Training Student Manual of

Darfur Solar Electrification Project

Which is funded by the Qatar Development Fund Under the United Nations Fund for Recovery Reconstruction and Development in Darfur ("UNDF")

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

REPUBLIC OF SUDAN
جمهورية السودان

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Table of Contents

Introduction:

Solar energy received on the earth surface in form of solar radiation that humans have harnessed and utilised since ancient times using a range of different ever-evolving technologies. Over the past few years, the solar energy sector has grown by about 50% per year, faster than any other energy source, and the equipment price has fallen by more than 80% since 2005, making solar energy more competitive with oil, gas and nuclear power. Increasing interest in solar energy and the expansion of its use require rehabilitation and training of human resources capable of dealing with these systems.

This textbook entitled "Solar PV Systems Technology" is dedicated to the third-grade engineering course (track) students in technical secondary schools. The book has eleven modules; the first module is concerned with the concepts of solar energy and its resources. The second module deals with the measuring devices. The following three modules deal with the conversion of solar energy into electricity using photovoltaic (PV) solar cells and PV solar modules, defining their technical specifications and explaining their methods of wiring and connections. Modules six to nine introduce the general layout of PV solar systems and its components discussing in detail the Storage Batteries, the battery charge controllers and the DC-AC Inverters. Module 10 presents some selected solar energy applications, advantages and disadvantages of using solar energy. The last module gives the concept of system sizing, installation and maintenance.

This book is designed for use by anyone who is interested in developing his/her knowledge and technical capabilities in the field of photovoltaic solar systems. The book is targeted to specific people wishing to engage in the supply, installation, operation and maintenance of the different components of photovoltaic solar systems.

1. Resources:

1.1 Solar energy:

The Sun is the main source of energy on our planet. It is the source of all other energies such as fossil fuels, wind, tides. The Sun produces its energy through the interaction of nuclear fusion.

1.1.1 Apparent movement of the Sun

1. The Earth revolves around the Sun, but it appears to us that the Sun moves across the sky from the east to the west.
2. The earth also revolves around its polar axis and the axis is inclined at 23°.
3. The position of the sun is defined by two angles; the azimuth and the height.

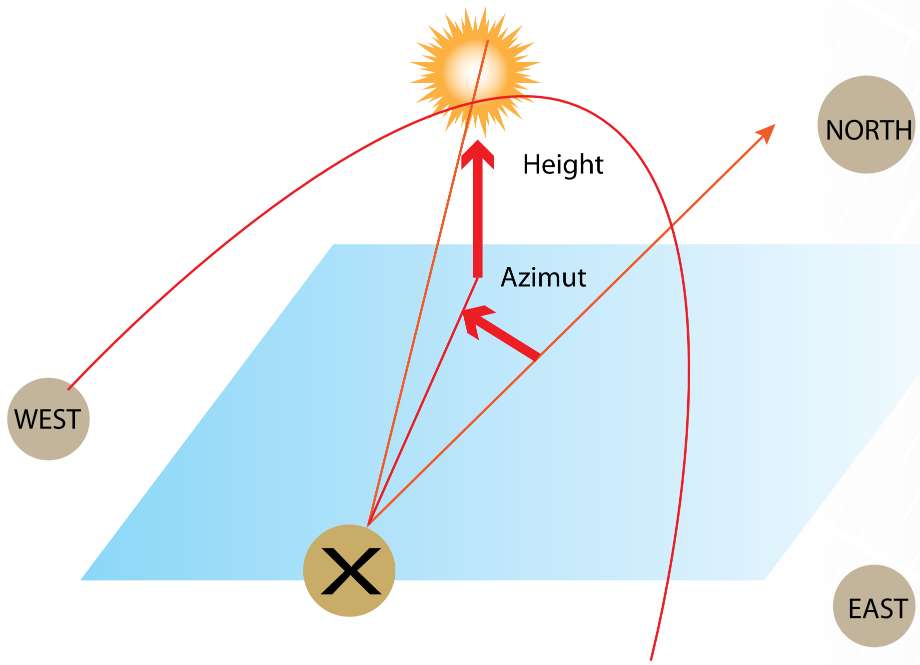


Figure 1: Show path of the Sun across the sky.

1.1.2 Solar radiation

1. Our Sun is a relatively small star, a hydrogen fusion generator, an enormous incandescent sphere, the source of all life on Earth.
2. Solar radiation is the electromagnetic radiation emitted by the sun and arriving on the surface of the Earth.

1.1.3 The Solar spectrum

1. The Solar Spectrum is electromagnetic radiation made up of a range of wavelengths.
2. Ultraviolet 9%
3. Visible 47%
4. Infra-Red 44%

1.1.4 Solar radiation on Earth

1. Direct radiation, clear sky, a surface inclined directly to the sun
2. Diffused radiation- the radiant energy from the whole sky, reflection from clouds.
3. Ground Albedo- radiation reflected by the ground, related to the nature of the ground.

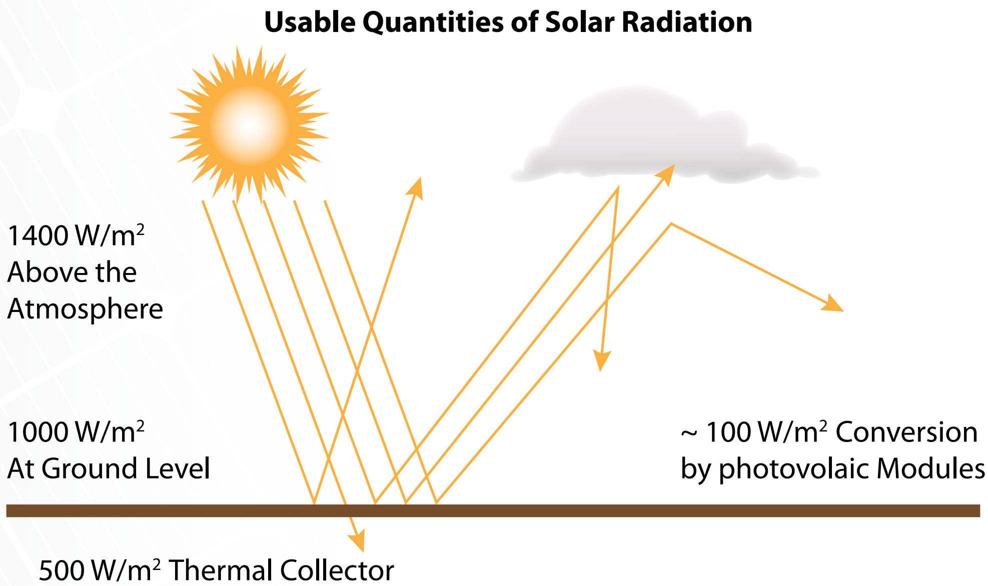


Figure 2: usable quantities of solar radiation.

1.2 Factors affecting the amount of solar radiation on a solar module:

1. Latitude at location (height angle).
2. Season of the year.
3. Amount of sunlight (clouds, dust).
4. Temperature.
5. Hour of the day (azimuth angle).
6. Module construction.
7. Other factors.

Season of the Year (affects sunlight angle on the array)

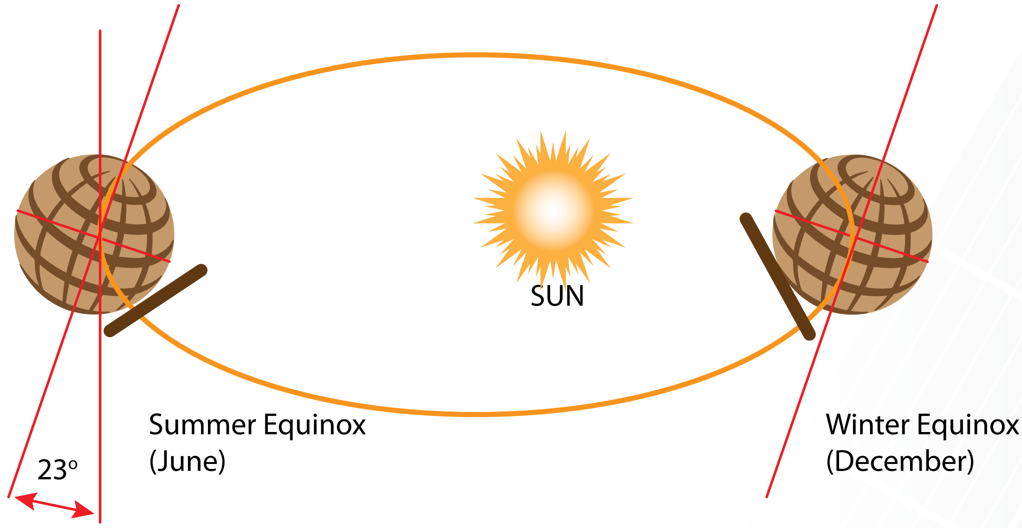


Figure 3: Show the earth’s rotation around the sun (season).

1.3 Measurements of Solar radiation.

Solar radiation measuring devices:

Generally, there is a need to measure solar radiation. The solar radiation measurement is based on the number of hours of sun brightness a day. From these values, average monthly and annual rates are calculated, in addition to the strength of solar radiation. Several devices are available to measure the solar radiation intensity at the surface of the earth, include:

- The Pyranometer.
- Solarimeter.

1.3.1 Pyranometer

Figure 4: Show Pyranometer

1.3.2 Pyranometer

Figure 5: Show Solarimeter

1.3.3 Reference Cell

Figure 6: Show a reference cell.

The instantaneous solar radiation power is measured in watts per square meter (W/m^2) which represents also the energy received per second per square meter.

The daily-accumulated energy received from the solar radiation is measured in megajoule per square meter per day ($MJ/m^2/day$) or in kilowatt-hour per square meter per day ($KWh/m^2/day$).

$$1\ KWh/m^2/day = 3.6\ MJ/m^2/day$$

1.4 Practical exercise No. 1, measurement of the intensity of solar radiation

1.5 Database of solar radiation in Sudan:

The table below shows the average daily solar radiation in megajoule per square meter per day (MJ/m^2/day), for the different months of the year, measured in different locations.

Table 1: The monthly average of total solar radiation is shown in MJ / m2 / day

Month	Dungola	Portsudan	Wad Medani	Abo Naama	Elfashir	Kadogli	Gazala Jawazat
January	19.23	15.33	21.39	21.76	20.71	21.23	20.52
February	21.09	19.42	23.46	24.8	23.46	22.83	22.48
March	24.98	32.48	24.94	26.55	24.7	23.13	23.36
¡Abril	25.81	25.96	26.03	26.07	25.43	23.97	23.57
May	25.88	25.38	26.44	26.02	25.10	21.25	23.53
June	25.68	26.08	24.05	23.83	23.92	19.23	21.65
July	24.54	22.69	22.76	22.12	22.45	20.01	20.47
August	23.74	22.76	23.48	22.6	23.3	18.15	21.23
September	22.92	22.61	23.48	23.84	23.3	18.57	21.31
October	22.04	2.53	22.67	22.47	22.76	20.13	21.39
November	19.84	16.92	21.63	22.01	21.88	21.77	21.23
December	18.41	15.14	20.72	20.67	20.58	22.66	20.35
Average	**22.85**	**21.36**	**23.37**	**23.32**	**23.03**	**21.8**	**21.6**

From these data, it appears that Sudan is rich in the resource of solar energy that can be converted into a useful source of energy.

2. Measuring devices:

2.1 The AVOMETER (AVO):

It is a device to measure the current, the voltage and the resistance. There are two types, the analogue Avometer and the digital Avometer.

