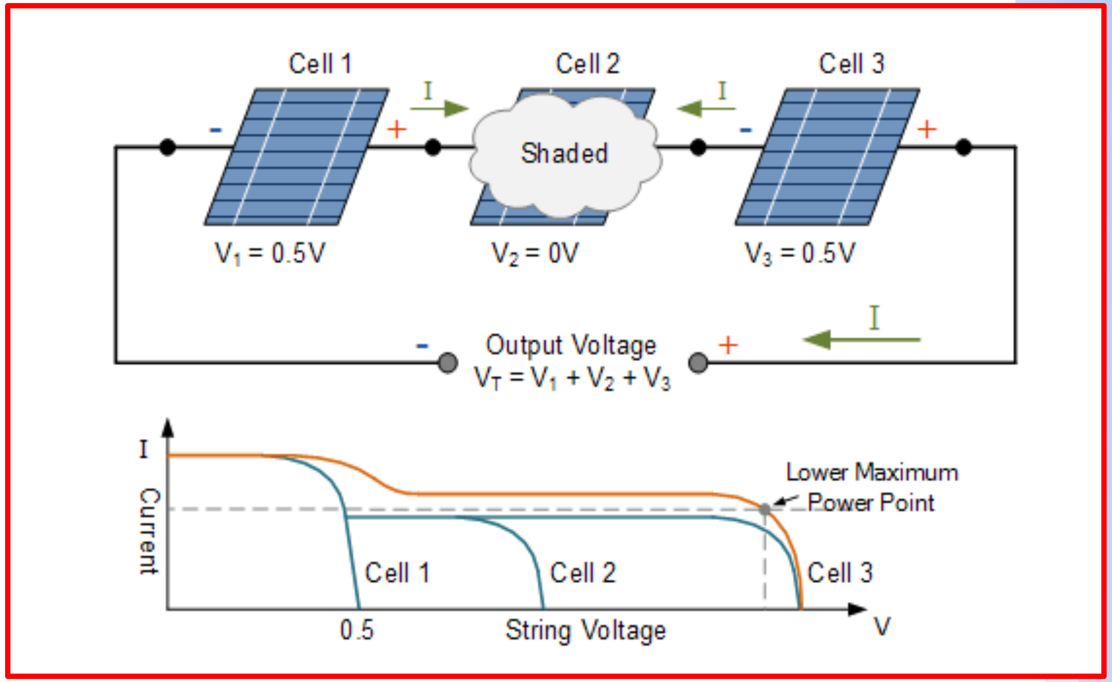
Effect of Irradiance

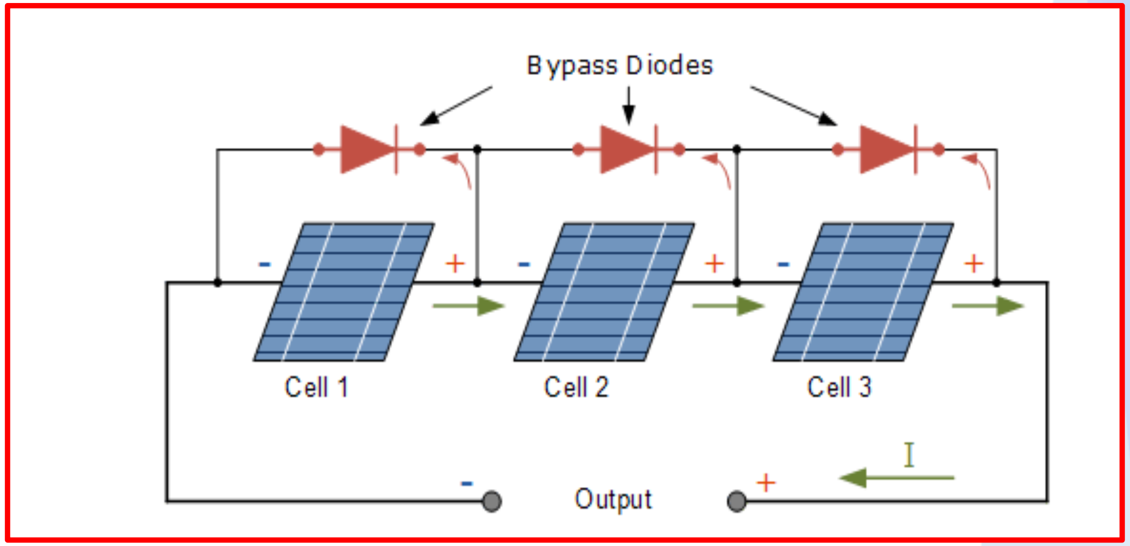


Electrical Property of solar module

Bypass Diodes and Blocking diodes

- The cells in the module are connected in series. So, the current through the cells are same. This helps to reduce ohmic losses.
- However, if one cell gets shaded, then the total current through the cells are affected. That means the current in the entire string is limited by the lowest current. Hence, impact the total power production.
- The shaded cell becomes a reversed bias and power gets dissipated through the shaded cell. This heat dissipation leads to "hot spot".
- This is called mismatch losses. Can also be caused by dirt, dust, leaves, bird droppings etc.
- This can be avoided by using a diode called Bypass Diodes. They are connected in parallel to the strings.





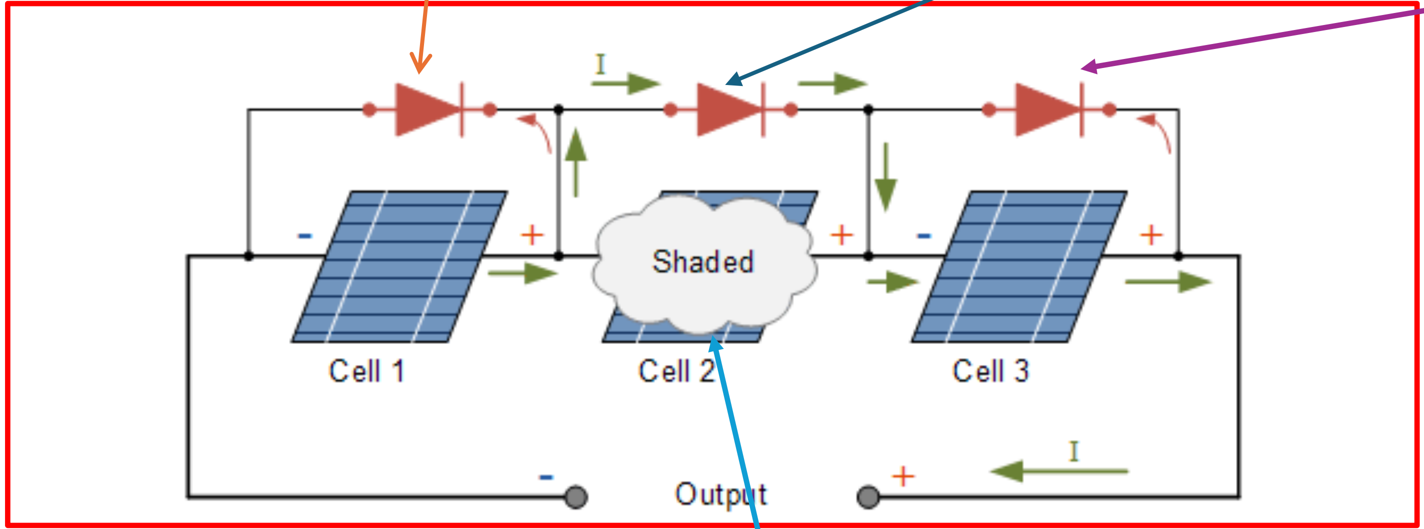
Electrical Property of solar module

Bypass Diodes and Blocking diodes

Bypass diode- Ratings
I = between 1 and 60 A.
V = up to 45V.

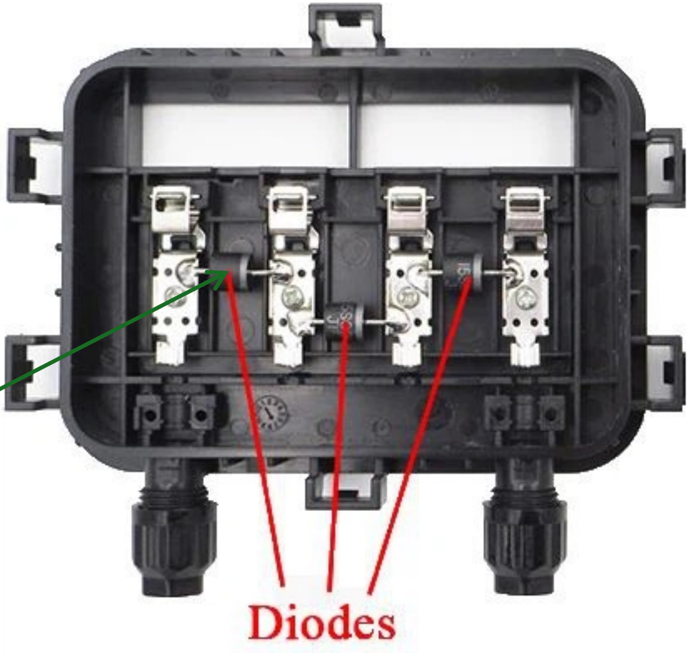
Current flow through bypass diode

Bypass diode is placed across groups or sub-strings of PV cell (typically between 16 and 24)



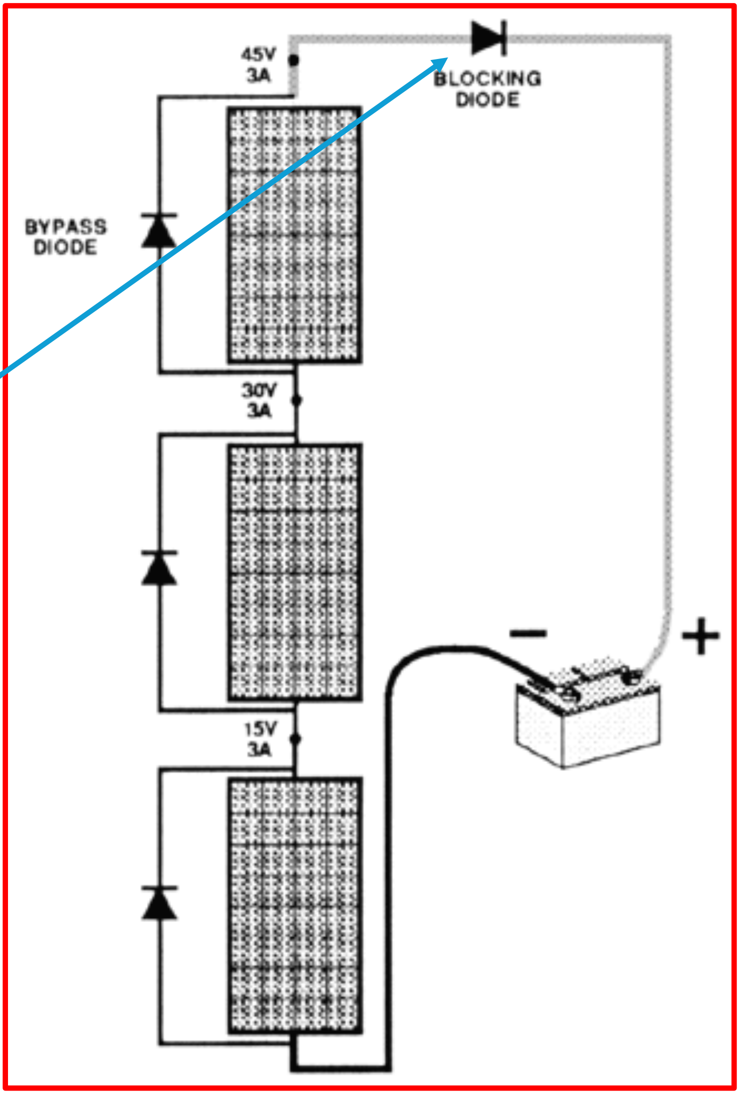
Shaded cell (reversed bias)

3 Bypass diodes – 1 diode/string.



Electrical Property of solar module

Bypass Diodes and Blocking diodes



Blocking diode – Safety measure

During the day, solar panel is at high potential.

