



**Strathmore University**

*Energy Research Centre*



# SOLAR TRAINING MANUAL

## (INTERMEDIATE)



For: Climate Resilient Low Cost Buildings in Marsabit County Project, 2018

Contents

Electrical Basics ..... 2

THE SUN AS AN ENERGY SOURCE..... 5

Basics of a Solar System ..... 7

    PV Module..... 8

    Battery ..... 9

    Charge controller..... 11

## **Electrical Basics**

### **Current**

Electricity flow can be compared to water flow. The higher the electrical flow, the higher the current flow. Current is the quantity of electrons flowing inside wires (conductors)

- Symbol: 'I'
- Unit: 'A'(ampere)

### **Voltage**

Voltage is the electrical potential, or the pressure that moves electrons through the wires (conductors) and can be compared to pressure in a water pipe. Voltage is the electric potential difference between two points

- Symbol: 'V'
- Unit: 'V'(voltage)

### **Resistance**

- ✓ Resistance limits the flow of electrons through the wires, like a nozzle restricts the flow of water through a pipe
- ✓ Smaller pipes restrict water flow, just like smaller wires restrict electrical flow (higher resistance)
- ✓ Longer pipes also restrict water flow. Similarly, the longer the wires, the higher the resistance

Resistance is the opposition to the passage of an electric current

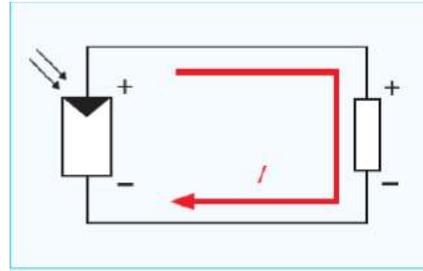
- Symbol: 'Ω'
- Unit: 'Ohms'

### **Ohms law**

Current, Voltage and Resistance are related and if you know any two you can calculate the third.

Ohm's Law		
$I = V / R$	$V = I \times R$	$R = V / I$
<p><math>V =</math> Voltage [Volt]</p> <p><math>I =</math> Current [Ampere]</p> <p><math>R =</math> Resistance [Ohm]</p>		

(Mikl, 2014)



(Mikl, 2014)

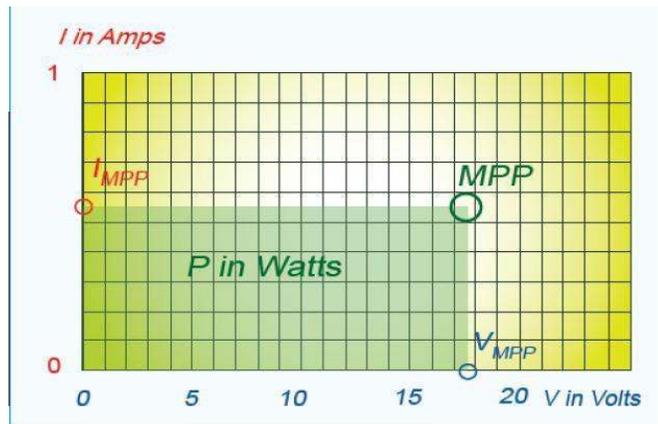
### **Power**

- Power can be thought of as a stream of water, which has both pressure and flow rate
- Power is derived from voltage (V) multiplied by current (I)
- $P = V \times I$
- Symbol: 'P' and Unit: 'W'(watt)

### **Power Law**

Electrical power
$P = U \times I$
<p><math>P =</math> Power [Watt]</p> <p><math>V =</math> Voltage [Volt]</p> <p><math>I =</math> Current [Ampere]</p>

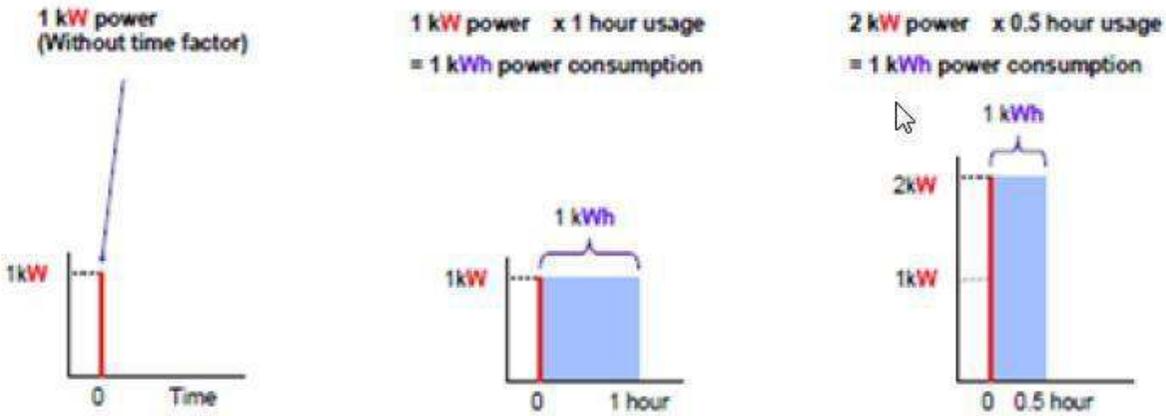
(Mikl, 2014)