2.1.1 Analogue AVOmeter

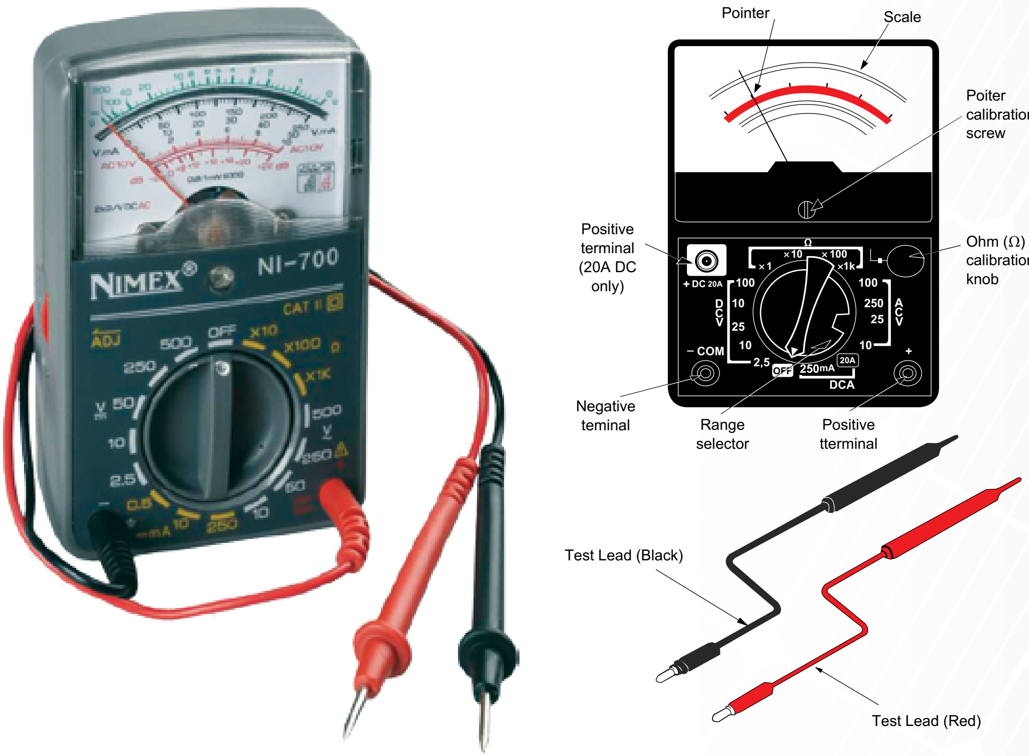


Figure 7: Show Analogue Avometer.

2.1.2 Digital AVOmeter:

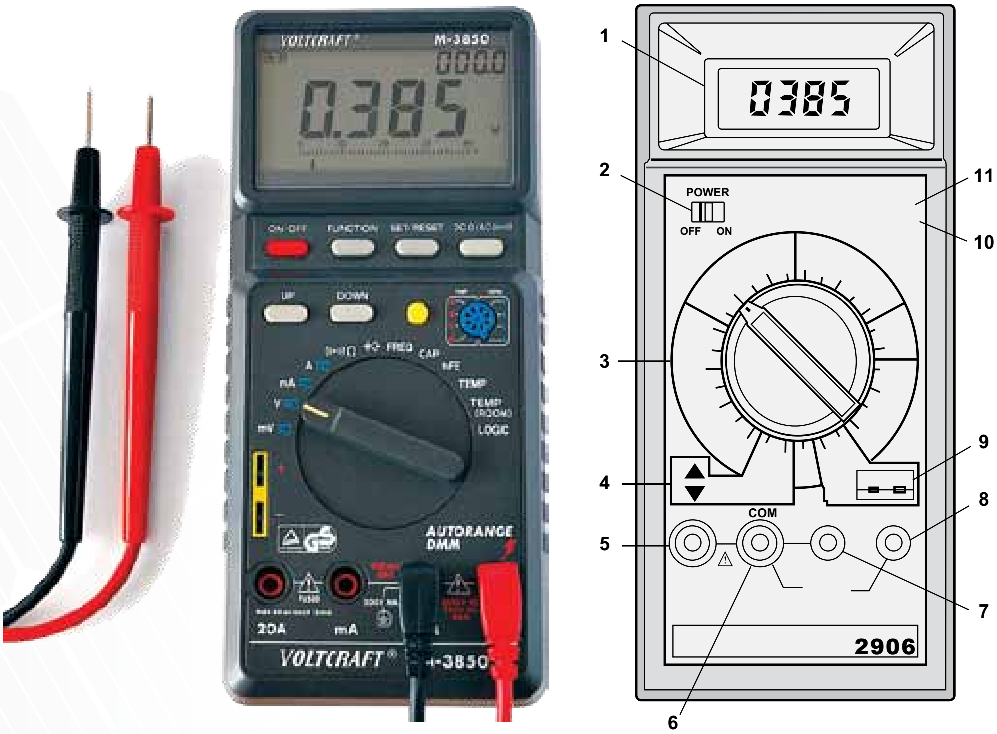


Figure 8: Show Digital AVOmeter.

Keterangan:

1. 312 digit display (1999 maximum) with automatic decimal pt. and minus sign.
2. POWER switch.
3. Function Range Switch.
4. LOGDC Indicaters: Red LED = logic high, green LED = lower.
5. W-OHM Jack: Input for dc or ac voltage, resistance, or continuity.
6. COM Jack: Input for common or reference test lead forall measurements.
7. mA Jack Input for dc or ac currents up to 200 mA.
8. 10 A Jack: Input for currents up to 10 A.
9. TEMP TYPE K Jack: Input for Type K thermocouple.
10. hFE Jack: Input for direct insertion of npn or em transistor leads.
11. LOGIC Jack: Inputs for three pin logic test leads.

Figure 9: Show Keywords Analogue AVOmeter.

2.2 Thermometer:

The device that measures the temperature. And temperature measurement unit (°C and ° F).

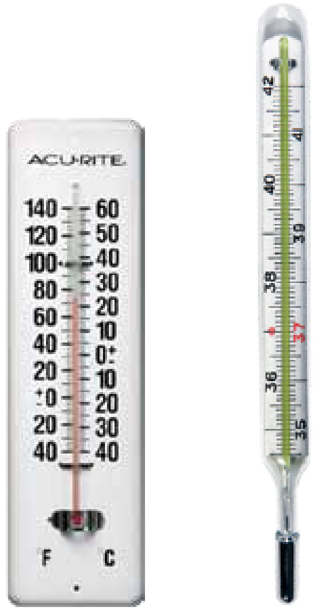


Figure 10: Show Thermometer.

Figure 11: Show Digital Thermometer.

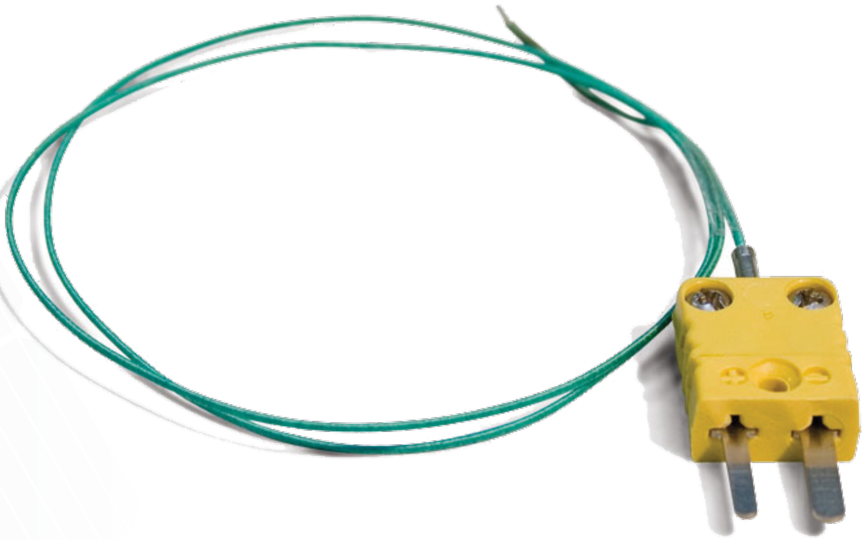
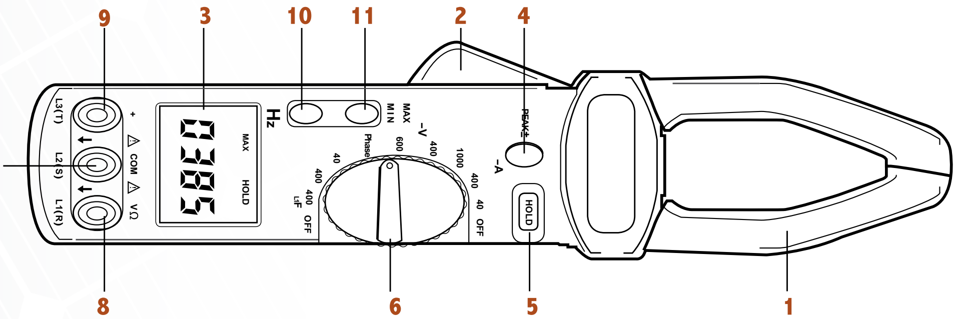


Figure 12: Show Thermo Sensor.

2.3 Clamp meter:

It is the type of Avometer that measures current without disconnecting the circuit, particularly high values of current.



1ـ فكا الجهاز.
2-ضاغط لفتح الفكين.
3-شاشة العرض LCD.
4-ضاغط لحفظ القيمة العظمى.
5-ضاغط لحفظ المعلومات التي على الشاشة.
6-مفتاح اختيار دوار.

7-بنانة لتوصيل الطرف COM
8-بنانة لتوصيل طرف قياس الجهد /Ω/ L1
9-بنانة لتوصيل طرف القياس L3
10-ضاغط لقياس التردد
11-ضاغط لإظهار آقل واقصى قيمة للقراءة.

Figure 13: Show Clamp meter.

Figure 15: Show Digital Clamp meter.   Figure 14: Show Analog Clamp meter.

How to use the Avometer:

1. Potential difference measurement.
2. Current measurement.
3. Resistance measurement.

2.4 Practical Exercise No2, How to use the AVOmeter:

2.4.1 Introduction:

When using the AVOMETER, the indicator (in the middle of the device) should be marked to indicate the object to be measured (voltage, current, resistance) before using it in the circuit, and any error, in this case, leads to damage to the measuring device. For example, the position of the indicator in the (ohm) and its use to measure the difference of effort.

2.4.2 Measuring voltage difference:

If the device is used to measure the voltage difference, the device shall be connected in parallel between the two points to determine the voltage between them so that the negative terminal in the device connects with the negative point and the positive terminal in the device with the positive point.

2.4.3 Current measurement:

When the AVOMETER is used to measure current intensity, it is connected in series with the circuit at the point where the current is to be observed, considering the directions at the connection. If the electrodes of the AVO (negative and positive) are reversed at the conduction, the indicator will move in the opposite direction. This is in the case of mechanical AVO. In the case of digital AVO, the reading on the screen is negative. In this case, the poles of the AVO should be reversed.

2.4.4 Resistance:

In the case of resistance measurement, the AVOmeter must be connected between the two ends of the resistance without regard to negative and positive directions.

2.5 The Oscilloscope:

An oscilloscope is a laboratory instrument commonly used to display and analyse the waveform of electronic signals. In effect, the device draws a graph of the instantaneous signal voltage as a function of time.

Oscilloscopes are used to observe the change of an electrical signal over time, such that voltage and time describe a shape, which is continuously graphed against a calibrated scale. The observed waveform can be analysed for such properties as amplitude, frequency, rise time, time interval, distortion and others. Most oscilloscopes can only directly measure voltage, not current. One way to measure AC current with an oscilloscope is to measure the voltage dropped across a shunt resistor.

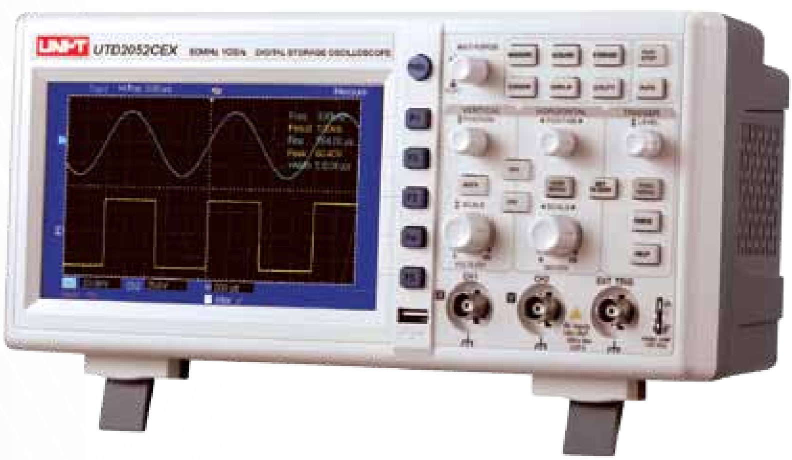


Figure 16: Show Oscilloscope.