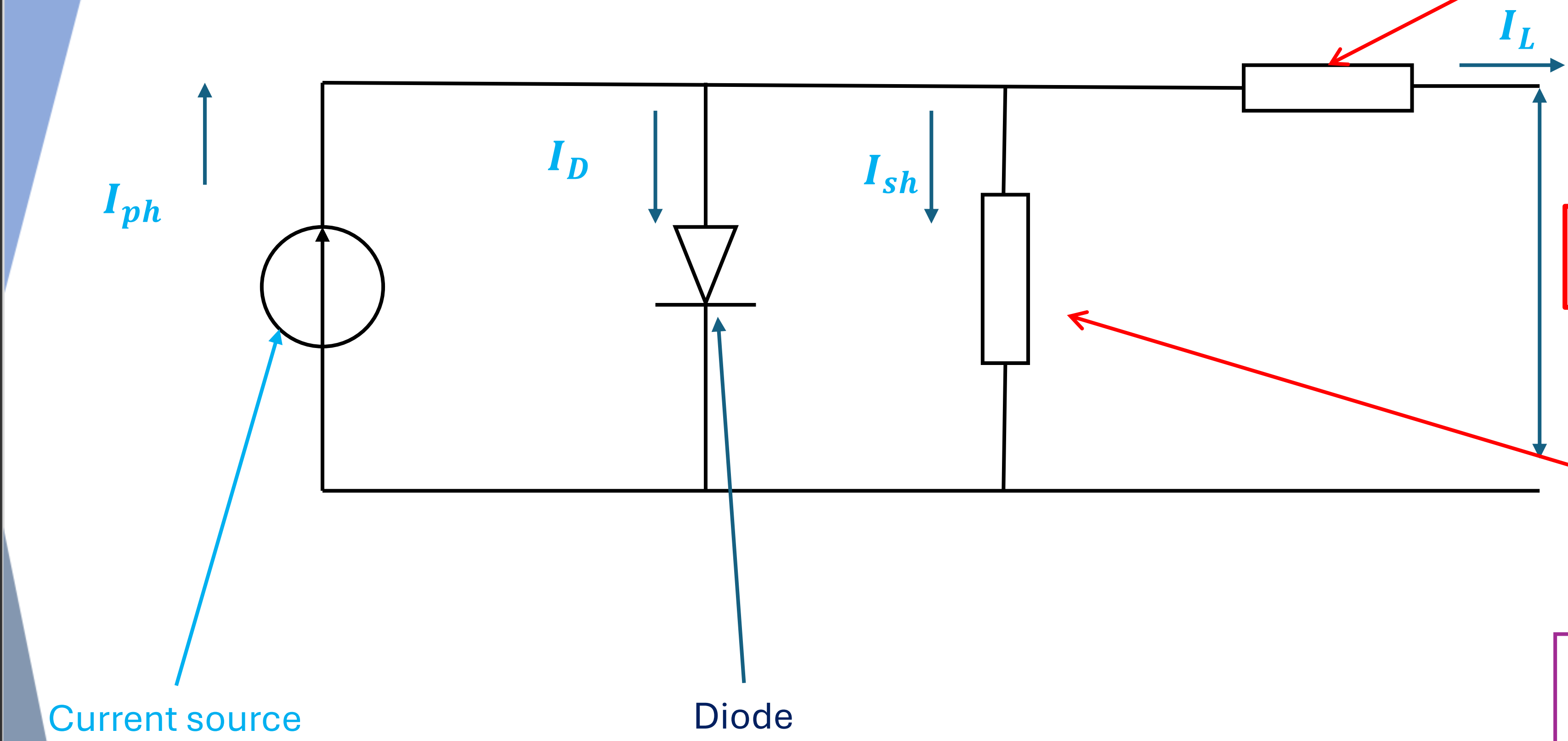
Batteries at low potential- current flows from PV to the batteries.

At night, solar does not produce energy. Thus, becomes low potential and batteries become high potential.

Current tries to flow from batteries to PV (starts to discharge). To prevent this, blocking diodes are used.

Electrical Property of solar module

- The Diode equation of a PV cell (Equivalent circuit model)



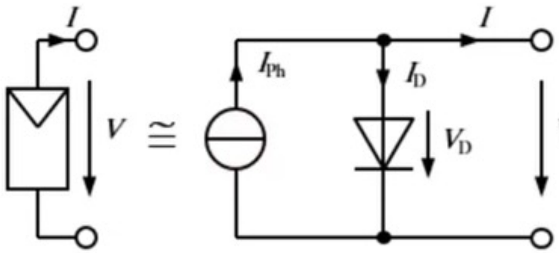
Series resistance Rs

- ❖ Rs – Defects and impurities in semiconductor.

$$I_L = \text{Iph} - \text{Id} - \text{Ish}$$

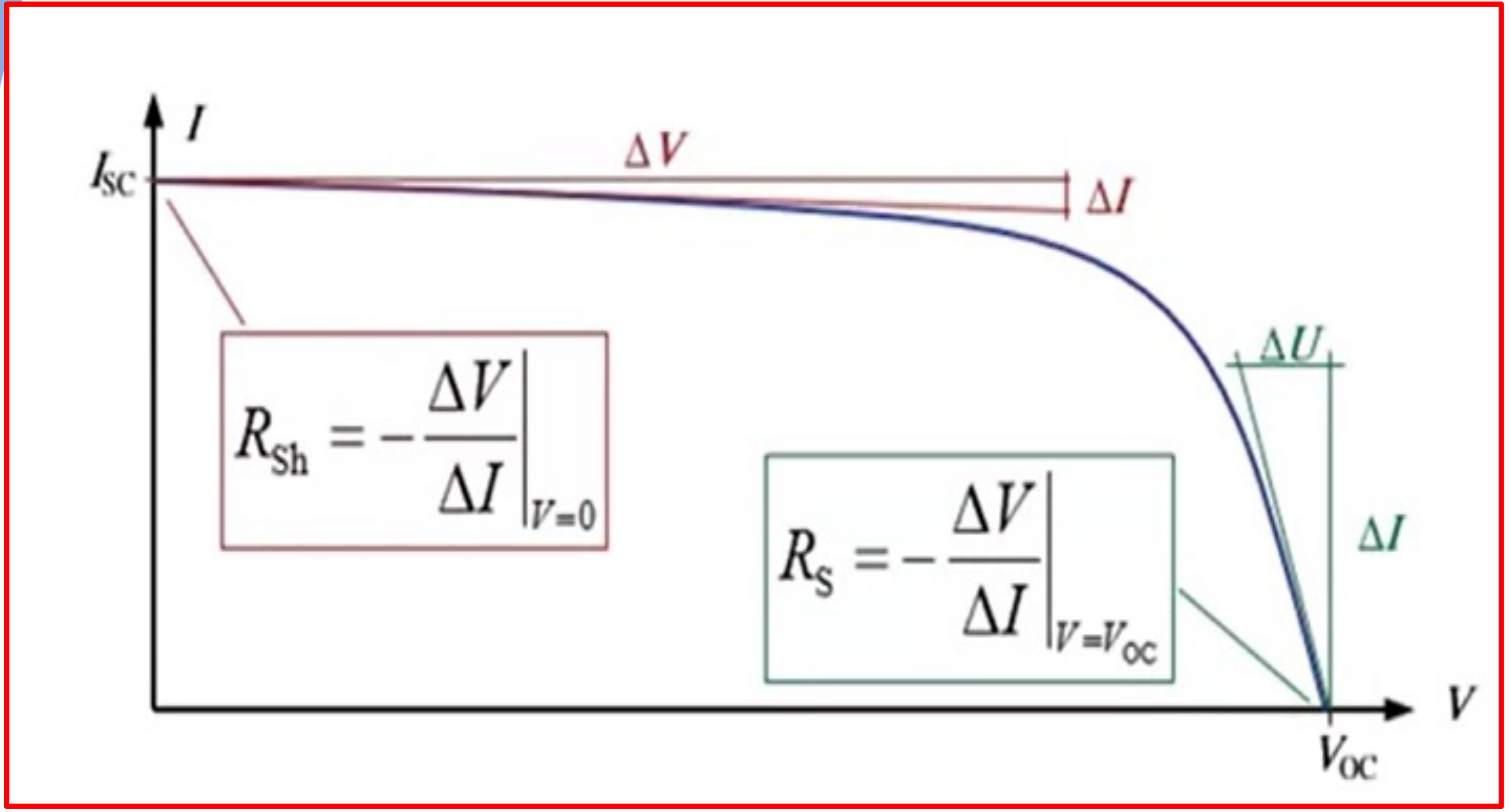
Shunt resistance (Rsh)

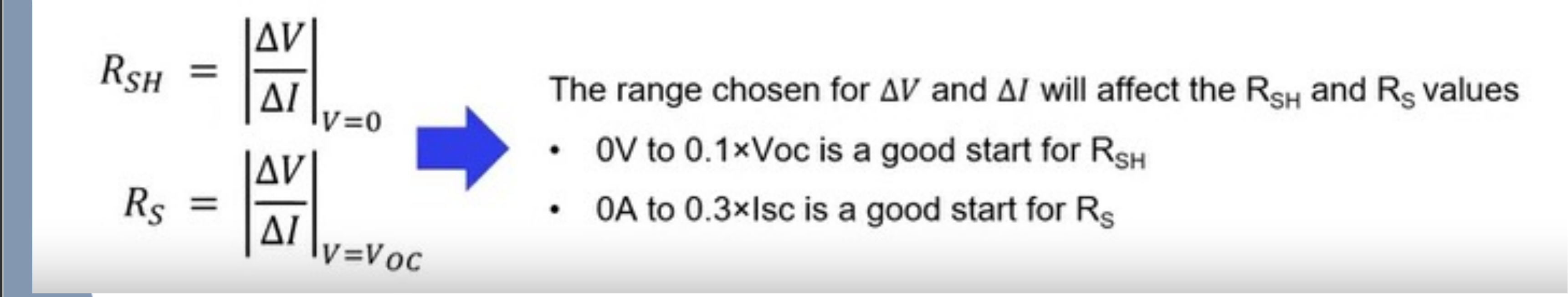
- ❖ Rsh – caused due to conductive path and resistance of the semiconductor itself. Should be low. (accounts for the internal resistive losses due to the movement of charge carriers through the cell material and contacts)



Electrical Property of solar module

- Finding shunt and series resistance from IV curve.





$$R_{SH} = \left|\frac{\Delta V}{\Delta I}\right|_{V=0}$$

$$R_S = \left|\frac{\Delta V}{\Delta I}\right|_{V=V_{OC}}$$

The range chosen for ΔV and ΔI will affect the R_{SH} and R_S values

- 0V to 0.1×Voc is a good start for R_{SH}
- 0A to 0.3×Isc is a good start for R_S

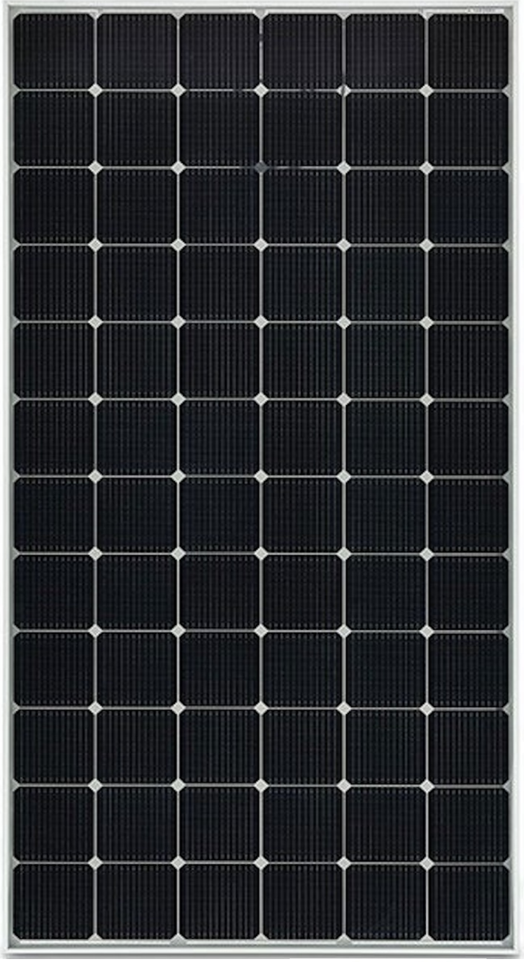
Important Notes:

- For calculating shunt resistance- recommended range of Voc is between 0% and 10%.

- For calculating series resistance- recommended range of Isc is between 0% and 30%.