(Mikl, 2014)

### **Power & Energy**

- The W (Watt) is a measure of power and it is the rate at which energy is generated or consumed.
- The Wh(Watt-hour) is the (integrated) power that is generated or consumed in one hour
- When a 1 kW appliance is used for one hour, the energy used is 1 kWh



(Mikl, 2014)

If the 20W module is used to charge a battery for 5 hours per day

Total energy generated per day is 20 W \* 5 hours = 100 Watt-hours (Wh)

### Parallel and series connections

Rules for serial circuits	
$V_{TOTAL} = V_1 + V_2$	The total of all voltage drops on serial resistors equals the source voltage (mesh rule)
$R_{TOTAL} = R_1 + R_2 (+...R_N)$	All resistors in series can be added to $R_{TOTAL}$
$I = V/R_{TOTAL}$	Equal current flows through all serial resistors

Rules for parallel circuits	
$V_{TOTAL} = V_1 = V_2$	The voltage across all parallel resistors is the same
$R_{TOTAL} = (R_1 \times R_2) / (R_1 + R_2)$	Parallel resistors form an equivalent resistance which is always smaller than the smallest single resistor
$G = 1/R = [S]$ $R = 1/G [\Omega]$	The conductance [Siemens] is the reciprocal of a resistance

(Mikl, 2014)

## **Alternating Current (AC) & Direct Current (DC)**

AC current is a specific type of electric current in which the direction of the current's flow is reversed, or alternated, on a regular basis. Direct current is no different electrically from alternating current except for the fact that it flows in the same direction at all times.

## **The Sun As An Energy Source**

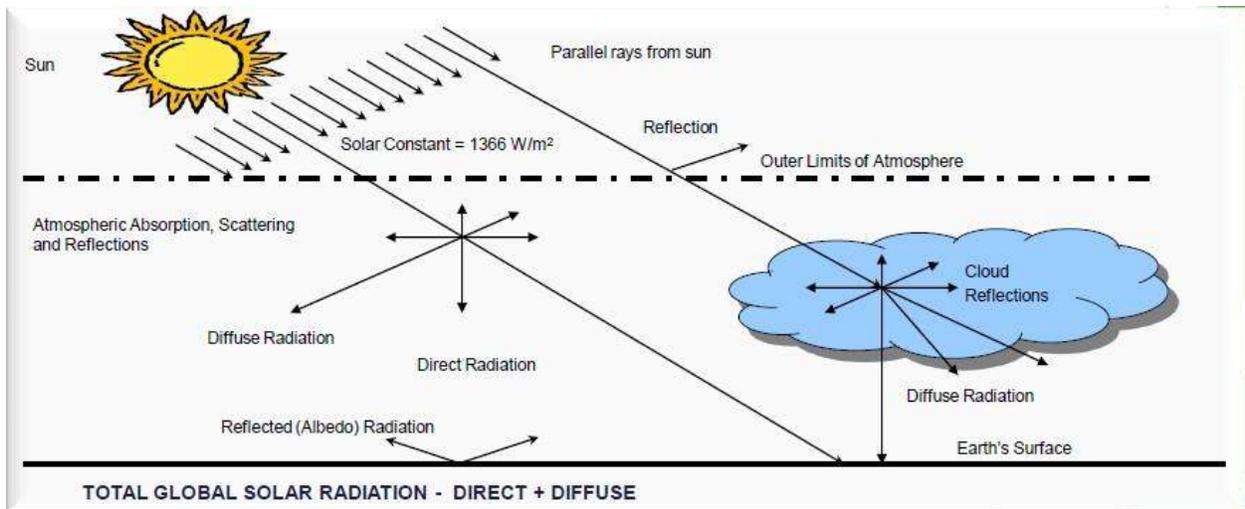
- The central star in our planetary system has 330,000 times the mass of the earth and its core pressure equals 200 billion earth atmospheres.
- For the next 4.5 billion years every second 560 million tons of hydrogen will be fused into lighter helium. The loss of mass creates an energetic power of  $3.85 \times 10^{26} \text{ W}$  ( $E=mc^2$ ).
- The portion of solar energy which reaches the outer parts of the earth's atmosphere in a rectangular angle is called solar constant.
- The solar constant at the outer earth atmosphere averages per year at approx.  $1,037 \text{ W/m}^2$ .
- About  $1,000 \text{ W/m}^2$  of this power reach the earth's surface.
- The energy accumulated by this radiation lies between  $2,200 \text{ kWh/m}^2$  at the equator and  $800 \text{ kWh/m}^2$  at the polar circles. Basics of PV solar system