2.6 Exercises:

Question 1:

Define the following terms:

1. Instantaneous power of solar energy
2. Clamp meter
3. Oscilloscope
4. Pyranometer
5. Solarimeter

Question 2:

Answer briefly:

1. Solar radiation reaching the earth is divided into:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

2. The cumulative energy of the sun depends on:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

3. Sun spectrum consists of:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

   3. ………………………..…..……..………

4. Write three factors that make solar energy variable in value and intermittent in its existence:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

   3. ………………………..…..……..………

5. Write three devices that are used to measure the current and voltage difference:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

   3. ………………………..…..……..………

6. Write three factors that affect the rate of future solar radiation by solar systems:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

   3. ………………………..…..……..………

7. The percentages of the components of the Sun spectrum are:

   1. ………………………..…..……..……… 2. ………………………..…..……..………

   3. ………………………..…..……..………

Question 3:

Draw a circle around a letter that has the **best** answer:

1. A device used to measure voltage, current and resistance, and the indicator system is used when reading. In this case, the indicator should be set (at zero) before using it:

   a. Thermometer b. Oscilloscope c. AVOmeter d. Clamp meter

2. The solar power per square meter is measured by:

   a. Voltage b. Amp c. Jol d. Watt

3. The sun reaches the Earth in the form of waves:

   a. Photographic b. Magnetism c. Photoelectric d. Electromagnetism

4. The best device to measure the intensity of solar radiation:

   a. Solarimeter b. Pyranometer c. AVOmeter d. Reference Cell

5. The four seasons (winter, spring, summer, fall) are produced by the rotation of the earth around:

   a. Earth axis b. Sun c. Moon d. Mars

6. One of the most important measuring devices and electronic circuit testing is where we can see the signals at multiple points of circuitry:

   a. Thermometer b. Oscilloscope c. AVOmeter d. Clamp meter

7. The maximum hourly daylight hours in Sudan ranges from:

   a. 8 to 10 hours b. 10 to 12 hours c. 12 to 14 hours d. 10 to 14 hours

8. Temperature measurement system:

   a. Cent b. Fahrenheit c. Kelvin d. All answers are correct

9. The spectrum of UV(Ultraviolet) rays from the spectrum of the sun represents:

   a. 7 % b. 9 % c. 44 % d. 47 %

10. A device used to measure current intensity during the operation of the electric circuit without having to separate the circuit and then reconnect it to another.

    a. Thermometer b. Oscilloscope c. AVOmeter d. Clamp meter

3. Conversion of solar energy into a useful energy:

Solar energy can be converted into a useful form of energy in different ways. Two popular types of converting solar energy are:

3.1 Thermal conversion:

Thermal energy technology is used to generate energy from the sun through solar collectors (usually flat plates), which in turn generates heat energy ranging from low to medium ready for direct use. One of the most popular uses of this energy is solar water heating systems, swimming pools as well as cooling systems both in residential and commercial buildings.

3.2 Photovoltaic conversion:

Solar cell technology is used to absorb and collect energy from solar radiation and convert light directly into electrical energy using photovoltaic effect. These cells manufactured using semiconductor materials such as silicon. They are also called photovoltaic cells (PV Cells).

3.3 Exercises:

1. What do we mean by "**Conversion of solar energy**"?
2. Compare between **Photovoltaic** conversion and **Thermal** conversion.

4. PV solar cells:

PHOTOVOLTAICS indicates the followings:

1. Photo - Light (solar radiation)
2. Volt- Electricity
3. Photovoltaic cells transform solar radiation directly into electricity

4.1 Photovoltaic Cells (or Solar cells):

1. The most common type of photovoltaic cells is made of sand. Sand is the silica form of the element, SILICON.
2. The first step in making a photovoltaic cell is to melt the silicon under extreme heat, remove the impurities and then re-crystallise it into a uniform (monocrystalline) or slightly non-uniform (polycrystalline) structure.
3. The second step in making a photovoltaic cell is to add small quantities of other types of atoms to the crystalline structure. This process is called DOPING.
4. If the other atom contains more electrons than the silicon atom, the structure would acquire an excess of electrons. This is called N-type. This is a part of the photovoltaic cell structure that has an excess of electrons, and therefore an overall negative charge. A common doping material is PHOSPHOROUS.
5. If the other atom contains fewer electrons than the silicon atom, the structure would have a shortage of electrons. This is called P-type. This is a part of the photovoltaic cell structure that has a shortage of electrons (sometimes called "holes"), and therefore an overall positive charge. A common doping material is BORON.

4.2 Making a Photovoltaic Cell:

1. The N-type and the P-type silicon are brought together.
2. When the two types of semiconductors are brought together, the N-P JUNCTION is created.
3. The N-P JUNCTION is an area of the photovoltaic cell where an electromagnetic field has formed. The electromagnetic field maintains the separation of the positive charges in the P-Type layer and the negative charges in the N-type layer.

4. The negative and positive charges balance each other at the N-P Junction.
5. The phenomenon of making electricity with light is caused by the interaction of light with atoms in the photovoltaic cell.
6. The sunlight varies in strength given its particular wavelength (ex. ultraviolet is stronger than infra-red).
7. If the light is strong enough, it can release electrons in the photovoltaic cell and these negative charges are free to roam around.
8. A free electron is accelerated by the electromagnetic field at the N-P Junction and is pushed up through the N-type layer.
9. A voltage drop appears between the two sides of the N-P junction, and if connected to an external circuit, a current is induced. ELECTRICITY FROM SUNLIGHT!

Solar radiation converted to electric charge movement

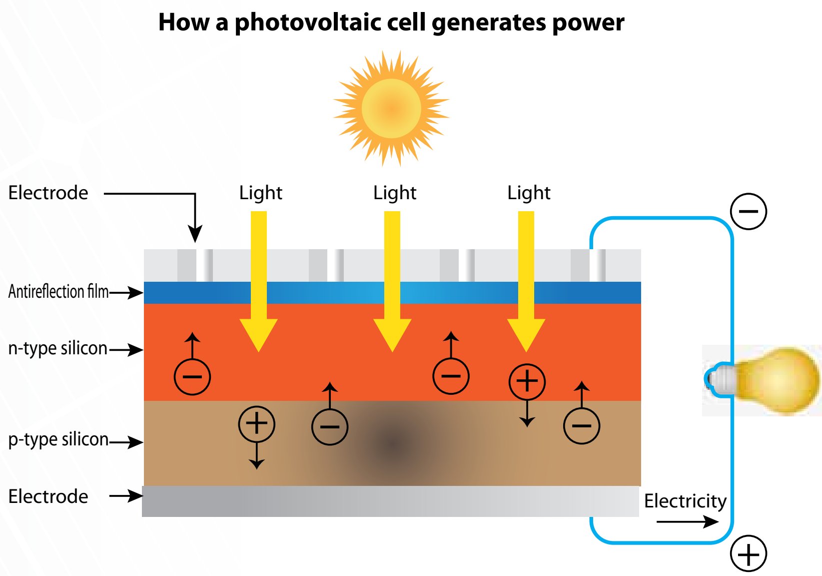


Figure 17: Show How a Photovoltaic cell generates power.

4.3 Types of Solar Cells:

Solar Cells are made of three different types of silicon namely: the first type is monocrystalline silicon which can have conversion efficiency up to 25% and a lifetime of more than 25 years.

First Type:

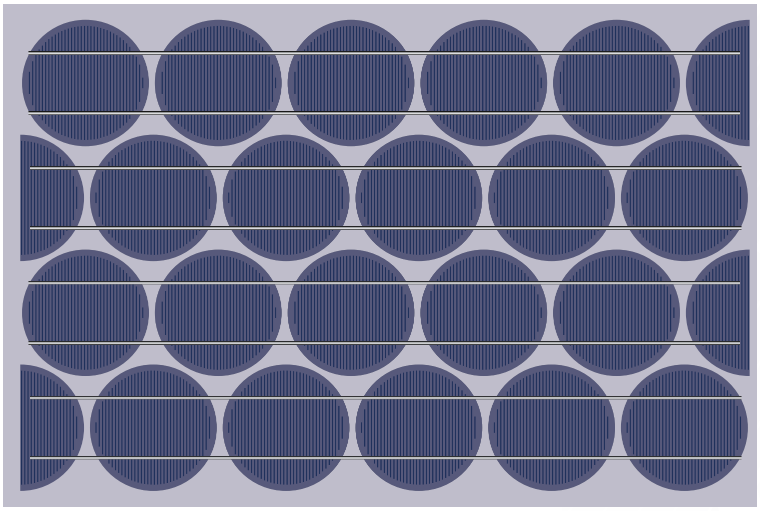


Figure 18: Monocrystalline Silicon Cell.

Second Type:

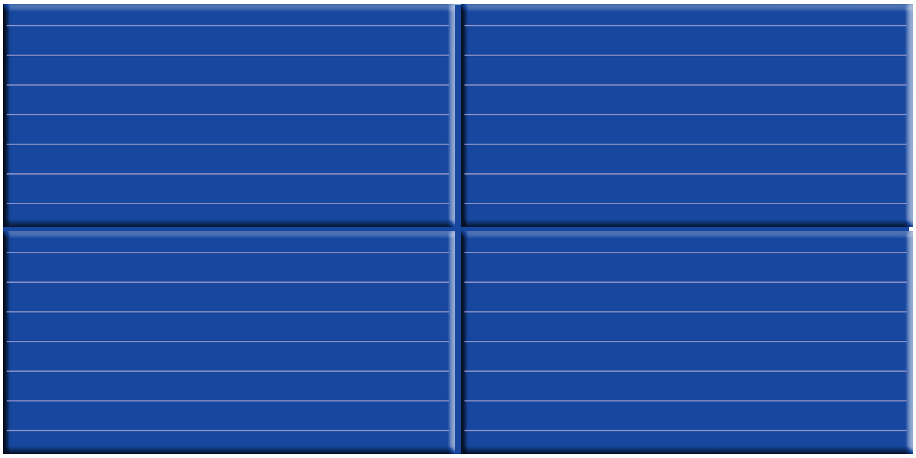


Figure19: Polycrystalline Silicon Cell.

Third Type:

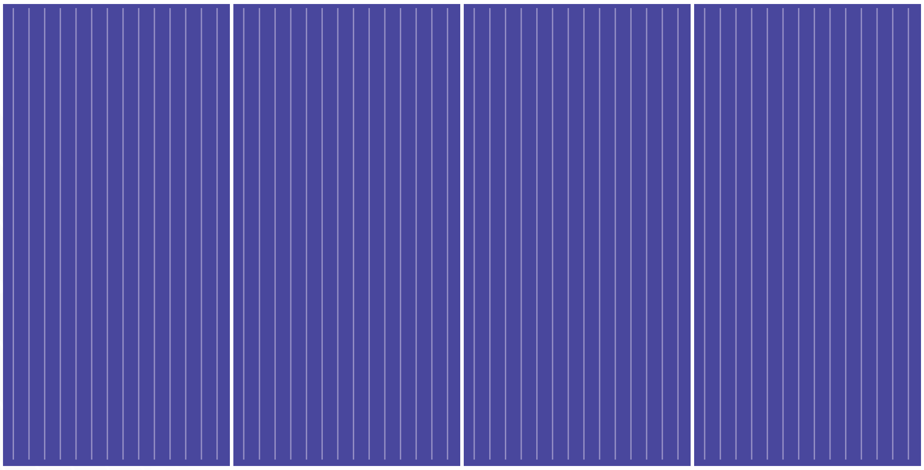


Figure 20: Amorphous Silicon Cell

4.4 Electrical Diagram representing a photovoltaic Cell

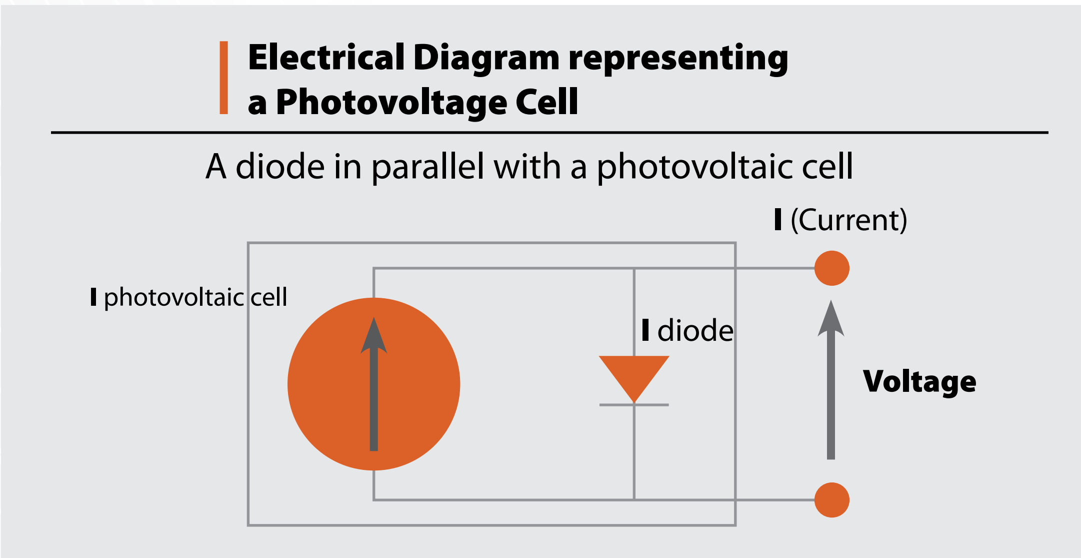


Figure 21: Show solar cell circuit.