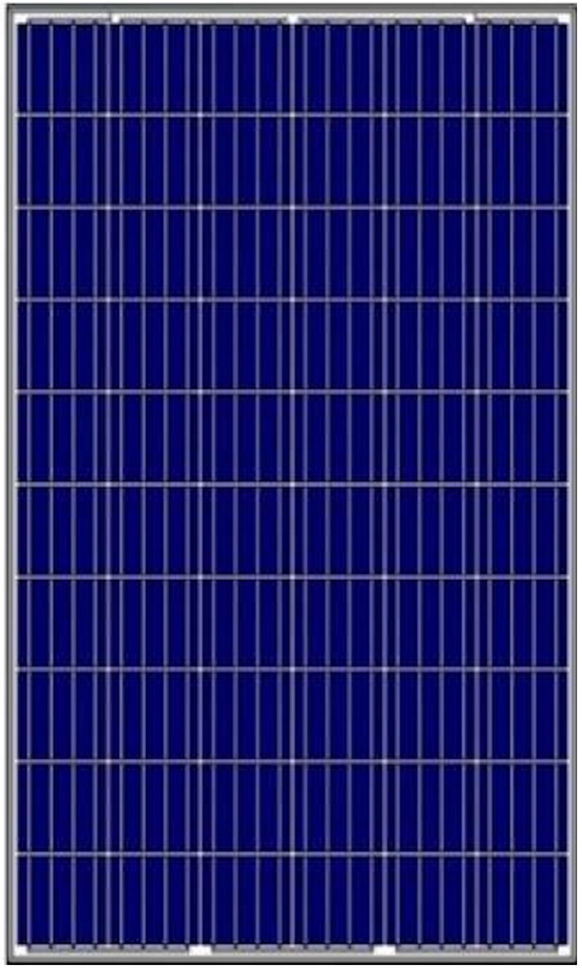
Types of Solar Panel

Monocrystalline Panel

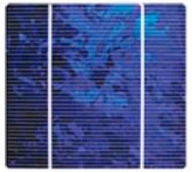


Monocrystalline Solar cell

Polycrystalline Panel



Polycrystalline Solar cell



Thin-film Panel

Thin film Solar cell

Types of Solar Panel

Type	Efficiency	Cost	Advantages	Disadvantages	Applications	Power
Monocrystalline	17% to 22%	High	High efficiency, long lifespan	Higher cost	Residential, commercial where space is limited	>375 watts
Polycrystalline	15% to 17%	Moderate	Lower cost, good efficiency	Slightly lower efficiency	Residential, commercial	between 240 watts and 300 watts
Thin-Film	10–13%	Low	Flexible, lightweight, good in high temps	Lower efficiency	Large-scale installations, BIPV, portable	

- Researchers have recently achieved 23.4% efficiency with thin film cell prototypes

References (Part 1)

1. https://www.solarreviews.com/blog/do-you-wire-solar-panels-series-or-parallel
2. https://www.4shoresolarelectrical.com.au/files/Photovoltaic_System___Panels.jpg
3. https://www.alternative-energy-tutorials.com/photovoltaics/bypass-diode.html
4. https://www.coursera.org/learn/photovoltaic-systems/lecture/V2AmP/mismatch-losses-and-bypass-diodes
5. https://www.coursera.org/learn/photovoltaic-systems/lecture/Ag2b1/the-non-ideal-diode-equation

Energy Storage for PV system – Battery (Part 2)

Learning objective

This lecture is to learn about battery as storage for PV system

- ☐ **Introduction to Battery.**
- ☐ **Types of Batteries – Primary and Secondary.**
- ☐ **Nominal voltage and capacity.**
- ☐ **C rate, Energy and Power.**
- ☐ **Battery life – Cycle and Calander life.**
- ☐ **Battery conditions.**
- ☐ **Battery connection – series and parallel.**
- ☐ **System losses.**
- ☐ **Battery sizing in PV system.**

Battery application in PV

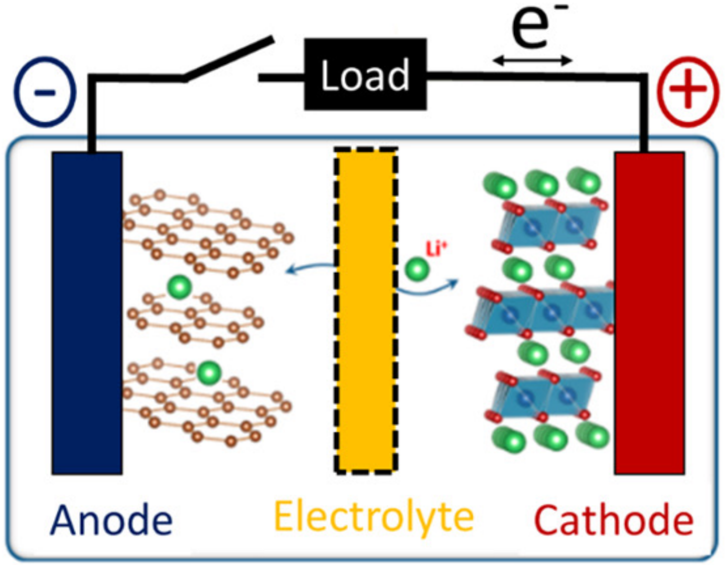
Introduction to Battery

- ❑ A device that store energy which can be later used to deliver powe to the appliances or other purposes.
- ❑ Stores energy in the form of chemical energy and then transform t electrical energy (electrochemistry).
- ❑ The basis for a battery operation is the exchange of electron between two chemical reactions, an oxidation reaction and reduction reaction
- ❑ A battery consists of group of two or more cells.
- ❑ The cells can be wired together in series, parallel or combination o both.
- ❑ Sometimes they are packaged in a single physical unit. For example, a 12V lead-acid consists of 6cells -2V per cell.
- ❑ Portable device.

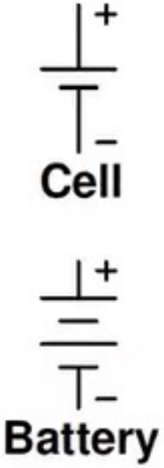
Two types of Batteries

- ○ Primary Batteries.
- ○ Secondary Batteries.
- ➢ Primary batteries are just for once time usage.
- ➢ Secondary batteries are reusable (rechargeable battery).

Basic structure of a battery



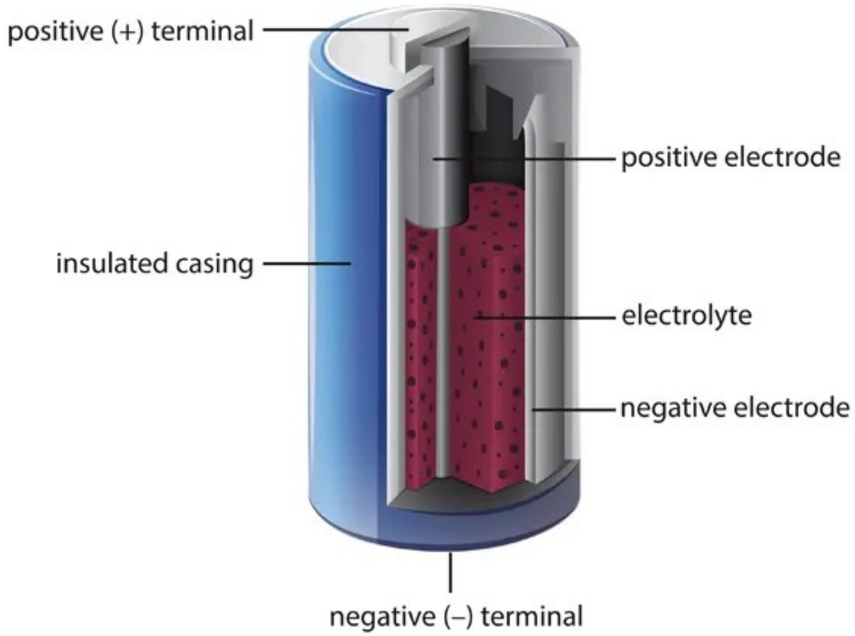
Schematic symbol of a cell and a battery.



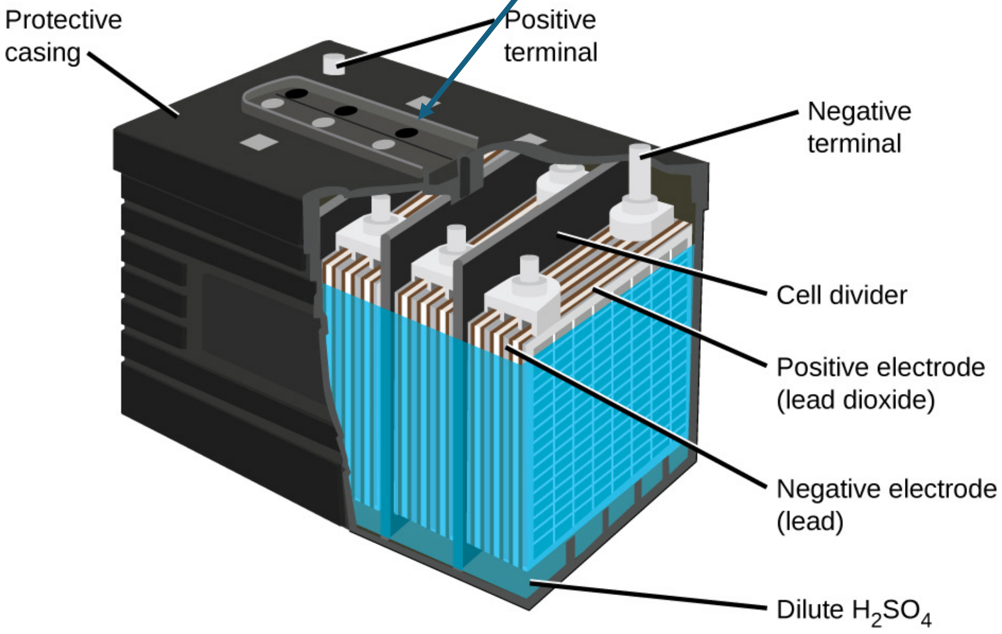
Battery application in PV

Types of battery – Primary and Secondary

The cathode and anode of primary battery



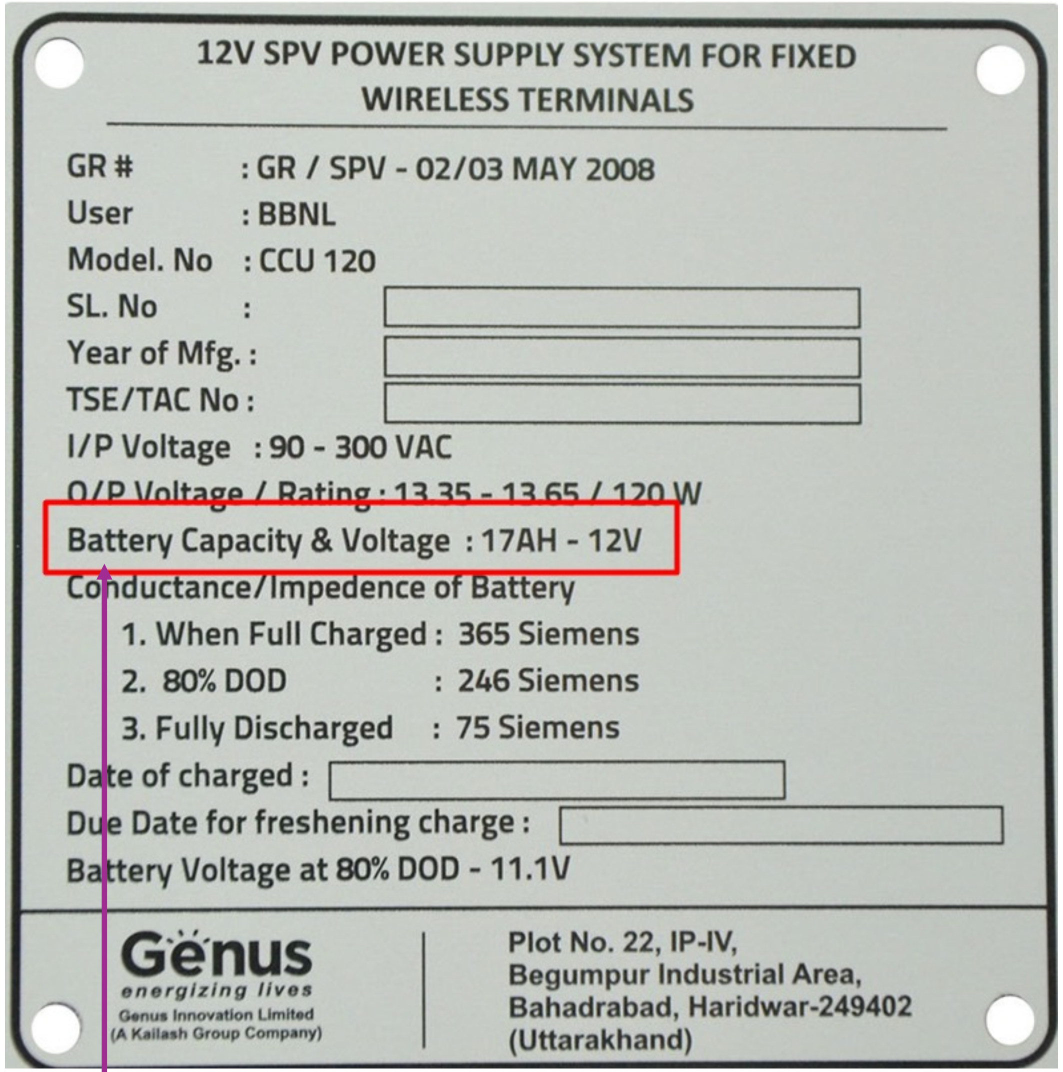
Basic structure of a lead-acid battery (secondary)



Battery application in PV

Nominal Voltage and Capacity

- Nominal voltage of a battery depends on the chemicals used in the cell.
- Nickel-based cells have 1.2V (primary battery- Dry cell) (Nickel cadmium -NiCad, Nickel metal hydride – NiMH)
- Lithium based cell over 3V (primary or secondary).
- Cell capacity – expressed as Ah (ampere hours) or milliampere hours mAh. If the rating of a battery is 1Ah, it means fully charged cell will deliver 1A for 1hour to be fully discharged.