## **Solar Radiation**

- Power produced by PV arrays is directly proportional to sunlight intensity
- The sunlight intensity on PV array is dictated by cloud cover and array orientation
- Cloud cover decreases sunlight intensity and diffuses sunlight
- Array orientation (tilt angle and azimuth angle) impacts the extent of direct and diffuse lights reaching the PV array

## **Irradiance: Direct/Diffuse Ratio & Installation**

Direct/diffuse ratio dictates tilt or tracking installation



(Mikl, 2014)

## Solar resource

Irradiance is power (unit: watt/m<sup>2</sup>); irradiation is energy (unit: watt-hour/m<sup>2</sup>/day or watt-hour/m<sup>2</sup>/year). **Solar irradiance** is the sun's radiant energy incident on a surface of unit area expressed in units of kW/m<sup>2</sup>. Diffuse could be considered "scattered" light; direct light is non-scattered light reaching the device directly from the sun. Peak sun is the irradiance when it is 1000 W/m<sup>2</sup>; peak sun hours are equivalent to the number of hours that the solar irradiance would be at a peak level/power of 1kW/m<sup>2</sup>

## Solar Irradiation or Insolation (kWh/m<sup>2</sup>)

Solar irradiation (energy) or solar insolation is equal to total solar irradiance (power) over time. Solar irradiation is the sun's radiant energy incident on a surface of unit area expressed in units of kWh/m<sup>2</sup>

- expressed on an average daily basis for a given month or year
- referred to as solar insolation or peak sun hours

**Peak sun hours (PSH)** is the average daily amount of solar energy received on a surface. PSH are equivalent to the number of hours that the solar irradiance would be at a peak level/power of 1 kW/m<sup>2</sup>. 1000 W/m<sup>2</sup> is a typical average globally at noon on a clear day. Modules are rated at 1000 W/m<sup>2</sup>.

## PV Array Orientation

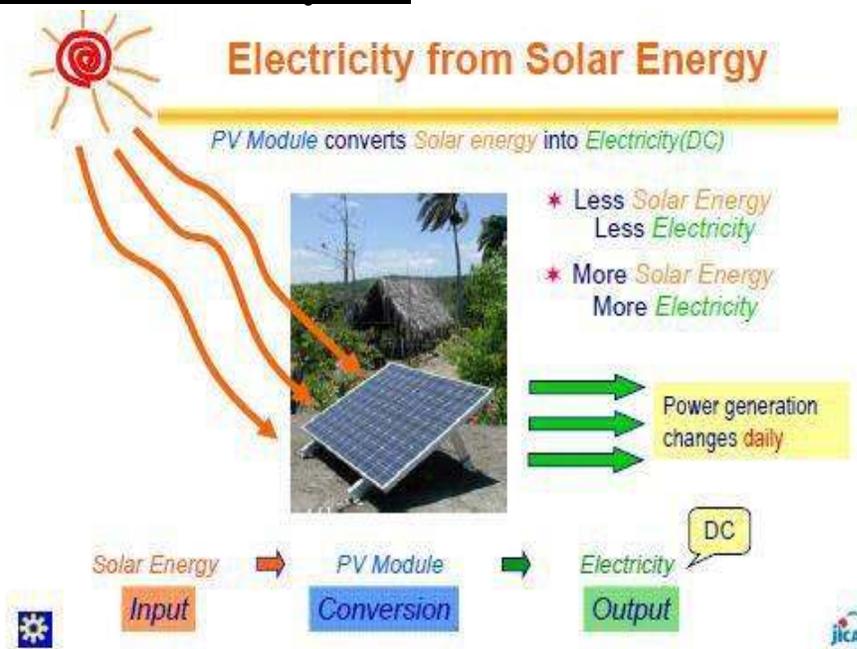
The orientation of PV arrays is defined by two angles with respect to the PV surface

- The PV array **azimuth angle** represents the angle between true north and the direction the array faces (in Nairobi, magnetic north is 0-3° west of true north).
- The PV array **tilt angle** represents the angle the array surface makes with the horizontal plane/earth.