Electrical Characteristics of a Photovoltaic Cell

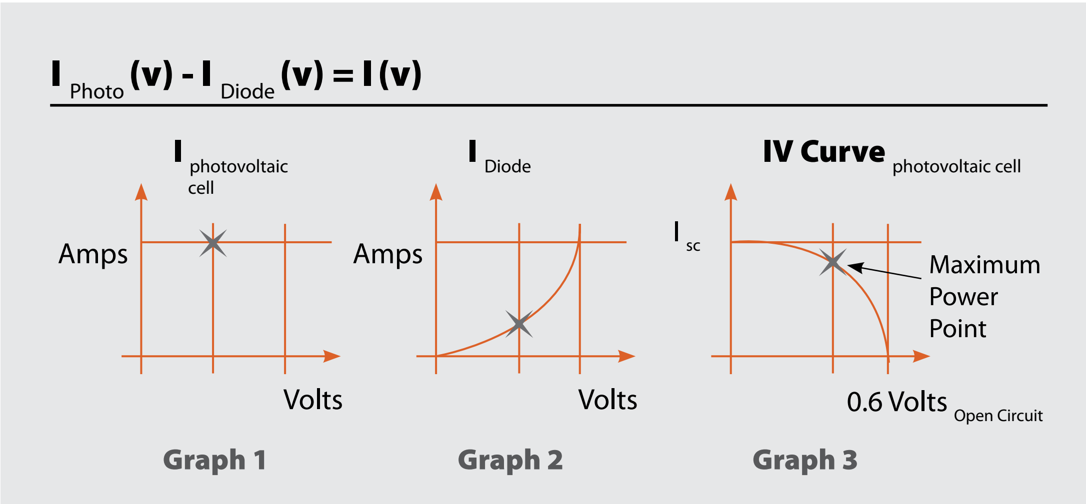


Figure 22: Show how the current is calculated in the solar cell circuit.

The voltage created by the creation of the N-P junction is .485 Volts, no matter how big or how small the cell is.

However, the amps that any one cell can produce is a function of the size of the cell. A 10cm x 10cm photovoltaic cell (ex. PWX500) produces about 3 amps at 25° C (1000 W/m^2).

Current and Voltage Curves for a Single Photovoltaic Cell

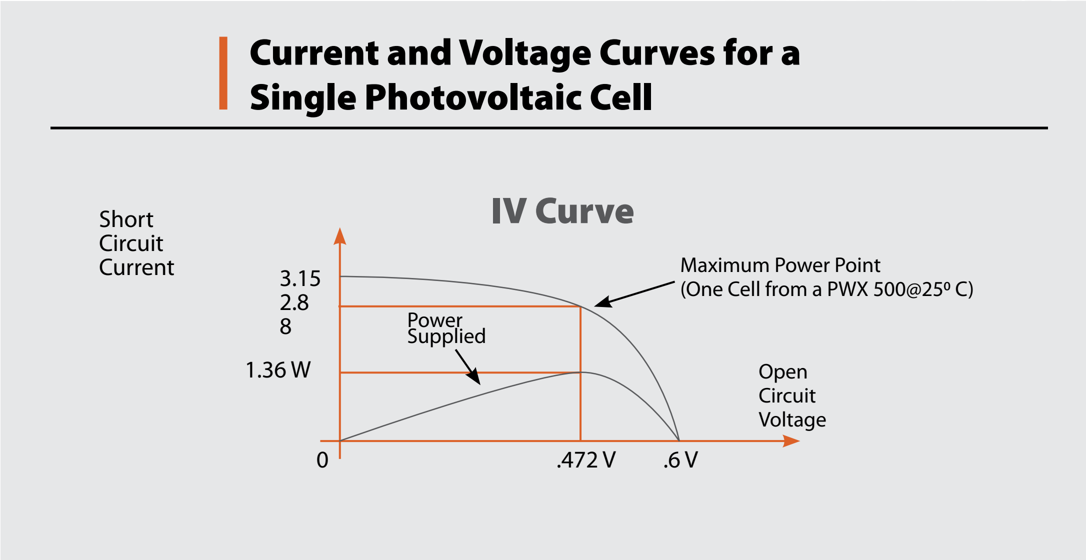


Figure 23: Show voltage and current curve.

Getting cells together

1. After the N-P Junction is created, an anti-reflective coating is applied to the cell.
2. After the anti-reflective coating, the thin grid of metal is applied to the top (18%) and bottom of the cell. These are the conductors for the electrons.
3. Finally, the cells are connected with thin ribbons of wire.
4. The Photovoltaic cell ready for placement in the Module

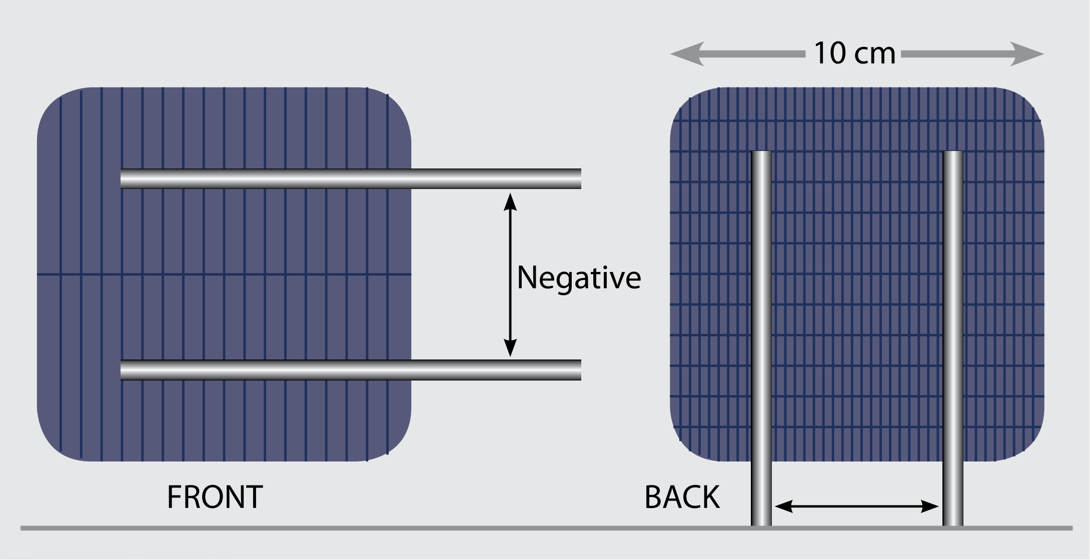


Figure 24: Show solar cell front and backsides.

4.5 Exercises:

Question 1:

Define the following terms:

1. Solar Cell
2. Solar Cell Circuit
3. Monocrystalline
4. P-N Junction

Question 2:

Answer the following:

1. Compare between **Polycrystalline** and **Amorphous silicon**
2. What is the thing that increases the scalability of silicon crystal conductivity?

5. PV solar modules:

5.1 Construction of a module:

A solar module is number of PV cells connected in series and/or parallel.

The cells are encapsulated with the EVA and then a gasket and aluminium frame is put around the glass to seal it against the environment.

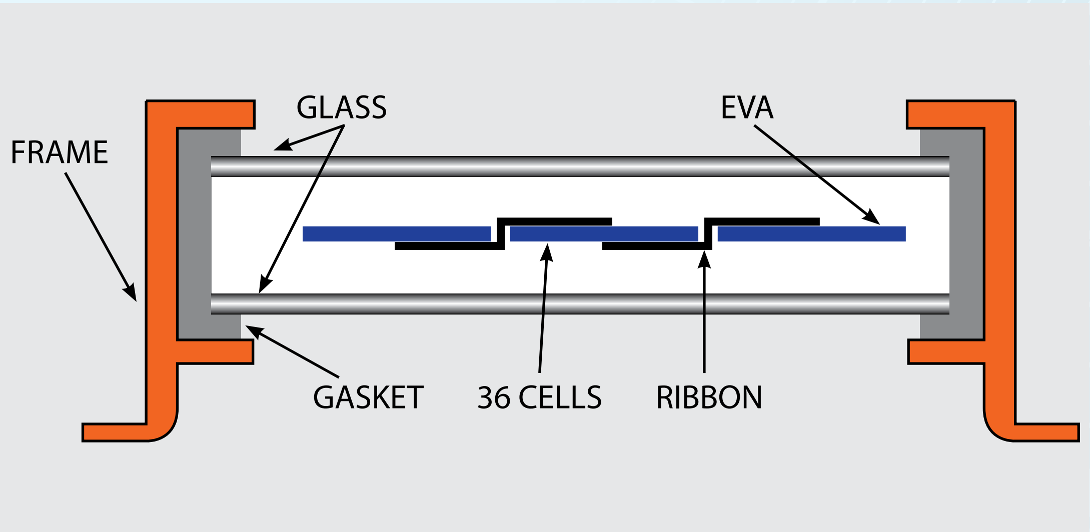


Figure 25: Show construction of solar panel.

1. Solar modules have the following specifications:

1. Open circuit voltage between 17 to 20 volts.
2. Module voltage when connected in a circuit is higher than 12 VDC.
3. Module current depends on its surface, solar radiation and temperature. For 100-Watt peak module it ranges between 4 and 6 Amp.
4. At the back of any solar module, the manufacturers put a preamble that specifies the characteristics of the solar cell, which includes:
   a. Peak Power (Watt Peak (W_p))
   b. Short Circuit Current (I_{sc})
   c. Open Circuit Voltage (V_{oc})

Table 2: Module Specifications

Code	
Model	50116
Power	FVG 50P
Peak (W)	50
Vm (V)	17,5
Im (A)	2,90
Voc (V)	22,00
Isc (A)	3,20

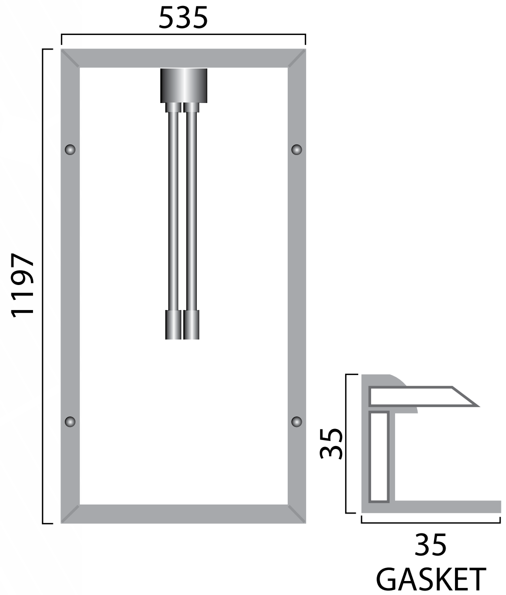
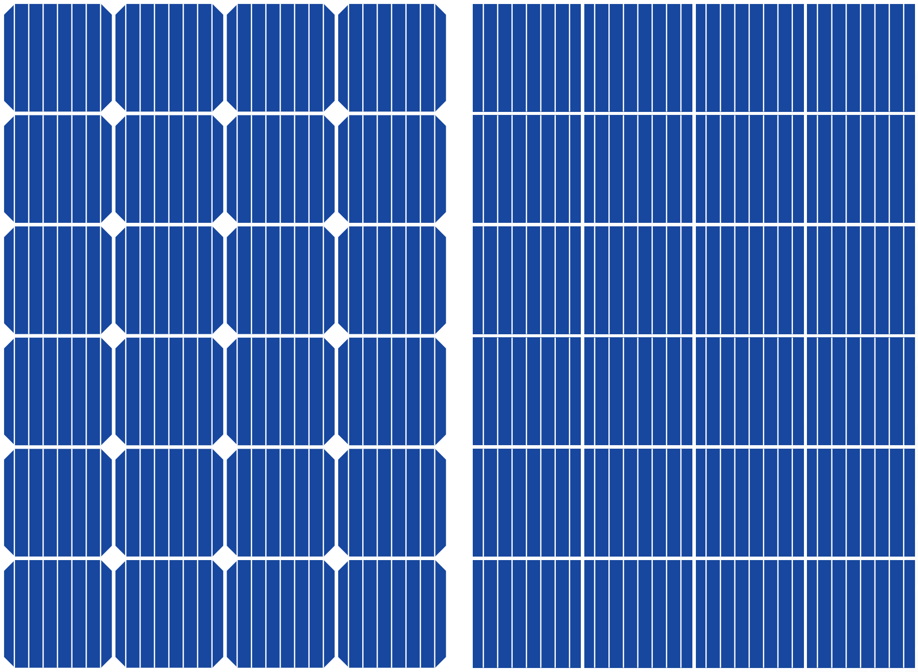


Figure 26: Surface of Solar Module.