12V SPV POWER SUPPLY SYSTEM FOR FIXED WIRELESS TERMINALS

GR # : GR / SPV - 02/03 MAY 2008
User : BBNL
Model. No : CCU 120
SL. No :
Year of Mfg. :
TSE/TAC No :
I/P Voltage : 90 - 300 VAC
O/P Voltage / Rating : 13.35 - 13.65 / 120 W
Battery Capacity & Voltage : 17AH - 12V
Conductance/Impedence of Battery
1. When Full Charged : 365 Siemens
2. 80% DOD : 246 Siemens
3. Fully Discharged : 75 Siemens
Date of charged :
Due Date for freshening charge :
Battery Voltage at 80% DOD - 11.1V

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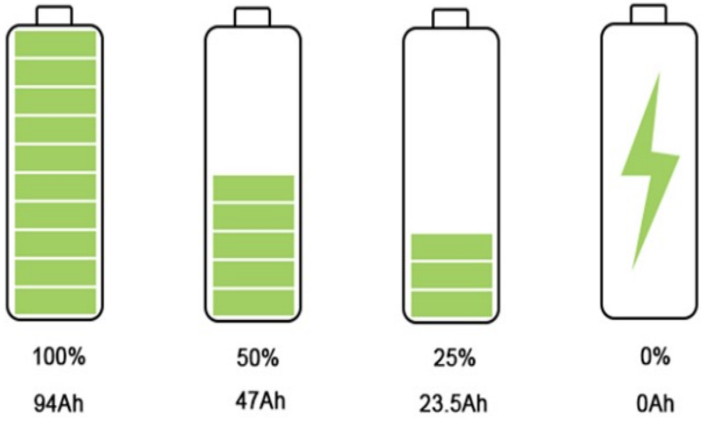
Nominal voltage and capacity of a battery

Battery application in PV

C rate, Energy and Power

- A C-rate is a measure of the rate at which a battery is charged or discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. A 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps.
- It is the constant-current charge or discharge rate the cell can sustain for 1 hour.
- A cells stores energy in the form of electrochemical form.
- The total energy capacity is voltage x capacity = V x Ah = Wh or kWhr or mWh.
- The energy storage capacity of a battery from the battery nameplate = 12V x 17Ah = 201Wh.

This understanding on energy and power will be handy when we will learn sizing the battery bank for your load.



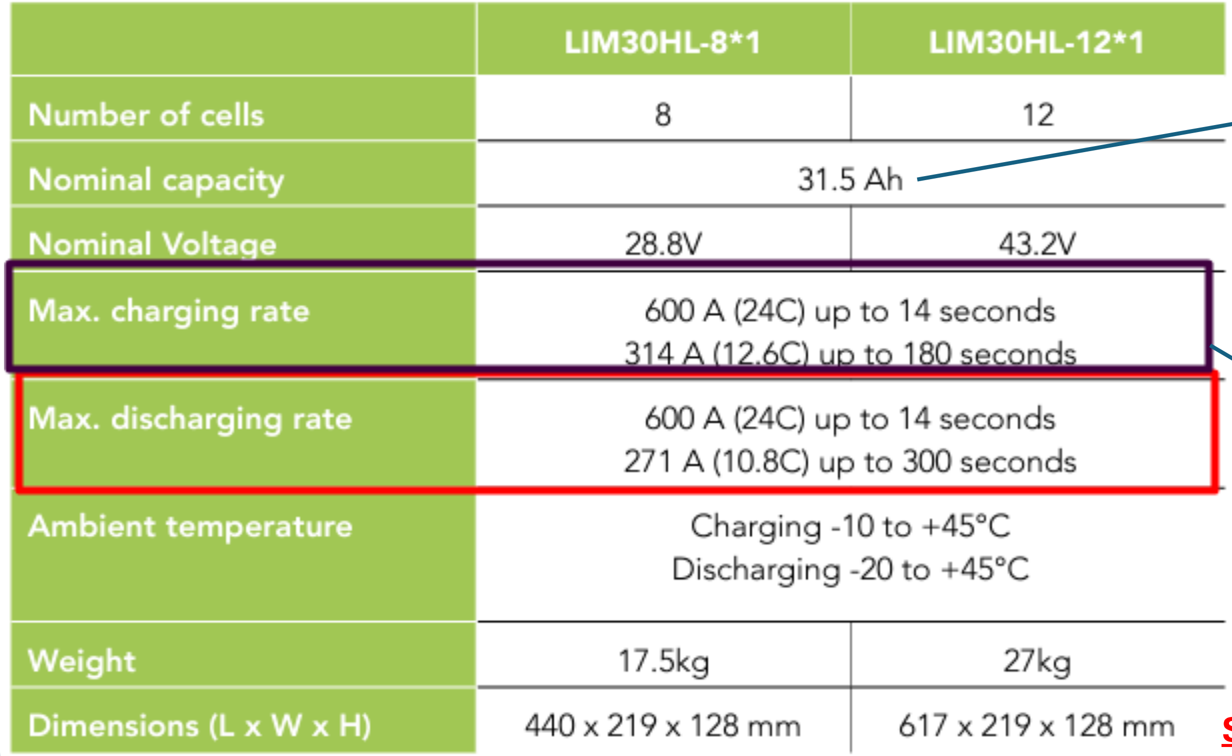
Battery application in PV

❖ C-Rate example and understanding C-Rate from Battery Data sheet

Exercise: A battery is rated 100Ah 1C rate. What will be the duration to discharge if it draws 5 times the current?

Solution:

100Ah – 1C means 100A will be discharged in 1 hour. If 500A current is drawn it will take 100/500 = 0.2 hour.



	LIM30HL-8*1	LIM30HL-12*1
Number of cells	8	12
Nominal capacity	31.5 Ah	
Nominal Voltage	28.8V	43.2V
Max. charging rate	600 A (24C) up to 14 seconds 314 A (12.6C) up to 180 seconds	
Max. discharging rate	600 A (24C) up to 14 seconds 271 A (10.8C) up to 300 seconds	
Ambient temperature	Charging -10 to +45°C Discharging -20 to +45°C	
Weight	17.5kg	27kg
Dimensions (L x W x H)	440 x 219 x 128 mm	617 x 219 x 128 mm

Nominal capacity = 31.5Ah

- The C-rate of 24C means the charging current is 24 times the battery's rated capacity, which is 24 x 31.5Ah = 756A.
- This indicates the maximum duration for which the 600A - 24C charging can be applied.
- In this case, the 600A - 24C charging can be applied for up to 14 seconds.
- This specification is that the 31.5Ah battery can be charged with a very high current (600A) for a short period of time (up to 14 seconds), at a very high C-rate (24C, which is 756A).

Summery: The 31.5Ah battery can be charged with a high current of 600A, which corresponds to a high C-rate (though less than the maximum theoretical 24C rate of 756A). This high current can be sustained for up to 14 seconds. This means the battery is designed to handle rapid charging for short bursts without being damaged

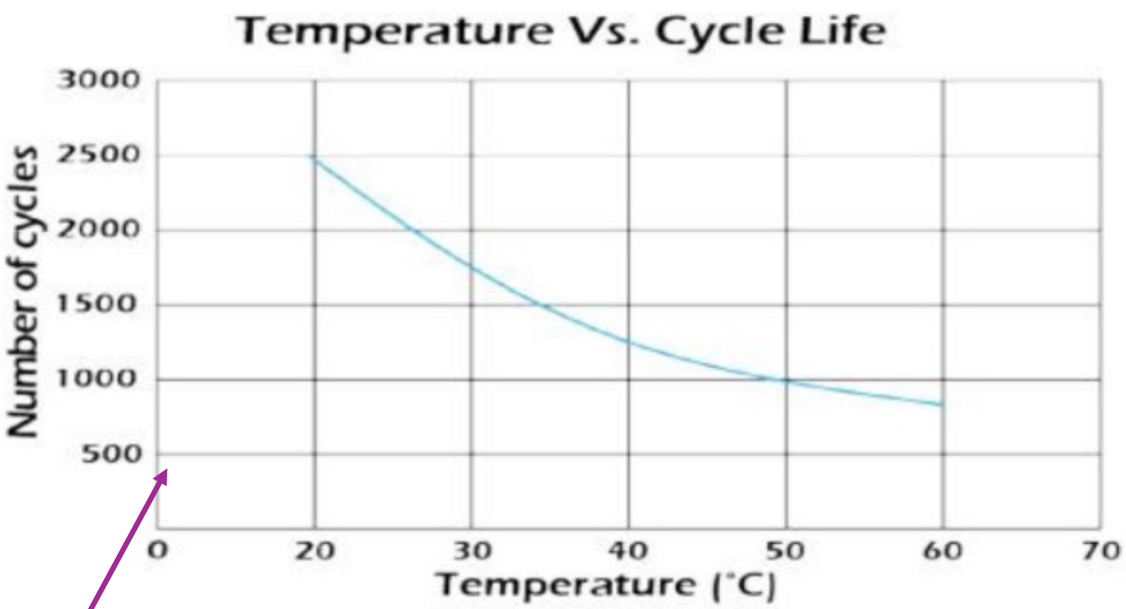
Battery application in PV

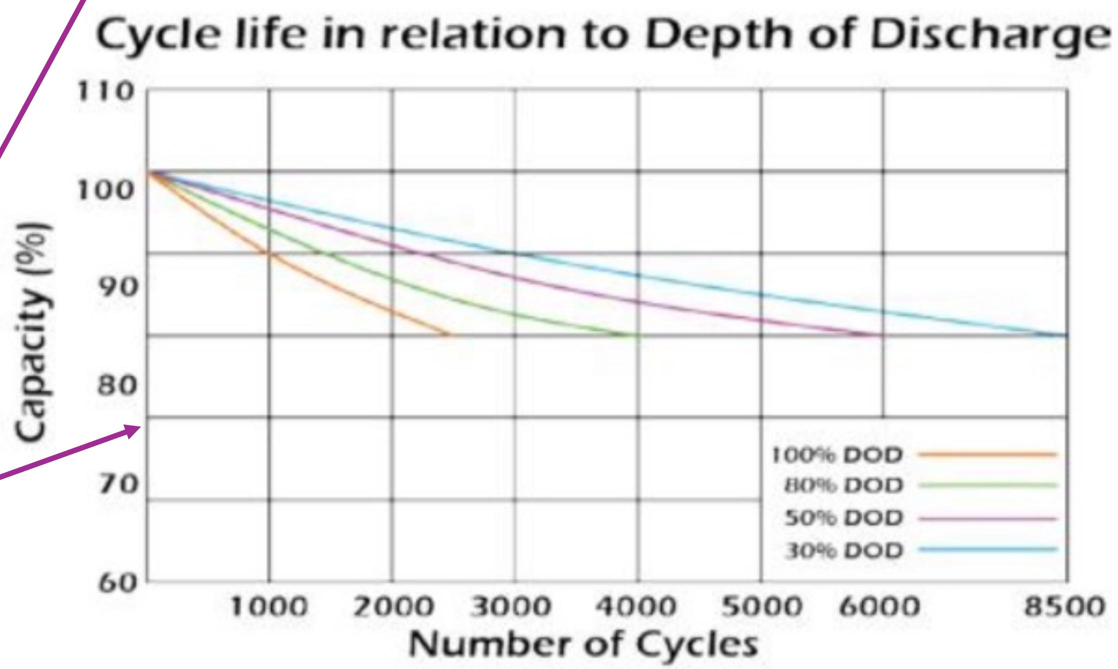
Battery life

- ☐ The number of charging and discharging cycles until its capacity loss reached (typically 20 to 30% of its initial capacity).
- ☐ Two main terms related to battery life – ***Cycle life*** and **Calendar life**.