### Tilt Angle

- The correct tilt angle should be determined based on the energy usage and the local weather conditions at different times of the year
- A tilt angle at less than 10° -is typically not recommended to allow for self cleaning (soiling losses).
- The self cleaning ability of solar panels starts at a tilt angle of 25°. Higher tilting angles are usually sufficient for the ability to self cleaning.

### Basics of a Solar System



(Manual for Solar PV training, 2009)

### Features of Solar PV System

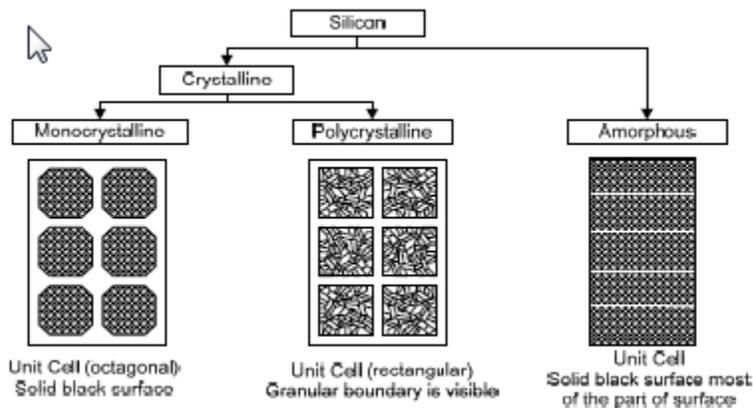
- PV Module
- Charge controller

- Battery
- Inverter

## **PV Module**

### **Types of PV modules**

- Monocrystalline
- Polycrystalline
- Amorphous

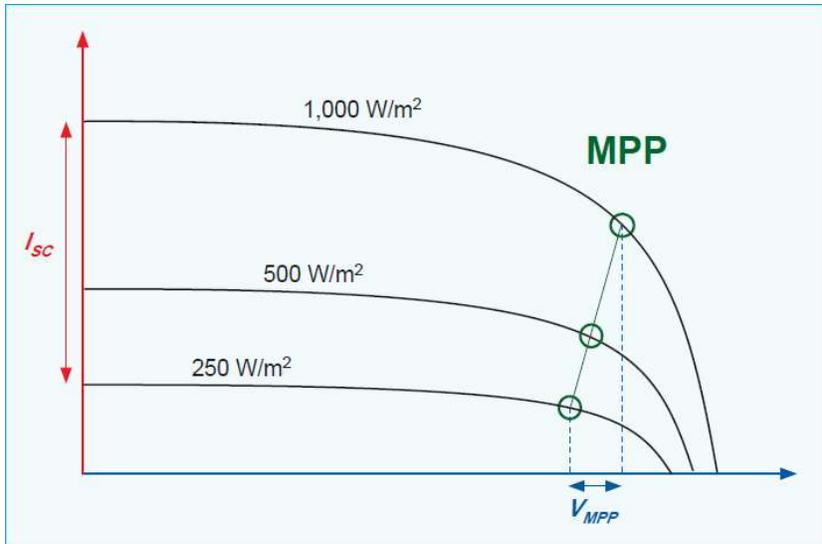


(Manual for Solar PV training, 2009)

- All PV modules must be marked with the following information (if not, then they might not be from a reputable source):
  1. Open-circuit voltage (Voc)
  2. Short-circuit current (Isc)
  3. Operating voltage (Vmp)
  4. Operating current (Imp)
  5. Maximum power (Pmp)
- Polarity of terminals
- Maximum permissible system voltage