Solar modules are produced in different powers, from 5 W_p to 400 W_p.

The Watt peak (W_p) is electrical power delivered by PV module at a standard condition, 1 KW/m2 solar radiation and at an ambient temperature of 27-degree C.



Monocrystalline PV Module Polycrystalline PV Module

Figure 27: Shape of solar PV modules.

1. Electrical Diagrams of a PV module:

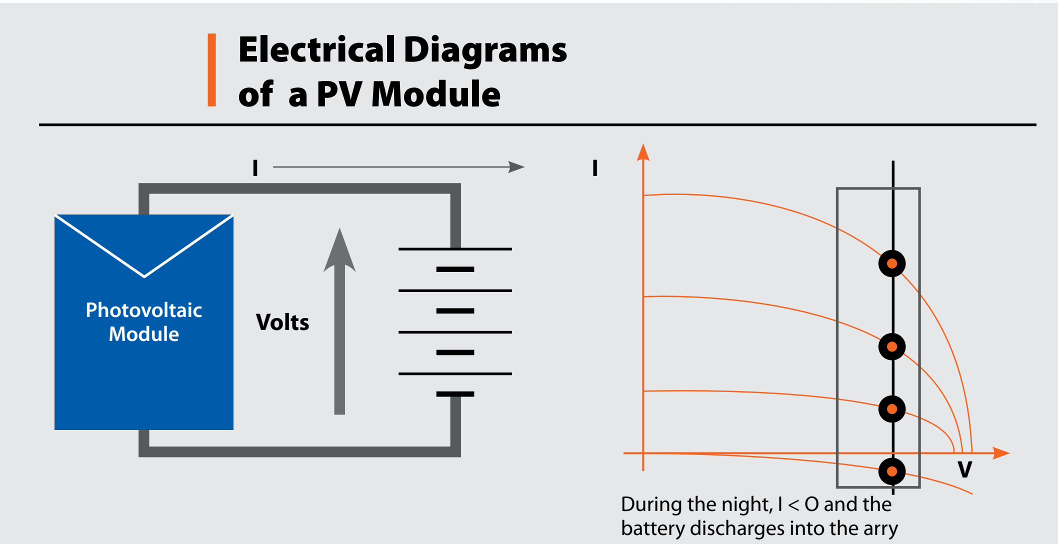


Figure 28: Show Electrical Diagrams of a PV module.

5.2 How to put solar cell panels (Orientation of modules):

- Solar cell panels are placed southward in the northern hemisphere and placed northward in the southern hemisphere at an angle of Milan equal to the latitude of the site to be installed.

The standard angles are:

5, 10, 15, ..., 25 degree

- The solar cells are placed where they will not get broken and there are no shadows like the shade of trees and buildings.
- It should be cleaned of dust and it is important to remove the barriers that block the sun periodically.

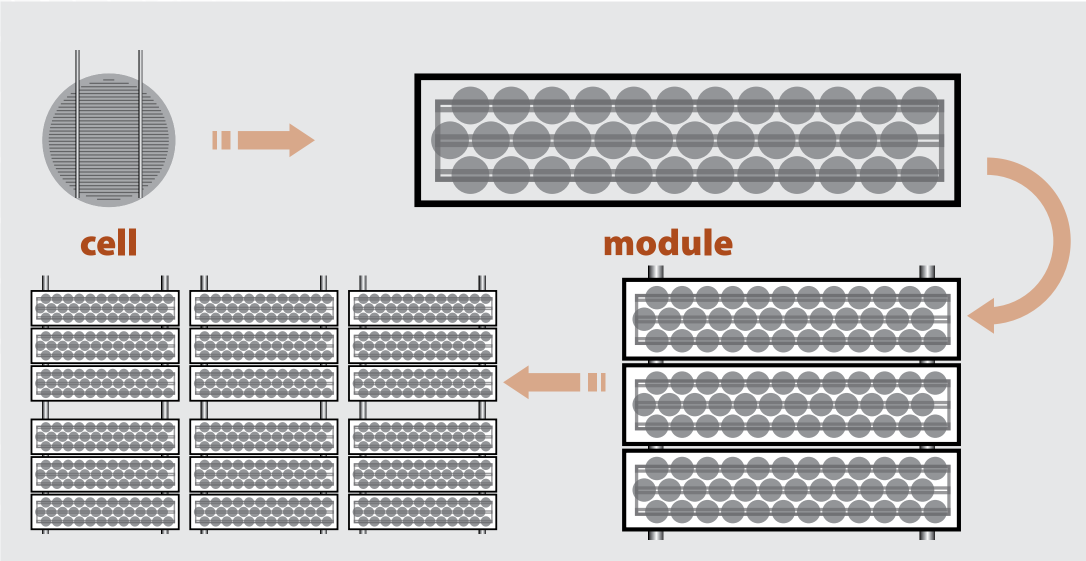


Figure 29: Flowchart for cell transformation of a cell panel then a cell array and then a solar generator.

5.3 Practical exercise No. 3. Wiring of solar modules

5.3.1 Parallel Strings of modules:

The amps add up while the voltage stays the same.

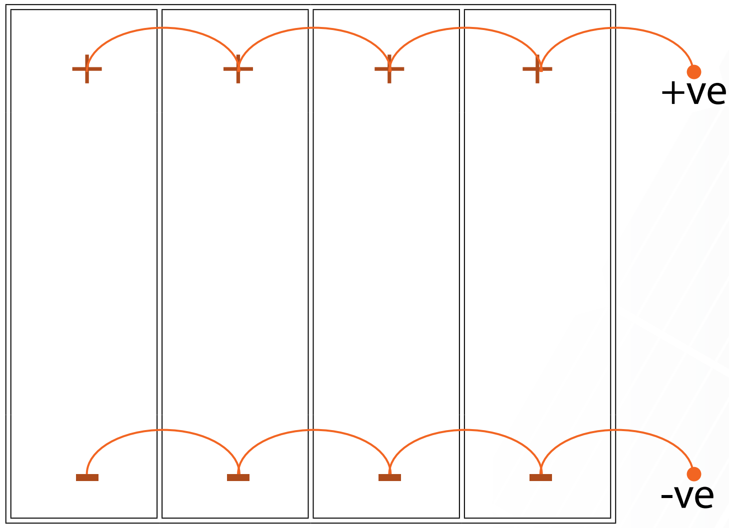


Figure 30: Parallel connection.

5.3.2 Series strings of modules:

The voltage adds up while the amps stay the same.

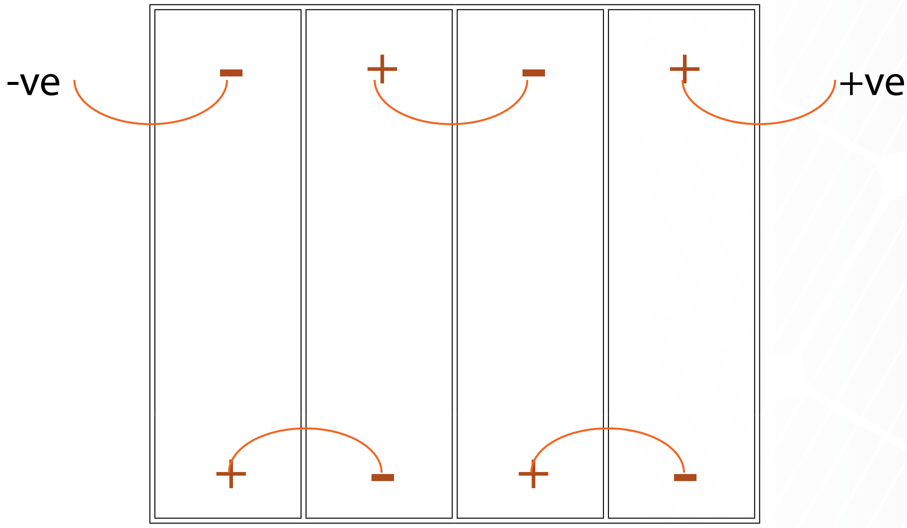


Figure 31: Series connection.

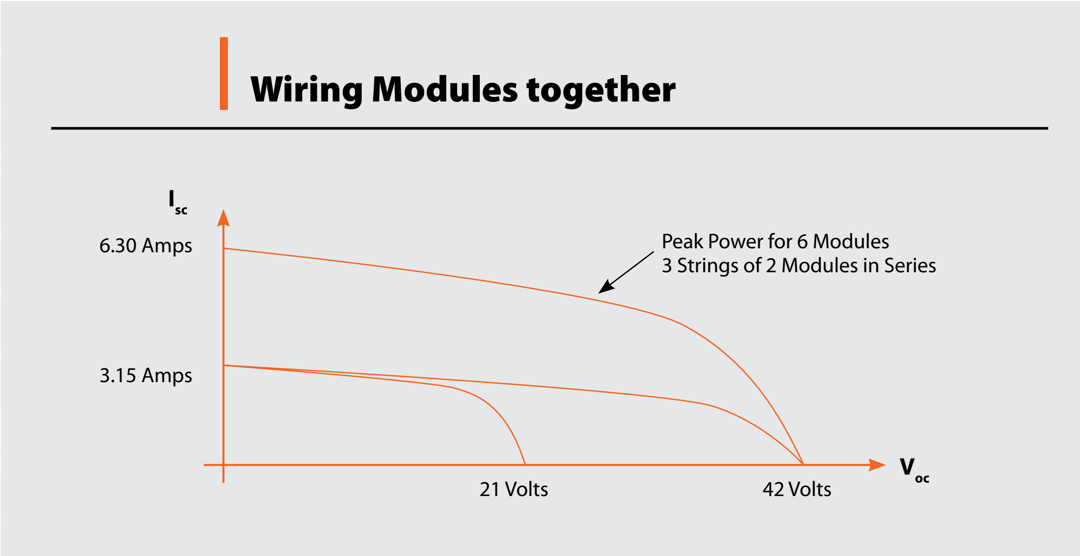


Figure 32: Show I-V curves of wiring modules.

People should careful when connecting solar modules in series. One can get very high DC voltages, which is dangerous and can kill.

5.3.3 Series- Parallel strings of modules:

Always make your series connections first and then make your parallel connections.