Cycle Life:

- ❖ Cycle life refers to the number of charge-discharge cycles a battery can undergo before its capacity degrades to a certain level, usually 80% of the original capacity.
- ❖ A charge-discharge cycle is when the battery is charged from a low state of charge to a full state of charge, and then discharged back to a low state of charge.
- ❖ With every cycle there will be a tiny amount of irreversibility set in.
- ❖ Cycle life is an important metric for rechargeable batteries, as it determines how many times the battery can be used before it needs to be replaced.
- ❖ Factors that affect cycle life include the depth of discharge (DoD), charge/discharge rates, operating temperature, and the battery chemistry.
- ❖ Depth of Discharge is a measure of how much of a battery's capacity has been used. It is typically expressed as a percentage of the total battery capacity. For example, if a battery has a capacity of 100 kWh and you use 30 kWh, the Depth of Discharge is 30%
- ❖ Generally, batteries with lower DoD and gentler charge/discharge rates will have a longer cycle life.

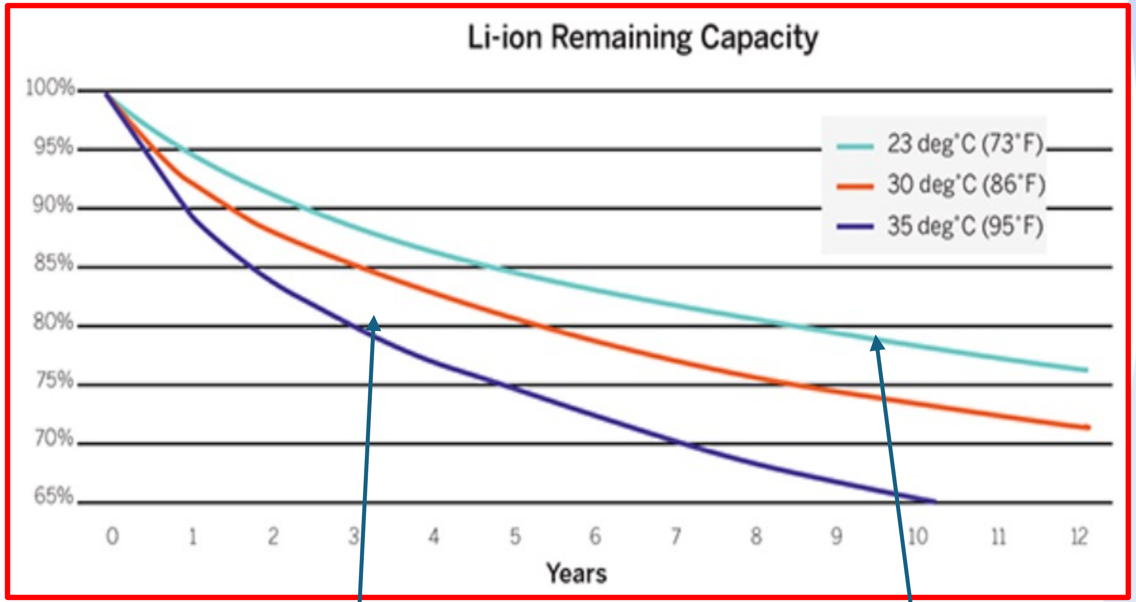




Battery application in PV

Calendar life:

- ☐ Calendar life refers to the expected lifespan of a battery, even if it's not used or cycled.
- ☐ It's influenced by factors like storage temperature, state of charge, and the battery's internal chemical and physical changes over time.
- ☐ Storing batteries at higher states of charge and higher temperatures can accelerate calendar life degradation through increased self-discharge and side reactions.
- ☐ Lower storage temperatures (e.g., 15-25°C) and lower states of charge (e.g., 30-50%) can help extend calendar life.
- ☐ Calendar life is especially important for batteries used in backup or standby applications, where they may sit idle for long periods.
- ☐ Some battery chemistries, like lithium-ion, have better calendar life compared to others, like lead-acid.



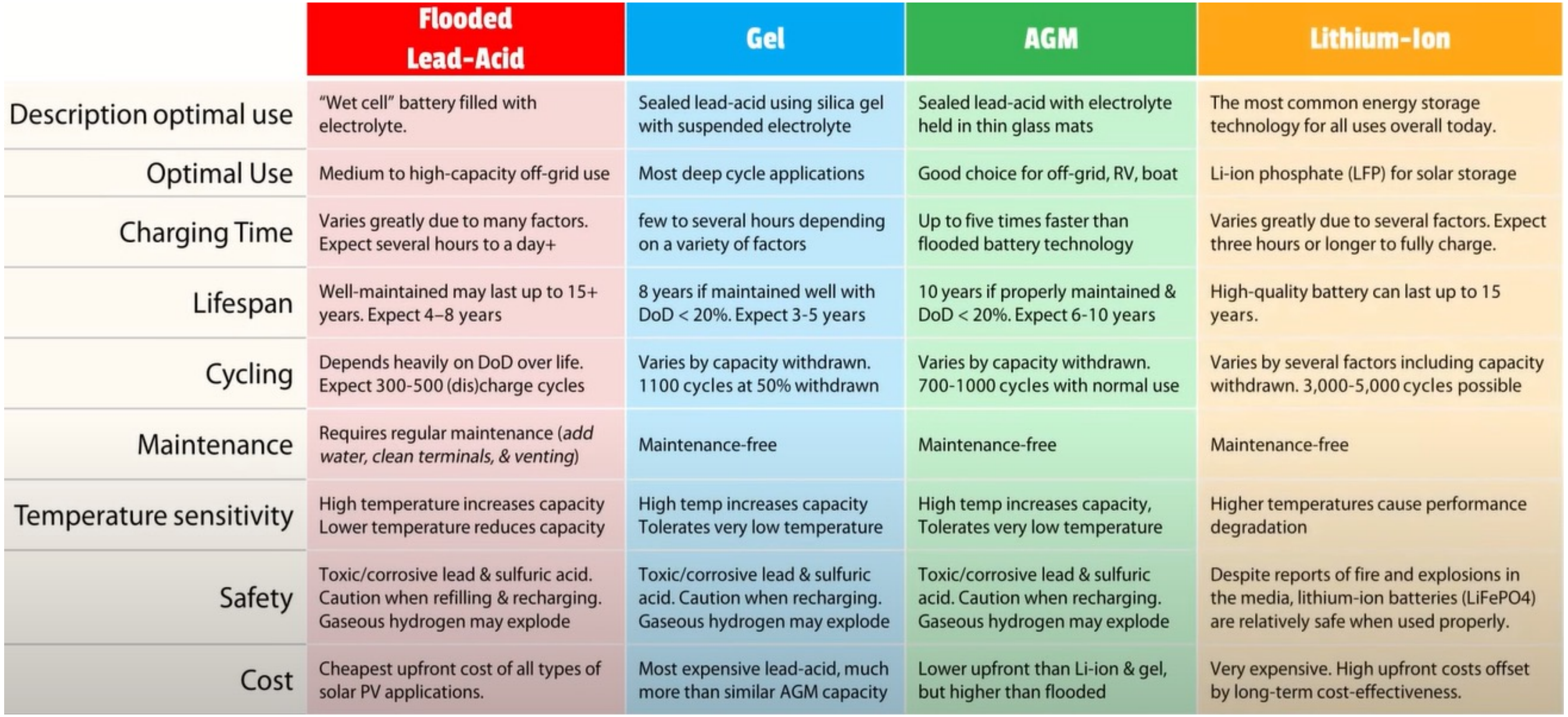
At 35 degree, the battery reached 80% of its capacity in about 3 years.

At 23 degree, the battery reached 80% of its capacity in about 9 years (3 times more).

Battery application in PV

❖ Battery cycle and calendar life

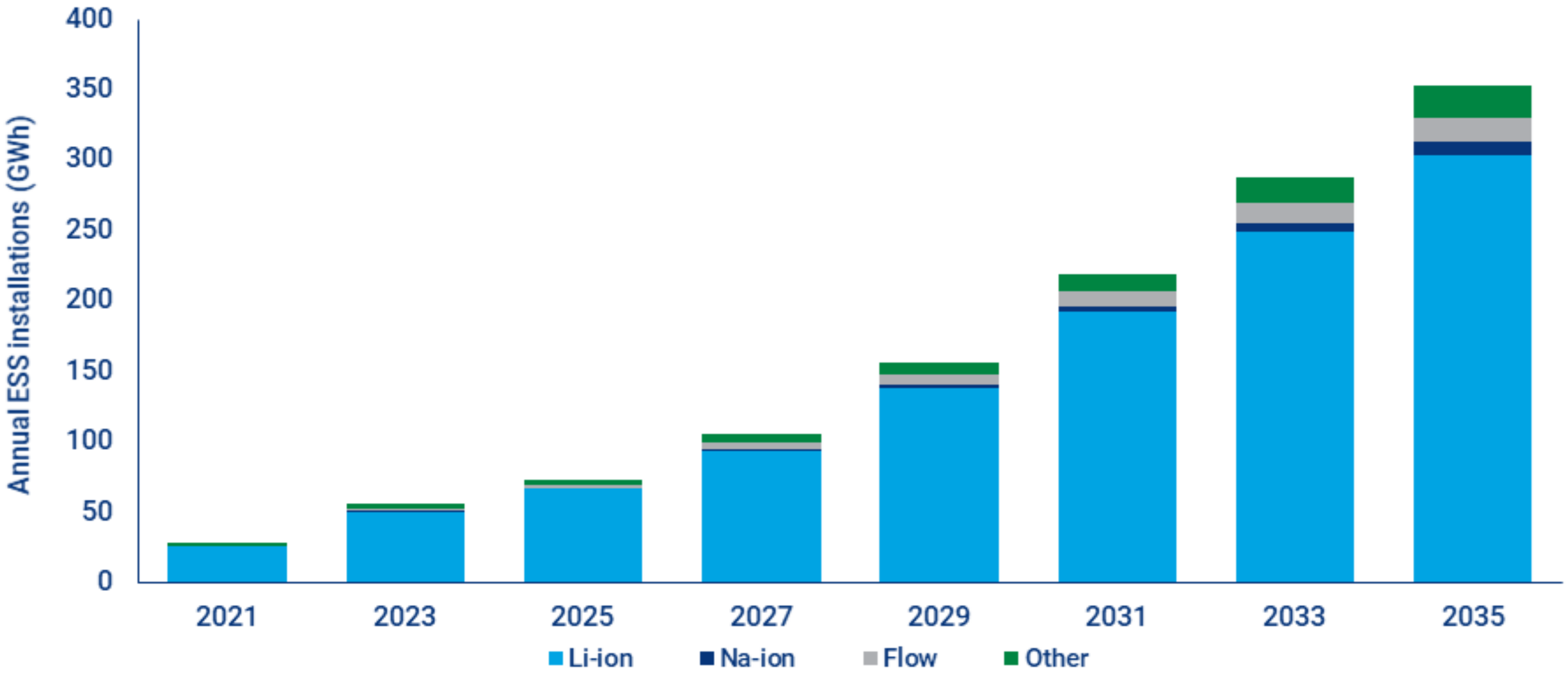
- It's important to note that both cycle life and calendar life are affected by the battery's operating conditions and usage patterns. Proper battery management, including charging strategies, temperature control, and depth of discharge, can help extend the overall life of a battery.
- Manufacturers typically provide estimates or specifications for both cycle life and calendar life, which can help users understand the expected lifespan of a battery and plan for replacements accordingly.
- Many battery technologies are currently available on the market, the most common batteries are ***lead acid which includes – Flooded lead acid, Gel lead acid and Absorbed glass mat (AGM) and Lithium-ion***.