### **Influence of Radiation Intensity**

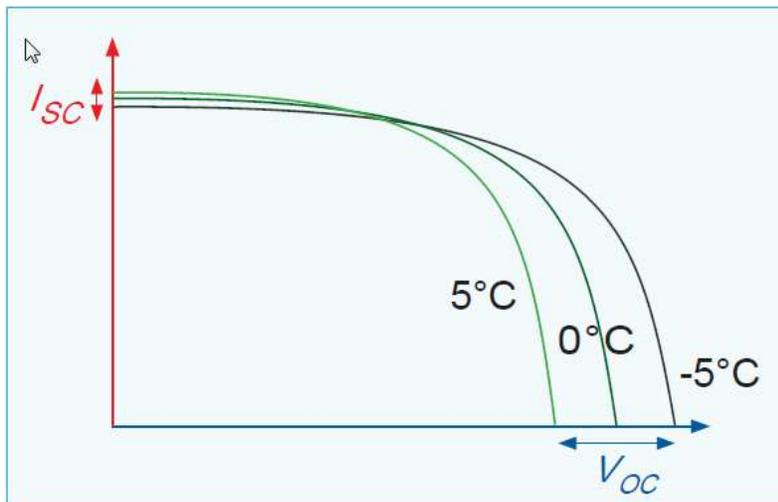
The biggest influence on the power output of a solar panel is naturally caused by the variation of sun light. The biggest effects happen in the changes of the panels current. A fifty percent decrease of solar irradiation also causes a fifty percent decrease of ISC. VOC only decreases by a few volts.



(Mikl, 2014)

### Temperature Influence

Like all semiconductors photovoltaic cells are strongly temperature dependent. Higher temperatures can minimize voltage values while low ambient temperatures lead to a higher VOC.



(Mikl, 2014)

### Battery

- Battery stores electrical energy in DC
- Mainly used during night time and charged during the day.

Unit cell for a battery is 2V. Which is the nominal voltage. Voltage range is around 1.85V to 2.40V

- 12V battery has 6 unit cells in series connected.
- 6V battery has 3 unit cells in series connected.

The main type of battery used in Solar PV systems are the Lead Acid type and they can either be flooded type of the maintenance free type.

## Capacity

Capacity is a measure of the stored electric charge or stored energy that a battery can deliver under specified conditions

- An ampere-hour (Ah) is the unit measurement of battery energy storage capacity, and equals to the transfer of one ampere for one hour.
- Capacity depends on the battery temperature, discharge rate and cut-off voltage.

## How to read capacity

- 960Ah at 24h discharge rate [ 960Ah (C/24) ]. 40A can be discharged for 24hours till voltage becomes 1.85V/cell
- 1200Ah at 120h discharge rate [ 1200Ah (C/120) ]. 10A can be discharged for 120hours till voltage becomes 1.85V/cell

(Manual for Solar PV training, 2009)

**Long-term discharge capacities for VARTA OPzS Batteries**

Discharge rate Duration of discharge (hours)	Type	Capacity							final voltage V/cell
		10 h <sup>(*)</sup>	24 h	48 h	72 h	96 h	120 h	240 h	
	4 OPzS 200	200	240	268	288	296	300	312	1.85
	5 OPzS 250	250	300	335	360	370	375	390	
	6 OPzS 300	300	360	402	432	444	450	468	
	5 OPzS 350	350	420	469	504	518	525	546	
	6 OPzS 420	420	504	562	604	621	630	655	
	7 OPzS 490	490	588	656	705	725	735	764	
	8 OPzS 600	600	720	804	864	888	900	936	
	8 OPzS 800	800	960	1072	1152	1184	1200	1248	
	10 OPzS 1000	1000	1200	1340	1440	1480	1500	1560	
	12 OPzS 1200	1200	1440	1600	1728	1776	1800	1872	
	12 OPzS 1500	1500	1800	2016	2160	2220	2250	2340	
	15 OPzS 1875	1875	2250	2512	2672	2760	2775	2895	

Model No. →

Final voltage Discharge is stopped at this voltage (Empty)

Capacity at each discharge rate (Ah)

JICA

(Manual for Solar PV training, 2009)

## Technical maintenance of batteries

- Maintain electrolyte level ( use distilled water only).
- Maintain homogenous electrolyte (Avoid stratification)- acid tends to accumulate in bottom areas, simple shaking could be done.
- Maintain healthy electrode (Avoid sulfation). Very common in case of no charge controller and due to over discharging of the battery of leaving the battery uncharged . Crystallized sulfation covers the surface of electrode permanently.
- Maintain equal cell voltage ( periodical equalization). Normally automatic by charge controller.

## **Charge controller**

The charge controller is the central equipment of a DC coupled PV stand-alone system. Its main tasks are

1. Overcharge protection by automated disconnection
2. Reverse current protection
3. Controlled recharging and continuous charge hold
5. Deep discharge protection