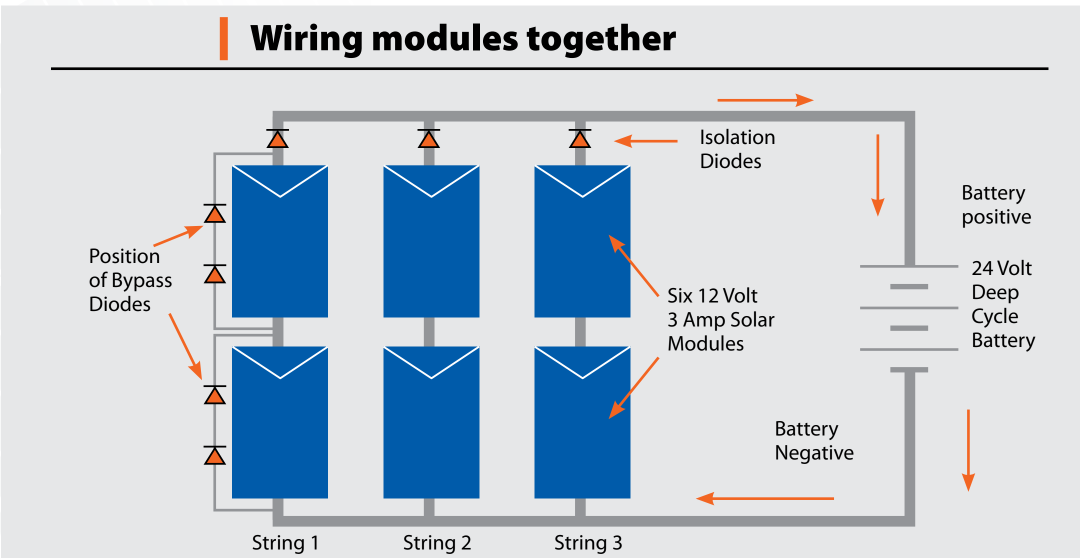


Figure 33: Show How to connect composite panels of solar cells.

5.4 Exercises:

Draw a (✓) mark in front of the correct answer and a (×) mark in front of the wrong answer; and then correct the wrong answer:

1. Solar cell panel is the smallest unit of solar cells commercially sold ....( )

   ....

   ....

2. In Home connection, total current intensity = current intensity of one cell × number of cells ....( )

   ....

   ....

3. It is preferable to use parallel connection in solar pumps used for water pumping and some solar refrigerators........................( )

   ....

   ....

4. When putting the panels of solar cells at an angle of inclination equivalent to the latitude of the location to be installed. And possible at an angle of 47 degrees .....( )

   ....

   ....

5. There are electrical devices working in the 24-volt voltage and pulls a current of more than 6 amperes depending on the electrical power of the device. In this case, a number of solar modules are connected in Parallel to increase the variation in voltage and Series to increase the current intensity ....( )

   ....

   ....

6. The solar module is placed in a copper frame to protect it from breakage and weather conditions. ....( )

   ....

   ....

7. Composite connection is the connection (Series - Parallel) to increase the voltage variation and current intensity .... (   )

....

....

8. To increase the voltage variation, this is done by increasing the number of solar modules. The positive pole is connected to the first module with the negative pole of the second module, then the second positive with the negative third, and so until the end of the connection. This type of connection is called the series connection .... (   )

....

....

9. Maximum electrical power can be obtained from the solar cell panel when the plate temperature is 20° C and the intensity of solar radiation is 100 watts / m 2 .... (   )

....

....

10. The plates of the solar cells shall be placed northward in the Sudan and placed towards the south in Brazil and at an angle of inclination equivalent to the latitude of the location to be installed.

6. PV solar systems and applications:

6.1 Layout of the general solar system and its components:

The solar cell system consists in the simplest form of the following components:

1. PV solar modules.
2. Storage Batteries.
3. Battery Charge Controller) BCU).
4. DC-AC Inverter.
5. Load or application.

The following images illustrate the general framework of any system using solar cells as an energy source:

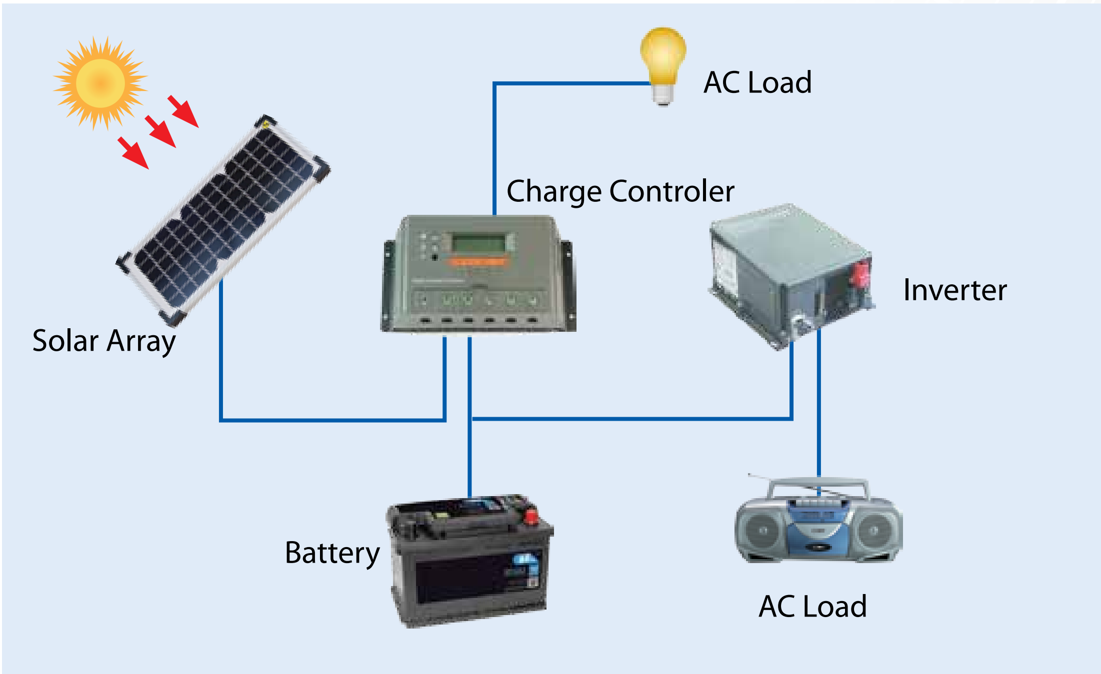


Figure 34: Show The general framework of any system using solar cells as an energy source.

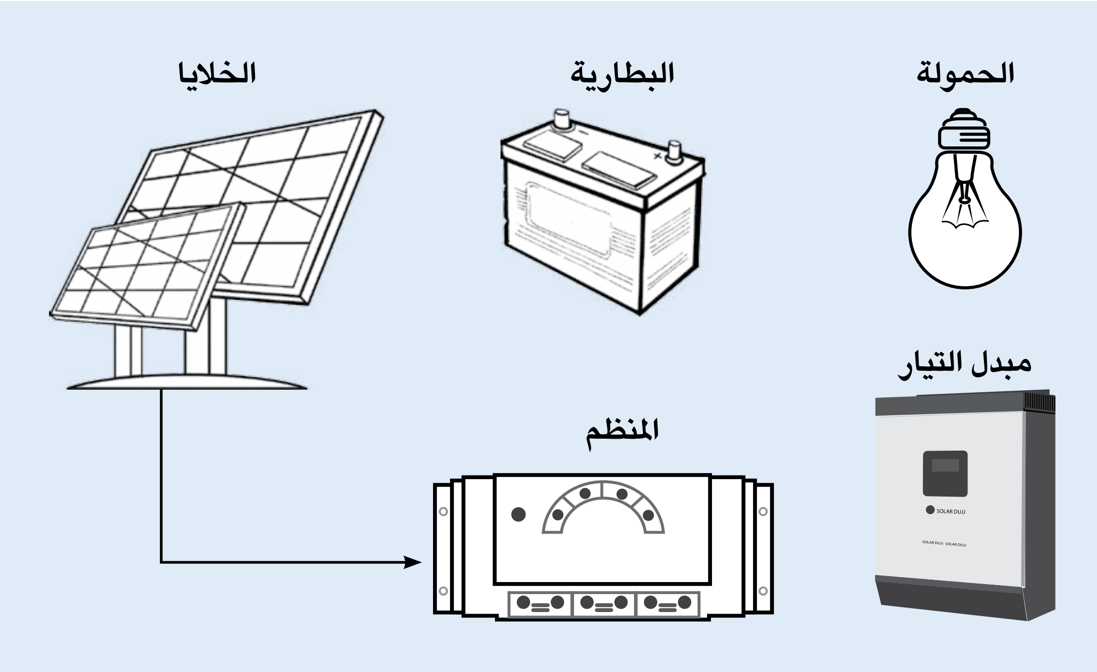


Figure 35: Show The general framework of any system using solar cells as an energy source

Figure 36: Show The general framework of any system using solar cells as an energy source.

6.2 Applications:

There are many applications that use solar cells such as:

- Lighting
- Battery charging
- Water pumping
- Telecommunication
- Refrigeration and air conditioning
- Others.

6.3 Exercises:

Answer briefly:

1. Write four applications that use Solar Cells:

   1.. 2. ....

   3. .... 4. ....

2. Write four components of Solar Cells:

   1.. 2. ....

   3. .... 4. ....

3. Write four devices that The Solar Cells can be their energy source:

   1.. 2. ....

   3. .... 4. ....

7. Storage Batteries:

7.1 Energy storage in PV systems:

1. There are many different types of batteries but the DEEP CYCLE LEAD-ACID Battery is the most common type used in photovoltaic systems.
2. Batteries are used to store electrical energy generated by the solar modules during the day and then deliver energy directly to DC loads or to the AC loads (via an Inverter).
3. Other types of energy storage include raised water tanks and alkaline batteries.

7.2 Battery terms:

1. Cycle - an interval that includes one period of discharging and one period of charging.
2. Amp-hour (AH) Capacity - the number of amps a battery can discharge, multiplied by the number of hours it can deliver that current.
3. Depth of Discharge - how much of the total AH capacity of the battery is used after a discharge.
4. State of Charge - measured with a hydrometer or voltmeter (the opposite of Depth of Discharge).

7.3 Internal construction of a battery:

1. A battery is a group of cells (or elements).
2. Each cell in a lead-acid battery delivers 2 volts (1.2 volts for an alkaline cell).
3. 6 lead-acid cells are connected in series to create a 12-volt battery.
4. Each ventilation hole on the top of a battery represents one cell.

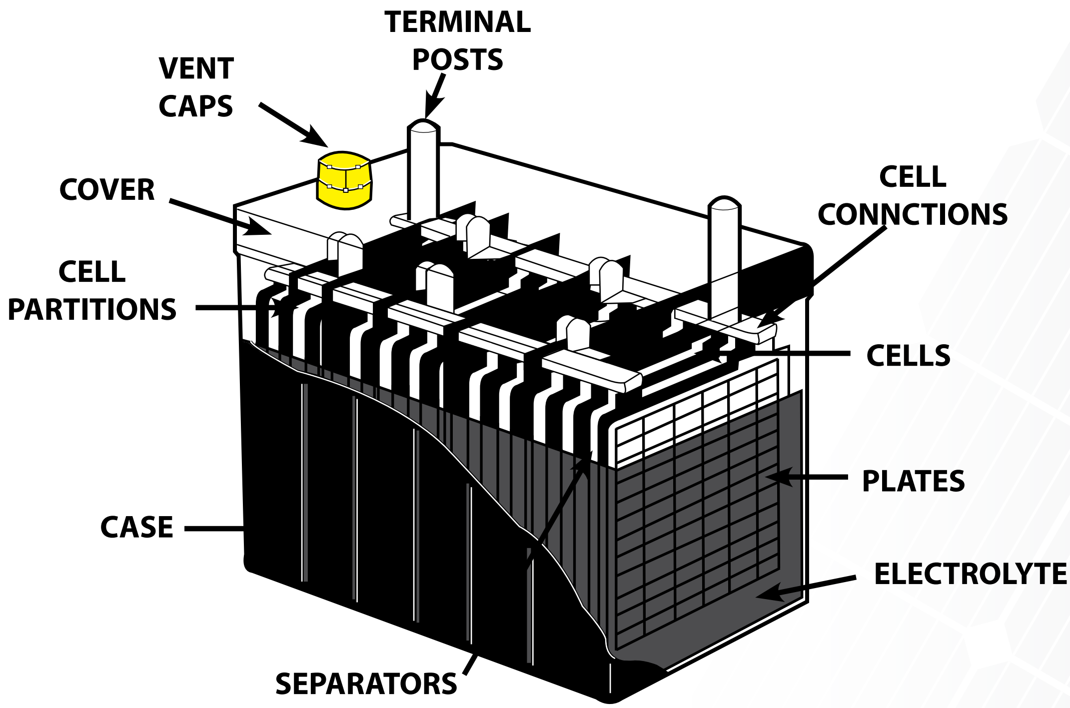


Figure 37: Show battery components.