	Flooded Lead-Acid	Gel	AGM	Lithium-Ion
Description optimal use	"Wet cell" battery filled with electrolyte.	Sealed lead-acid using silica gel with suspended electrolyte	Sealed lead-acid with electrolyte held in thin glass mats	The most common energy storage technology for all uses overall today.
Optimal Use	Medium to high-capacity off-grid use	Most deep cycle applications	Good choice for off-grid, RV, boat	Li-ion phosphate (LFP) for solar storage
Charging Time	Varies greatly due to many factors. Expect several hours to a day+	few to several hours depending on a variety of factors	Up to five times faster than flooded battery technology	Varies greatly due to several factors. Expect three hours or longer to fully charge.
Lifespan	Well-maintained may last up to 15+ years. Expect 4–8 years	8 years if maintained well with DoD < 20%. Expect 3-5 years	10 years if properly maintained & DoD < 20%. Expect 6-10 years	High-quality battery can last up to 15 years.
Cycling	Depends heavily on DoD over life. Expect 300-500 (dis)charge cycles	Varies by capacity withdrawn. 1100 cycles at 50% withdrawn	Varies by capacity withdrawn. 700-1000 cycles with normal use	Varies by several factors including capacity withdrawn. 3,000-5,000 cycles possible
Maintenance	Requires regular maintenance *(add water, clean terminals, & venting)*	Maintenance-free	Maintenance-free	Maintenance-free
Temperature sensitivity	High temperature increases capacity Lower temperature reduces capacity	High temp increases capacity Tolerates very low temperature	High temp increases capacity, Tolerates very low temperature	Higher temperatures cause performance degradation
Safety	Toxic/corrosive lead & sulfuric acid. Caution when refilling & recharging. Gaseous hydrogen may explode	Toxic/corrosive lead & sulfuric acid. Caution when recharging. Gaseous hydrogen may explode	Toxic/corrosive lead & sulfuric acid. Caution when recharging. Gaseous hydrogen may explode	Despite reports of fire and explosions in the media, lithium-ion batteries (LiFePO4) are relatively safe when used properly.
Cost	Cheapest upfront cost of all types of solar PV applications.	Most expensive lead-acid, much more than similar AGM capacity	Lower upfront than Li-ion & gel, but higher than flooded	Very expensive. High upfront costs offset by long-term cost-effectiveness.

Battery application in PV

- ❖ Global energy storage systems – Dominated by Li-ion battery and will be dominated for next 10 years.



Lithium-ion dominates energy storage installations, though newer tech will gain traction long-term

Global energy storage systems annual installations by type

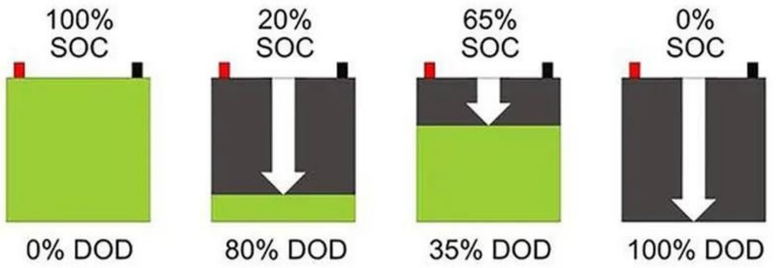
Source: Wood Mackenzie

Battery application in PV

❖ Battery Condition

This section describes some of the variables used to describe the present condition of a battery.

- State of Charge (SOC)(%) – An expression of the present battery capacity as a percentage of maximum capacity.
- State of Health (SOH) - a measure of the overall health and performance of a battery over time. It reflects the battery's ability to hold a charge and deliver its rated capacity. A battery with a high SoH will be able to hold a charge for a longer period of time and will have a longer overall lifespan than a battery with a low SoH.
- Depth of Discharge (DOD) (%) – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80 % DOD is referred to as a deep discharge.
- Cycle Life (number for a specific DOD) – The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria.
- Battery efficiency: No battery is 100% efficient. Energy is lost in storage, charging and discharging. Its efficiency is a measure of energy loss in the entire discharge/recharge cycle eg. For an 80% efficient battery, for every 100kWh put into the battery, only 80kWh can be taken out.
- Battery Autonomy: The period the battery will last for at specific load without taking power externally (charging).



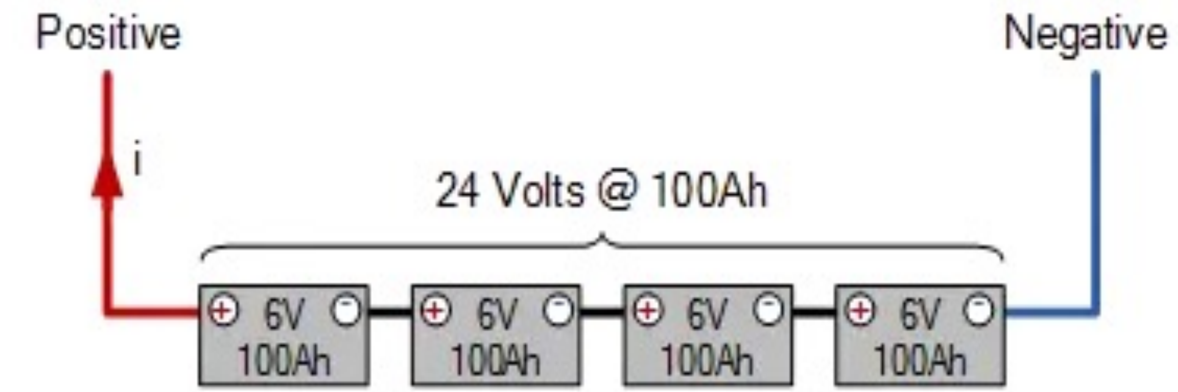
Data sheet will have this information.

Battery application in PV

- **Battery connection - Series and Parallel.**

☐ The batteries can be connected in series or parallel.

Series connection of batteries.



In series, the voltage per battery is added.

In series, the batteries should have same ampere-hour (Ah) rating.

If different ratings are used, then the output current will be determined by the lowest rating.

Why is the capacity not added?

☐ In series, the current is same through the cell. So, the cells will be discharged at the same rate.

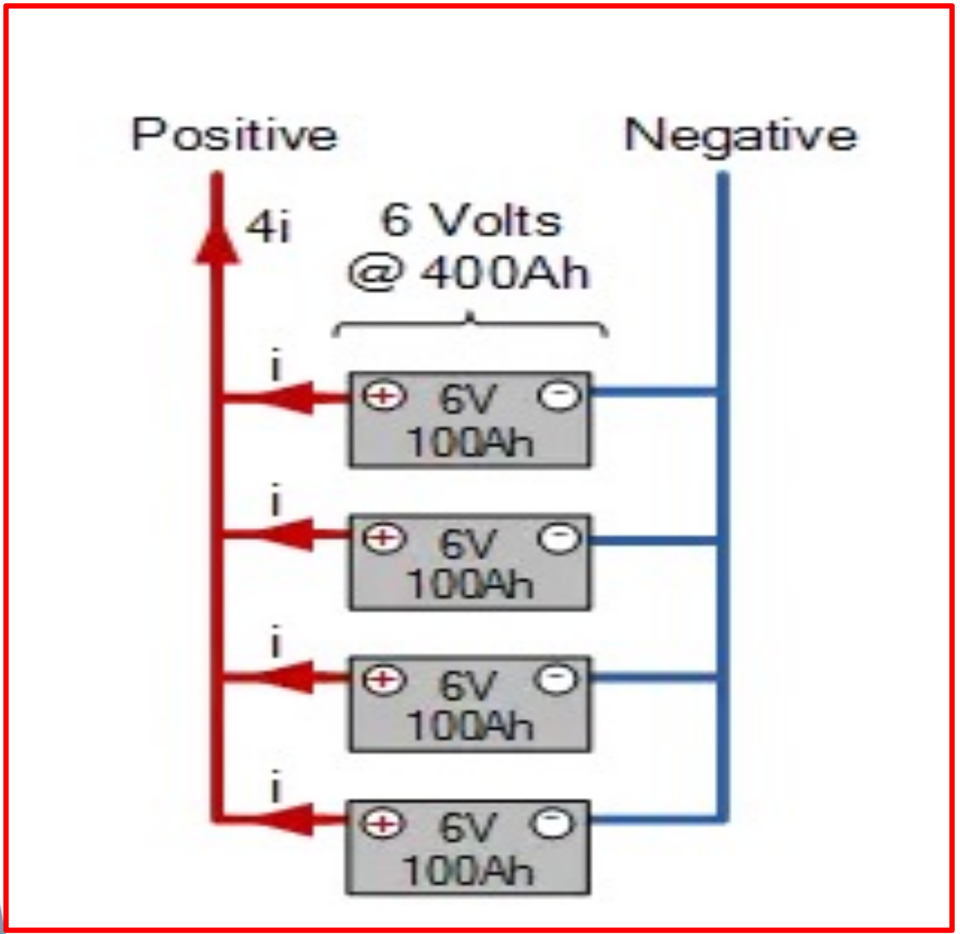
What about total energy capacity?

Energy capacity = 24V x 100Ah = 2400Wh

Battery application in PV

- Batteries can be connected in parallel.

Parallel connection of batteries.



In parallel configuration, the voltage per battery stays the same.

However, the currents are added. Hence, the power becomes higher.

The voltage and ratings of the battery should be the same.

What will happen if the same voltage, but different energy rating is used?

- ☐ ***The battery with higher capacity will contribute.***
- ☐ ***The unequal current sharing will cause fast discharge.***
- ☐ ***Higher battery capacity will be charged faster and reach full charge before lower capacity, resulting overcharging and overheating.***
- ☐ ***Hence, will reduce the life span of the higher battery capacity, since it will go through high stress.***

Battery application in PV

Battery sizing in PV system

- ❑ Battery is an important electrical source power to power electronic devices. The energy acquired from the solar panel needs to be stored. And batteries are the ideal option to do that. Therefore, battery sizing is required to determine how many batteries the stand-alone system needs to provide the required power.

Steps for doing battery sizing

- Find the battery capacity required for the required load

$$\text{Battery capacity in Ah} = \frac{n\ x\ load\ (kWh) X\ temperature\ compensation\ factor}{DOD\ X\ load\ subsystem\ efficiency\ x\ battery\ voltage}$$

Temp comp factor. IEEE 485-2020 document.

n= battery autonomy in days

- Then calculate the number of batteries required in series

$$\text{Batteries in series} = \frac{Vdc}{Battery\ voltage}$$

- Finally, the number of battery configuration required in parallel

$$\text{Batteries in parallel} = \frac{Battery\ capacity}{Number\ of\ batteries\ in\ series\ X\ Battery\ Ah}$$

The term "battery autonomy in days" refers to the number of days a battery can supply power without needing to be recharged

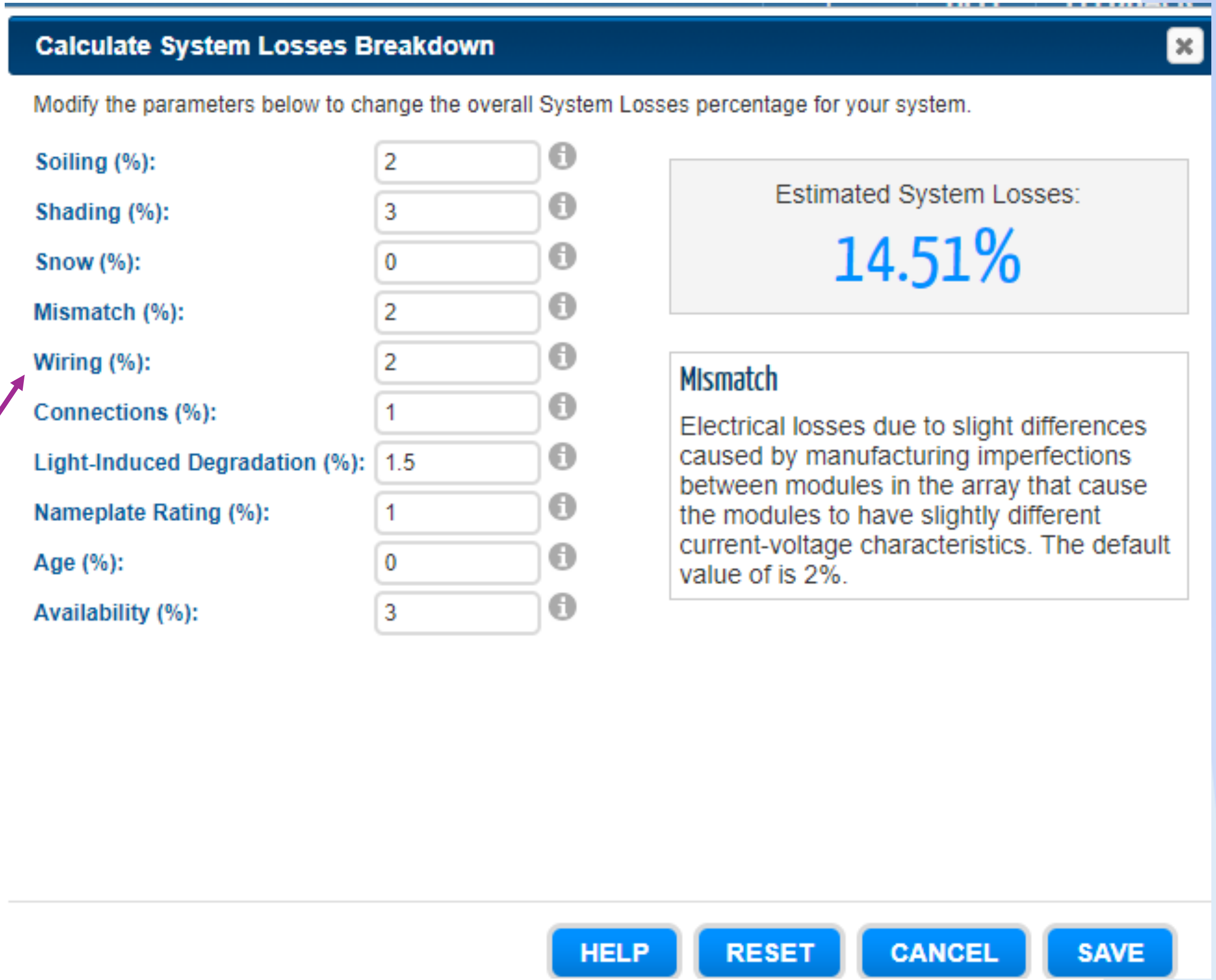
Battery application in PV

PVWatts Calculator

- ❑ A tool to provide energy production of a PV systems. A detail of using this web-based tool can be found in the handbook.
- ❑ System loss calculation (load subsystem efficiency) by using PVWatts Calculator.