7.4 Types of batteries:

There are two types of batteries, which are dry batteries and liquid batteries.

7.4.1 Lead-acid Batteries (Liquid Batteries):

They are two types of plates- the lead and the lead oxide, representing the negative and positive pole. These plates are immersed in sulfuric acid of a certain density.

This battery unit is called a cell, and it gives a voltage variation of 2 volts.

The battery is a set of connected cells, respectively (series). An example of a battery that produces a 12-volt voltage variation consists of 6 connected cells, respectively.

Figure 38: Show Liquid Battery.

7.4.2 Dry Batteries:

This type of battery uses sulfuric acid diluted in chemical reaction and it is rigid. It is used in the operation of satellites and solar devices.

Its default age ranges from 5 to 15 years.

Figure 39: Show Dry Battery.

7.5 Practical exercise No. 4, acid filling and connecting batteries

1. Fill the battery with pure sulfuric acid, density of 1,250 degrees. Load the battery up to the top of the layers by 10 mm 3.
2. Stabilise the battery stoppers and wash off traces of acid that may have fallen on them and dry them.
3. If the acid density is less than 1,220 degrees, the battery should be charged until the density reaches 1,250 degrees again.
4. The acid density is measured by the Hydrometer and can be used by immersing it in the acid (inside the battery) with the pressure of the tube in the back and leaving the acid until it reaches the highest level in the device.
5. When the battery is charged, the positive pole is connected to the positive pole of the charging current source and the negative pole to the negative pole of that source.
6. When the battery is used after charging, the positive pole must be connected to the positive electrode as well as the negative electrode pole of the load.
7. The cleanliness of the bulbs shall be observed at the connection, and the wires shall be firmly connected to prevent the energy leakage and the polarisation of the poles together.
8. If the load needs 12 volts but to two batteries, the two batteries must be connected in parallel in this case.
9. If the load requires 24 volts, two batteries must be connected in series by connecting positive one to the second negative.
10. By following the above method, any number of batteries can be connected in series, parallel or series-parallel connection.

7.6 Categories with Depth of Discharge (DOD):

The batteries are divided by the depth of the discharge (D.O.D) to:

7.6.1 Shallow Discharge:

This type of battery life has a short life (3 years) and discharge is not likely to exceed 30% of the battery capacity. If the discharge is higher than this, it will lead to lead consumption and reduce the battery life. Commercial Batteries are used for vehicles.

Figure 40: Show Commercial Battery.

7.6.2 Deep Discharge Batteries:

It is one of the best types of batteries in terms of capacity and long lifespan (5-25 years). It can be discharged to 60% of its capacity and there is a difference of 2, 6 or 12 volts. They are found in different capacities. The battery life is estimated by the number of cycles, and it means charging and discharging the battery.

Figure 41: Show Deep Discharge Battery.

7.7 General maintenance:

1. The water level of the battery should be detected once a week. If it is low, add distilled water (only) until it reaches 10 mm above the layers.
2. The battery must be kept clean and dry from impurities.
3. If the battery remains unused and is full, it must be recharged once a month.

7.8 Charging:

1. The battery status should not be detected by connecting the two ends of the battery with a cable or screwdriver and sparking, as this causes a high amp current to damage the internal battery parts, and the active material is dissipated on the panels.
2. The battery should be charged at a maximum of 10% of the battery capacity, and the charging should continue until the bubbles are formed and confirmed for two hours, leaving the plugs unplugged during charging.
3. If the temperature is above 50°C, the charging amp should be reduced or the charging stopped until the battery is fully cooled.
4. Distilled water should be added if the water level inside the battery drops to 10 mm above the plates during and after charging.
5. Overload the acid quickly consumes the lead plates and thus reduces the battery life.
6. Battery life depends on the quality of the battery but if the above maintenance method is followed, it can achieve the largest time to be utilised.
7. In the towing of the charged battery, the charged power should not exceed 30% of its capacity. Therefore, the battery should be charged as low as 30% of its capacity, in order to reduce its lifetime.

7.9 Practical exercise No. 5, connection of batteries

✓ When the battery is used after charging, the positive pole must be connected to the positive electrode as well as the negative pole of the negative electrode.
- Note the cleanliness of the coils when connected and connect the wires firmly to prevent energy leakage and the poles' contact with each other.

- ✓ If the load needs 12 volts but to two batteries, the two batteries must be connected in parallel by connecting the two poles in the two batteries with each other.
- ✓ If the load requires 24 volts, then two batteries must be connected respectively by connecting one positive one to the other.

By following the above method, any number of batteries can be connected in parallel, parallel or parallel-parallel mode to obtain the desired voltage and power.

As an example: if we have four batteries, each of 12 volts, and we need 24 volts to operate the load and also need the capacity of all four batteries, in this case we must connect two batteries in a row and connect the group in parallel or we can connect two batteries in parallel and then connect the group respectively.

7.10 Different factors affecting battery performance:

1. Charge & Discharge Rate, the "C" Rate (capacity/hours)
   C/20 = it will take 20 hours to fully discharge the battery
2. Temperature (25°C is ideal).
3. Daily average Depth of Discharge (10-20% is ideal).

Different factors affecting Battery Performance

- Charge & Discharge Rate, the "c" Rate (capacity / hours) C/20 = it will take 20 hours to fully Discharge the battery.
- Temperature (25° C is ideal).
- Daily average Depth of Discharge (10 - 20% is ideal).

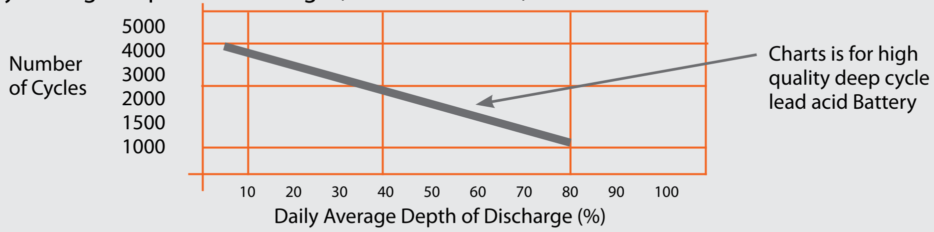


Figure 42: Shows reliance of battery cycle on the Depth of Discharge.

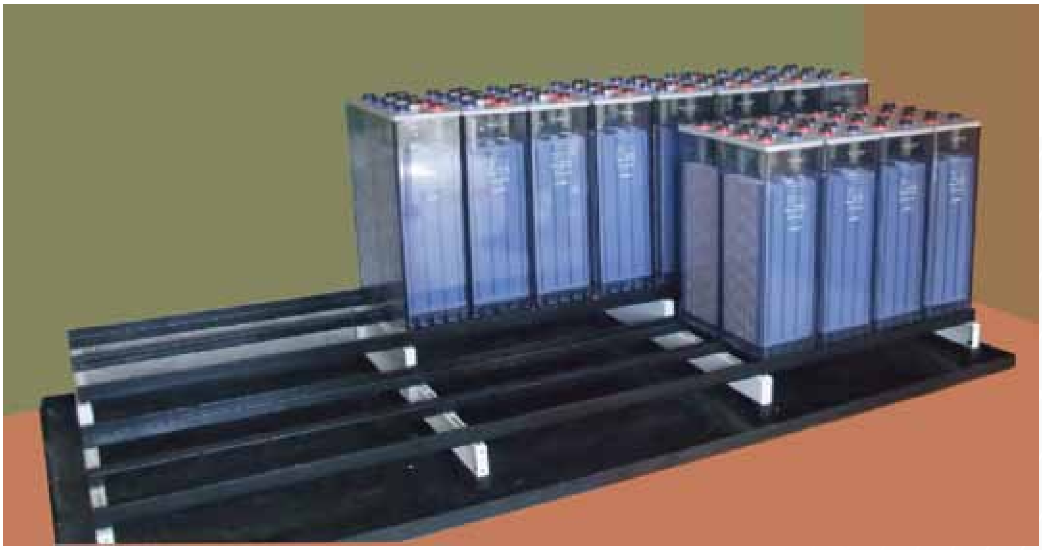


Figure 43: Show installation of battery bank.

Large 2V cell batteries each cell ~ 3500 Ah weighing 150 kg each. (Large installation). Note plastic tray to catch any acid as well as robust mounting system.

But we only get two or three years out of our batteries…!

1. Sulfation - the result of a low average Depth of Discharge (crystallisation of the lead sulfate).
2. Stratification - no equalisation charges every 60 cycles (electrolyte separates into water and acid).
3. Insufficient charge rate - can happen when corrosion is allowed to build upon the post connections.
4. Diminished capacity - electrolyte level has not been checked and lead plates are exposed.
5. The primary function of the charge controller is to protect the battery from overcharge or over-discharge with the following characteristics:
    - Rated Nominal Voltage (12, 24, 48+).
    - Maximum current capabilities.
    - Indicator lights or alarms.
    - Equalisation charge function.
    - Low voltage disconnect.

7.11 Exercises:

Question 1:

Draw a (✓) mark in front of the correct answer and a (×) mark in front of the wrong answer, and then correct the wrong answer:

1. The battery is a set of connected cells in parallel.. (   )

   ....

   ....

2. When using the electric energy stored in the battery to operate electrical appliances, this process is called "battery discharge".. (   )

   ....

   ....

3. The battery capacity is not affected by battery type and manufacturing .... (   )

   ....

   ....

4. In the liquid battery, the sulfuric acid is diluted in the chemical reaction and it is rigid...(   )

   ....

   ....

5. The battery is a container that stores direct electrical energy (DC) in the form of chemical energy and turns it back into direct electrical energy when needed......................... (   )

   ....

   ....

6. When storing the amount of electrical energy in the battery for later use, this process is called "electrical energy stored in the battery"...(   )

   ....

   ....

7. Battery capacity is the electrical energy that can be stored in the battery and measured in volts-hours".. (   )

   ....

   ....

8. The Depth of Discharge (DOD) is the maximum amount of battery capacity that can be used at discharge, an it is proportional to the total battery condition..(   )

....

....

9. The battery-level water level is detected once a week and must be 20 g above the layers ....(   )

....

....

10. Life cycle is the number of times the battery can be charged and discharged and it determines the battery life...(   )

....

....

Question 2:

Draw a circle around the letter that has the best answer:

1. If the voltage variation of a battery is 48 volts, this battery consists of:
   a. 6 Cells b. 12 Cells c. 24 Cells d. 48 Cells

2. Battery capacity, when charged to a certain level proportional to the total battery capacity, is called:
   a. Capacity level b. Capacity state c. Charge level d. Charge state

3. The capacity of the battery is measured by:
   a. Voltage b. Amp c. Jol d. Watt

4. The unit of a single liquid battery gives a voltage variation equal :
   a. 1 volt b. 2 volt c. 3 volt d. 4 volt

5. In deep-discharge batteries, the battery can be discharged at a capacity of up to:
   a. 30 % b. 40 % c. 50 % d. 60 %

6. The acid density in which the battery is filled is measured by:
   a. Pyrometer b. Galvanometer c. Jol d. Hydrometer

7. If the battery remains unused for a period of one month and is full, it should:
   a. Replaced b. Change of acid (water)
   c. Recharged d. Change the lead boards to it

8. In the clouds of charged battery, preferably not withdrawn the energy of more than:
   a. 30 % b. 40 % c. 50 % d. 60 %

9. If the load needs 48 volts but 4 batteries, in this case the batteries should be connected to:
   a. Series b. Parallel c. Series-parallel d. It's not possible

10. From factors that affect battery performance:
   a. Battery capacity b. Battery type c. Life cycle d. Intensity of acid

8. Battery Charge Controllers:

8.1 Definition

The battery charge controller is an electronic device that controls the operation of the battery and protects it from the charging and discharging of the battery and also protects it from short circuit c/t.

Different types are available depending on the voltage and current voltage required: 12 volts, 24 volts, 10 or 20 amperes or more.