Link: https://pvwatts.nrel.gov/pvwatts.php

You can get the sub system efficiency by putting the calculated values in loss calculator.



Calculate System Losses Breakdown

Modify the parameters below to change the overall System Losses percentage for your system.

Soiling (%): 2
Shading (%): 3
Snow (%): 0
Mismatch (%): 2
Wiring (%): 2
Connections (%): 1
Light-Induced Degradation (%): 1.5
Nameplate Rating (%): 1
Age (%): 0
Availability (%): 3

Estimated System Losses:
14.51%

Mismatch

Electrical losses due to slight differences caused by manufacturing imperfections between modules in the array that cause the modules to have slightly different current-voltage characteristics. The default value of is 2%.

Battery application in PV

- Temperature correction factor – IEEE 485 -2020 (For lead acid battery)

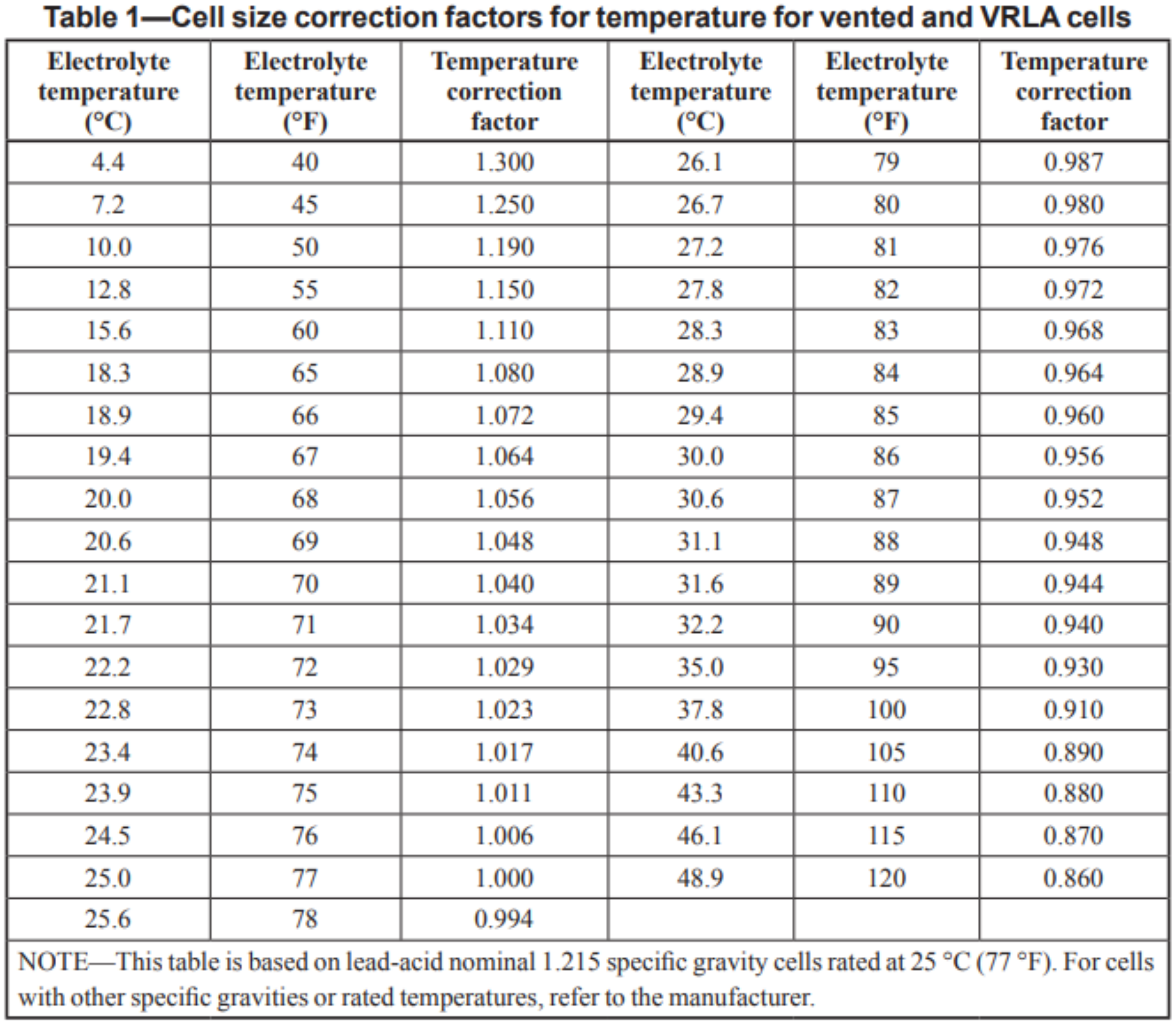


Table 1—Cell size correction factors for temperature for vented and VRLA cells

Electrolyte temperature (°C)	Electrolyte temperature (°F)	Temperature correction factor	Electrolyte temperature (°C)	Electrolyte temperature (°F)	Temperature correction factor
4.4	40	1.300	26.1	79	0.987
7.2	45	1.250	26.7	80	0.980
10.0	50	1.190	27.2	81	0.976
12.8	55	1.150	27.8	82	0.972
15.6	60	1.110	28.3	83	0.968
18.3	65	1.080	28.9	84	0.964
18.9	66	1.072	29.4	85	0.960
19.4	67	1.064	30.0	86	0.956
20.0	68	1.056	30.6	87	0.952
20.6	69	1.048	31.1	88	0.948
21.1	70	1.040	31.6	89	0.944
21.7	71	1.034	32.2	90	0.940
22.2	72	1.029	35.0	95	0.930
22.8	73	1.023	37.8	100	0.910
23.4	74	1.017	40.6	105	0.890
23.9	75	1.011	43.3	110	0.880
24.5	76	1.006	46.1	115	0.870
25.0	77	1.000	48.9	120	0.860
25.6	78	0.994			

NOTE—This table is based on lead-acid nominal 1.215 specific gravity cells rated at 25 °C (77 °F). For cells with other specific gravities or rated temperatures, refer to the manufacturer.

"The available capacity of a cell is affected by its operating temperature. If the lowest expected electrolyte temperature is below the rated battery temperature, select a cell large enough to have the required capacity available at the lowest expected temperature".

Battery application in PV

❖ Estimate System losses

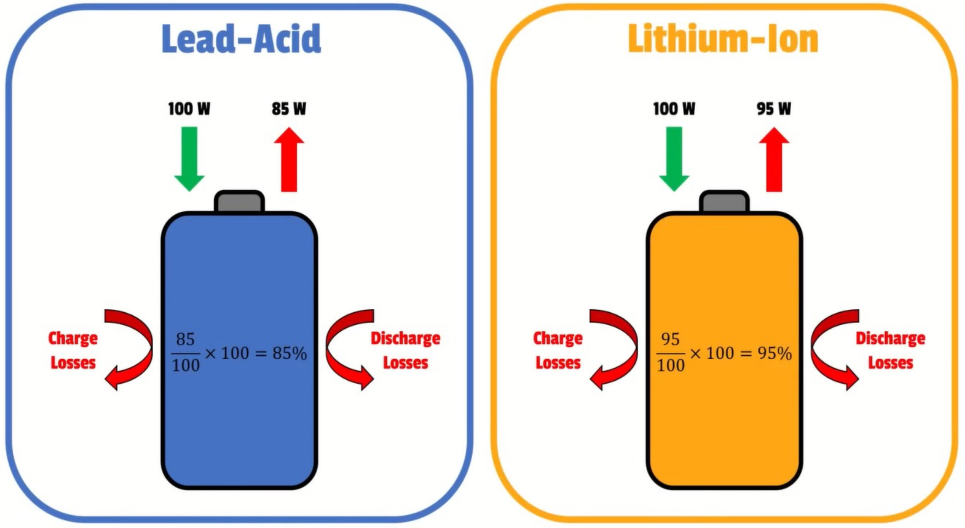
As the growth of PV systems installation is ramping up, it is very important to consider system losses to maximise output power.

Effective system design takes system losses into consideration to minimise the losses by considering possible solutions to minimise the impact of the losses.

- ☐ Round Trip efficiency.
- ☐ Wiring losses.
- ☐ Conversion efficiency.

→ **Load subsystem efficiency**

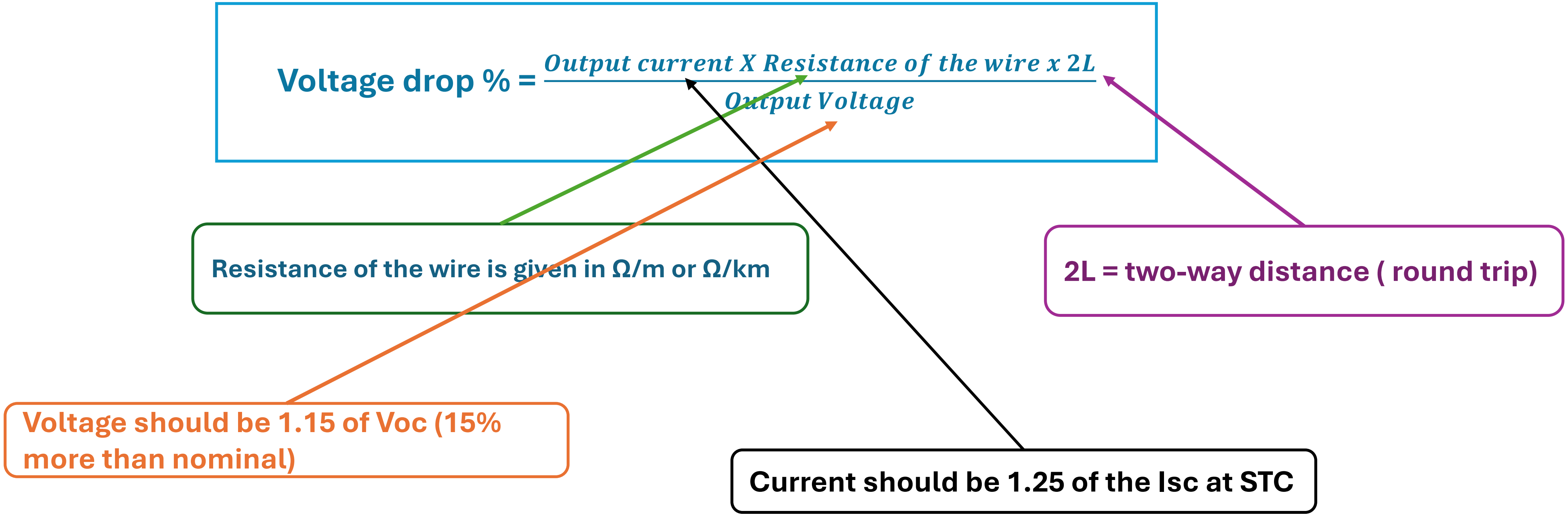
- ➢ No battery is 100% efficient. Therefore, commonly used round trip efficiency factor to measure the energy retention of a battery after it's been charged. This is because there is always a loss of power during charging and discharging.
- ➢ Round trip efficiency is the combined loss of energy added to and withdrawn from a battery.
- ➢ Round trip efficiency of lead-acid batteries is about 75%, whereas for Li-ion batteries is about 90%.



Battery application in PV

Wiring losses

- Between the battery bank, the conversion equipment and the electrical load.
- Voltage drop is calculated by using the formula below:



$$\text{Voltage drop \%} = \frac{\mathit{Output\ current\ X\ Resistance\ of\ the\ wire\ x\ 2L}}{\mathit{Output\ Voltage}}$$

Resistance of the wire is given in Ω/m or Ω/km

2L = two-way distance (round trip)

Voltage should be 1.15 of Voc (15% more than nominal)

Current should be 1.25 of the Isc at STC

Voltage drop should be less than 2%. So, check the selected wire has voltage drop less than 2%.

***PV installation guide*: https://files.bregroup.com/solar/Guide_to_the_installation_of_PV_systems_2nd_Edition.pdf**

Battery application in PV

Conversion efficiency

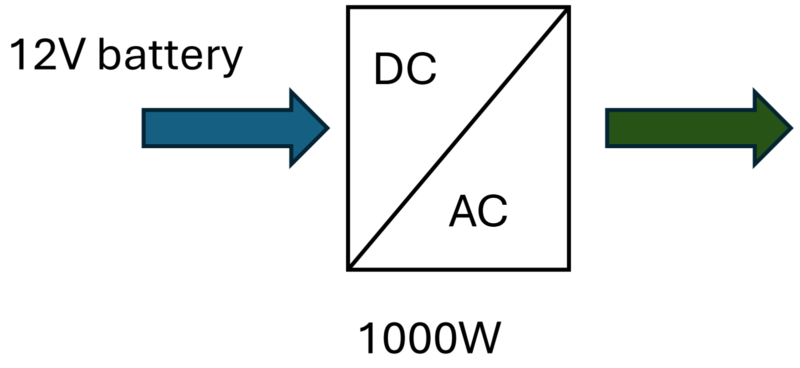
- Inverter converts DC to AC, and it has efficiency.
- PV inverter efficiency is around 97%.
- Battery inverter efficiency is between 92 and 95%.
- Also, consider the charge controller efficiency as well.

Battery application in PV

❖ Battery sizing in PV

☐ Selecting battery Voltage – Higher battery voltage is beneficial.

- Reduces wiring costs.
- Increases efficiency.
- Decreases current requirement for charge controller. Limit current to 100A.



$$\text{Current, I} = \frac{1000}{12} = 83\text{A}$$

Inverter size for different battery voltage

For 12V: 1000W or lower.

For 24V: up to 2kW.

For 48V: up to 5kW.

More power: Multiple inverters in parallel.

Battery application in PV

Consider you are required to do the battery sizing of a household which consumes 4kWhr of energy per day. The following parameters are given:

- Days of autonomy = 3 days
- Battery voltage = 24V, 190Ah
- DoD = 90%
- Vdc = 240V
- Load sub-system efficiency = 88%
- Temperature compensation factor = 1.01

Solution

Battery capacity in kWhr = $\frac{n\ x\ load\ (kWh) X\ temperature\ compensation\ factor}{DOD\ X\ load\ subsystem\ efficiency\ x\ battery\ voltage} = \frac{3\ x\ 4000\ x\ 1.01}{0.9\ x\ 0.88\ x\ 24}$ ≈638Ah

= 638Ah x 24V= 15312Wh.

Now, to find the number of series batteries required = $\frac{Vdc}{V\ batt}$ = 240/24 = 10

Parallel battery arrangement required = 638 / (10 x 190) = 0.33 (**Not required for parallel arrangement**)

Therefore, 10 series batteries with no parallel arrangement. Total 10 batteries.

Battery application in PV

What about solar panels? How many you need?

Solution

From previous calculation we found for 23.77kWhr load, we need 3800Ah battery capacity per day.

To charge the battery, you need to consider DoD which is 90%. So, you need to charge 90% of 3800Ah

0.9 x 638Ah = 574Ah

574 x24V = 13781Wh.

Already included in Battery capacity calculation

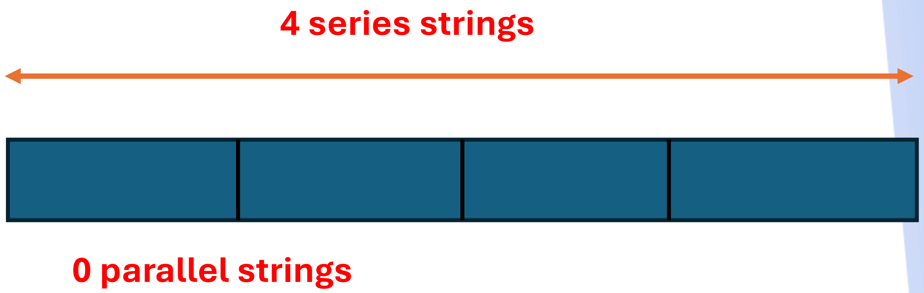
Required solar panels = 13781 /(Sun hour x **system efficiency**) = 13787 / (4.25) = 3242W

Panel's parameter: Voc = 50V, Isc = 17.26A, Power = 700Wp

Series strings = 240/50 = 4.8 = 4

Parallel strings = 3242W / (4 x 700)= 1.1

When considering sun hour, take the least favourable one.



Check the calculation

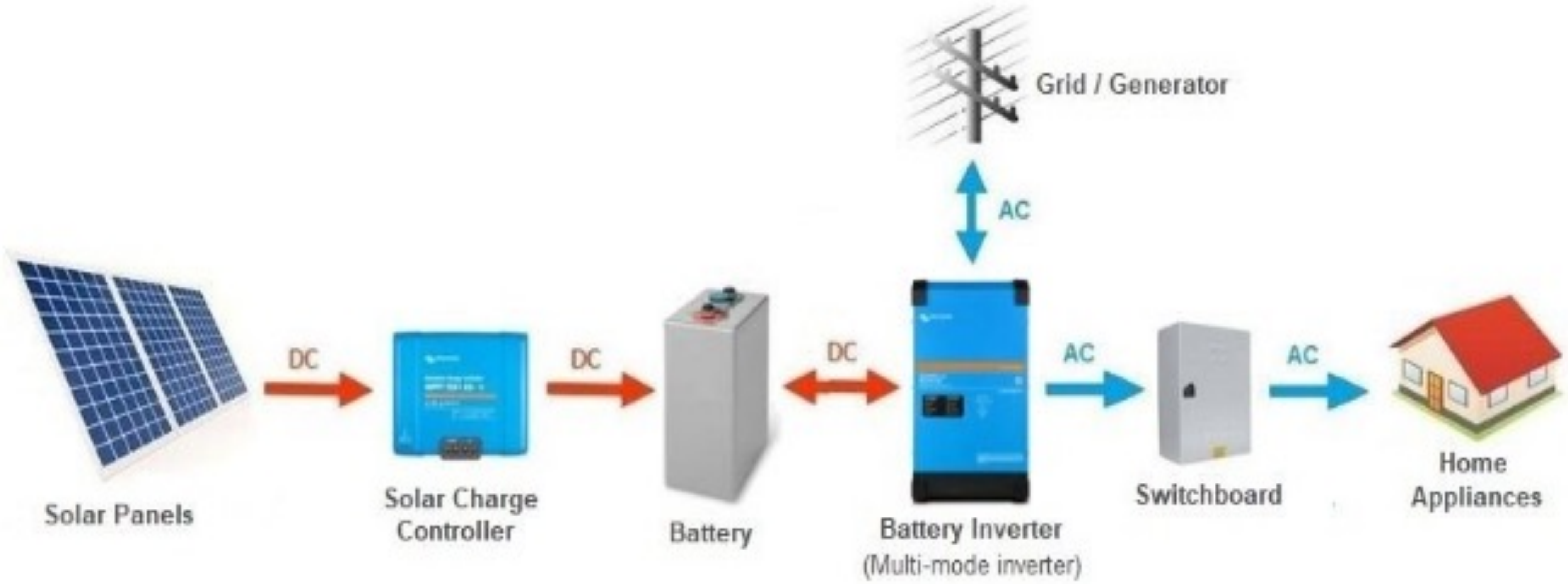
- 4 series strings voltage = 50 x 4 = 200V
- 1 parallel strings (V stays same),

Total current = 17.26 x 1 = 17.26A

- Total PV power = 200 x 17.26 = 3452W

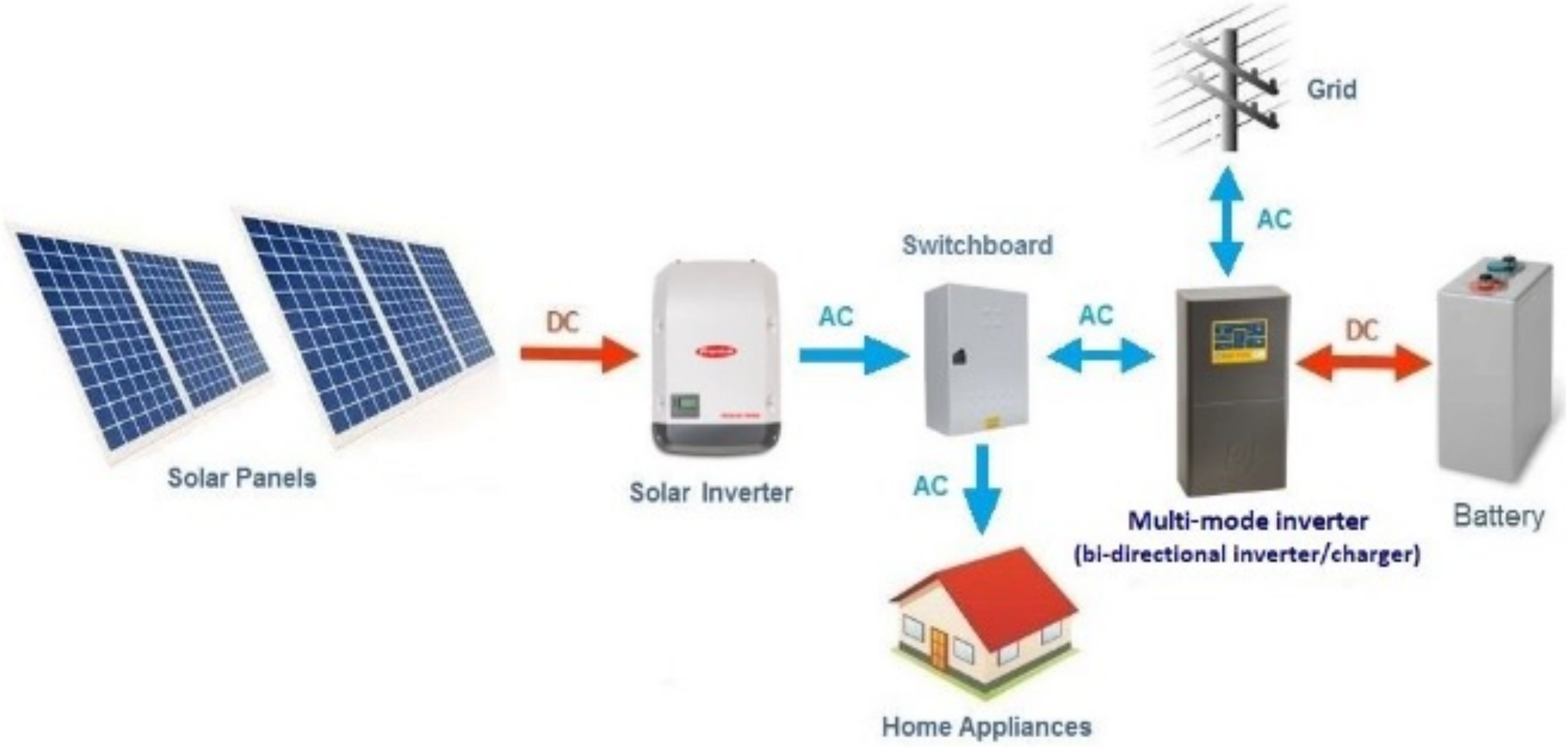
or 3.5kW

Battery application in PV



Basic layout diagram of a DC-coupled (off-grid) solar battery system using an MPPT solar charge controller

Battery application in PV



Basic layout diagram of an AC-coupled solar battery system - Grid-tie (hybrid) setup

Battery application in PV

Combination AC and DC-Coupled system - Can be configured as Grid-interactive or Off-grid with generator

References (PART 2)

1. https://www.pveducation.org/pvcdrom/battery-basics/basic-battery-operation
2. https://www.coursera.org/learn/battery-management-systems/lecture/RlMSs/1-1-2-introducing-important-battery-terminology
3. https://www.monolithicpower.com/learning/resources/an-introduction-to-batteries-components-parameters-types-and-chargers
4. https://www.tycorun.com/blogs/news/primary-battery
5. https://www.indiamart.com/proddetail/square-meter-nameplate-14283922512.html
6. https://web.mit.edu/evt/summary_battery_specifications.pdf
7. https://www.alternative-energy-tutorials.com/energy-storage/understanding-batteries.html
8. https://issuu.com/solarbatterywarehouse/docs/v-lfp-12-240_spec_sheet_eml__1_
9. https://pvwatts.nrel.gov/pvwatts.php