Basic Voltage regulation using a Charge/Discharge Controller

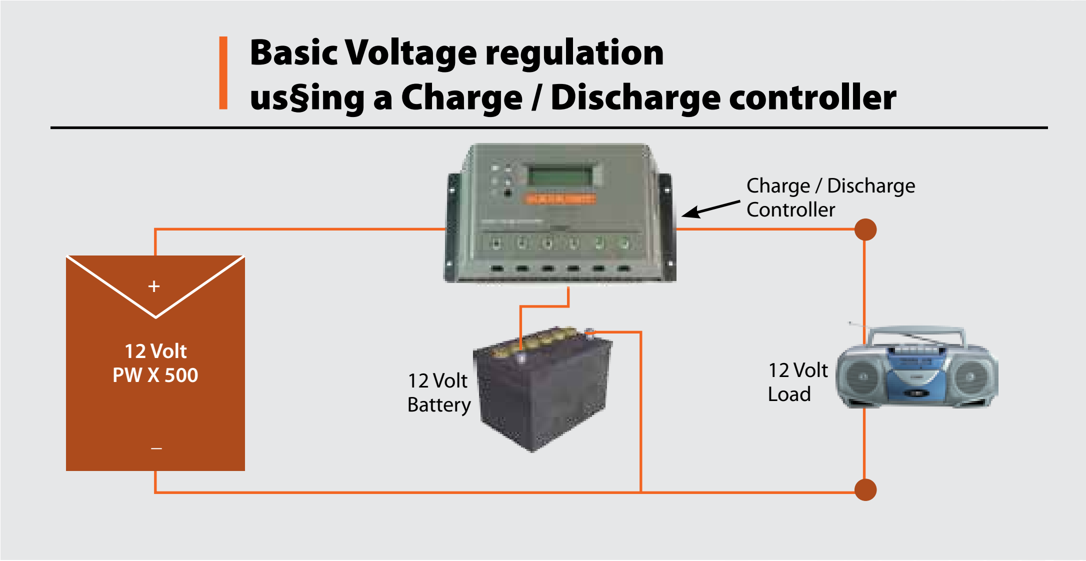


Figure 44: Shows series Battery Charge Controller operation.

8.2 Types

1. Series type.
2. Parallel type.
3. Microprocessor controlled type.

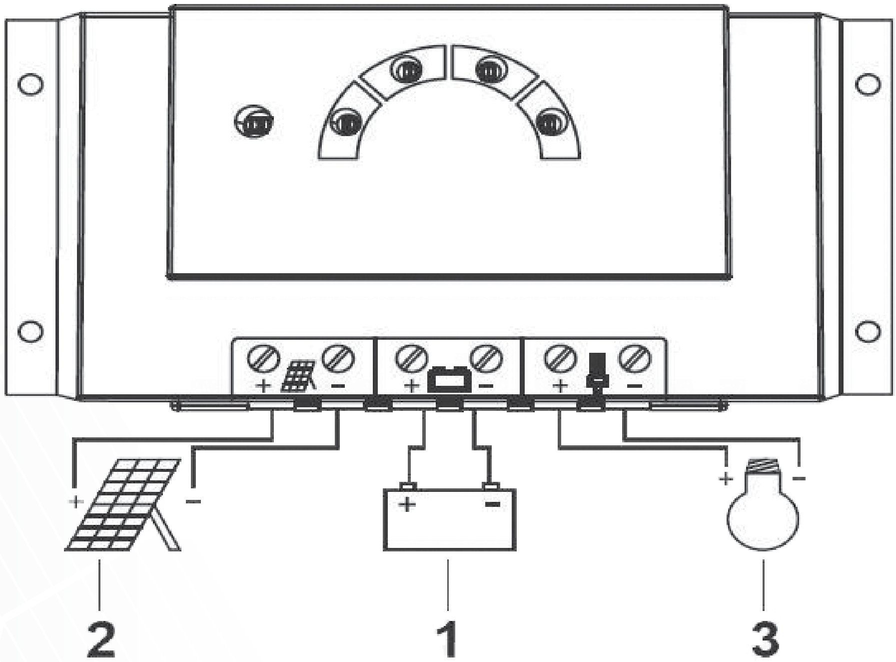


Figure 45: Shows front side of the Battery Charge Controller.

8.3 Practical exercise No. 6, connection of Battery Charge Controllers

When connecting any battery charge controller, the following steps should be followed as shown in the above figure 35:

1. First, connect the battery terminals to their corresponding terminals in the controller (point 1).
2. Second, connect the PV modules terminals to their corresponding terminals in the controller (point 2).
3. Finally, connect the load to its corresponding terminals (point 3).

When disconnecting the battery charge controller, the following steps should be followed:

1. First, disconnect the load.
2. Second, disconnect the PV solar modules.
3. Finally, disconnect the batteries.

Note: Never disconnect the battery before the PV solar modules.

Table 3: Show state of charge of battery with voltage values

Remarks	charge State of Charge	Battery voltage (volts)
Deep Discharge alarm	Less than 40%	11.2
Disconnect load	Less than 30%	10.8
Reconnect load	More than 50%	12.1
Equalise charge	More than 70%	8.12
Stop battery charge	Near 100%	14.18

- **Other types used as Battery Charge Controller:**

Steca Battery Charge Controller

Figure 46: Show Steca Battery Charge Controller.

8 Amp Controller

Figure 47: Show 8 Amp Battery Charge Controller.

21 Amp Controller

Figure 48: Show 8 Amp Battery Charge Controller.

8.4 Exercises:

1. What is the Battery Charge Controllers?
2. Write briefly about Microprocessor battery charge controller.
3. Compare between (Series Type) Battery Charge Controller and Parallel Type.
4. Compare between (8 Amp) battery charge controller and (21 Amp).

9. DC – AC Inverters:

9.1 Introduction & definition:

1. Inverters convert DC power from the batteries or solar array into AC power.
2. Different types of AC power can be produced; square wave, modified square wave and sine wave power. Inverters can be designed to produce 50 or 60 Hz.
3. The two main types of Inverters are the transformer-based types and the high-frequency switching types.
4. Maximum output watts (amps) - number of watts the Inverter can produce continuously.
5. Surge watts - number of watts the Inverter can produce temporarily (15-30 minutes).
6. Efficiency (95-98% mod. sine wave, 80-95% sine wave) rated at a certain wattage.
7. Harmonic distortion - stability of the frequency output (2-35%).
8. DC voltage limits (10.5 - 15 Volts for 12 V model).

Figure 49: Show Current Inverters.

9.2 Inverter Wave Forms (Types of DC-AC Inverters):

Divide the Inverters devices into three types depending on the wave produced from the device type, a three-wave forms of AC are shown in the figure below:

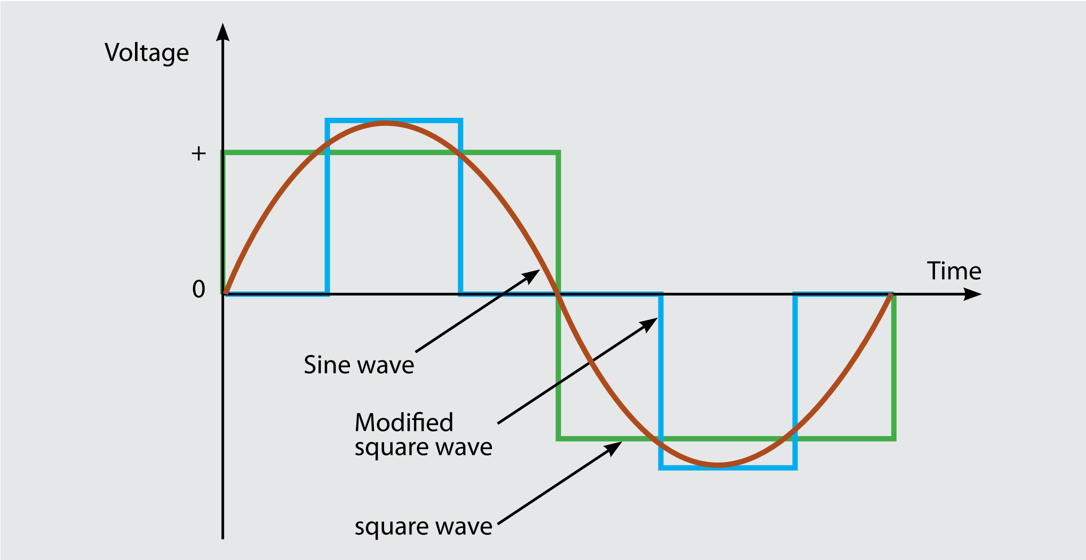


Figure 50: Show types of three -waveforms Inverters.

9.2.1 Sine-wave Inverters:

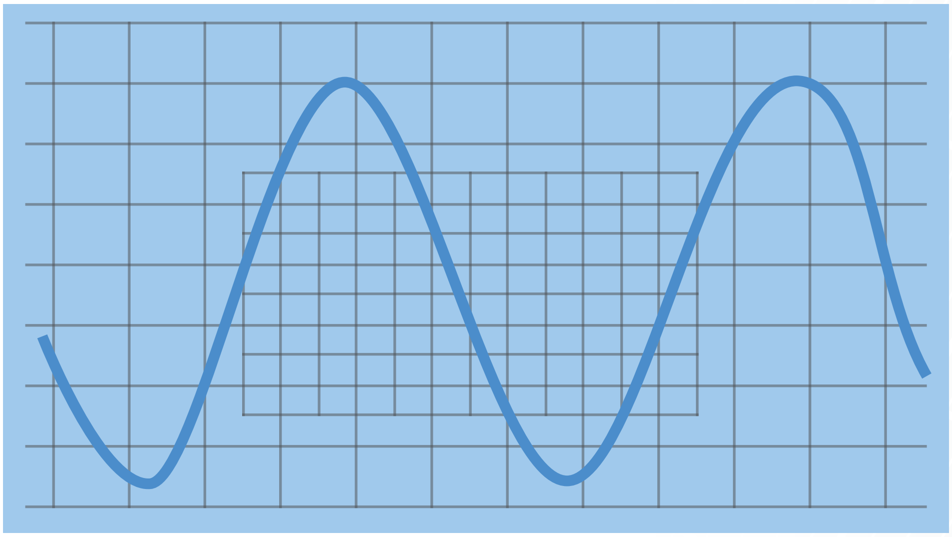


Figure 51: Show Sine-wave Inverters.

9.2.2 Modified Sine-wave Inverters:

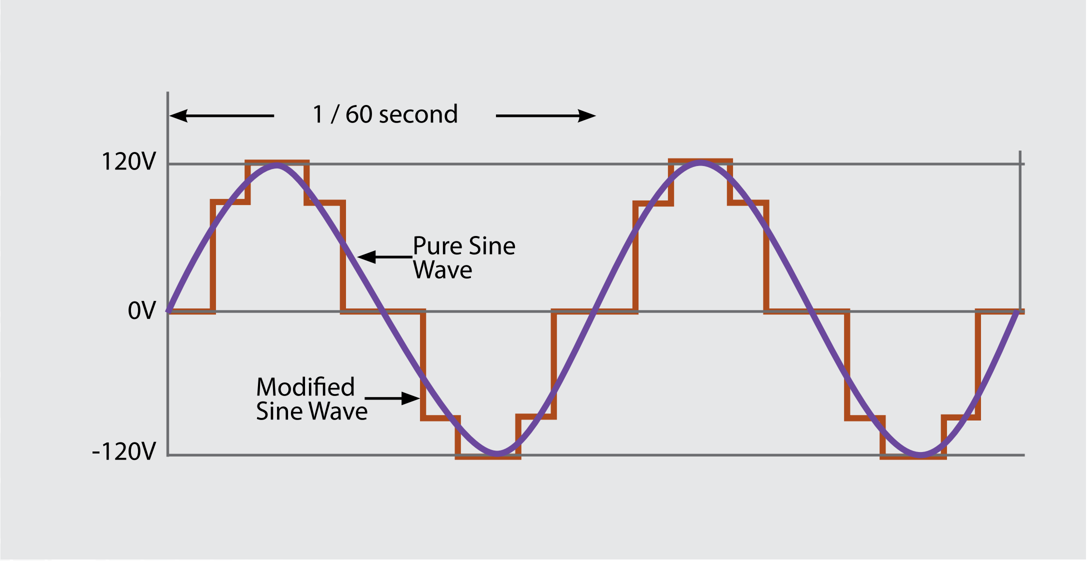


Figure 52: Show Modified Sine-wave Inverters.

9.2.3 Square-wave Inverters:

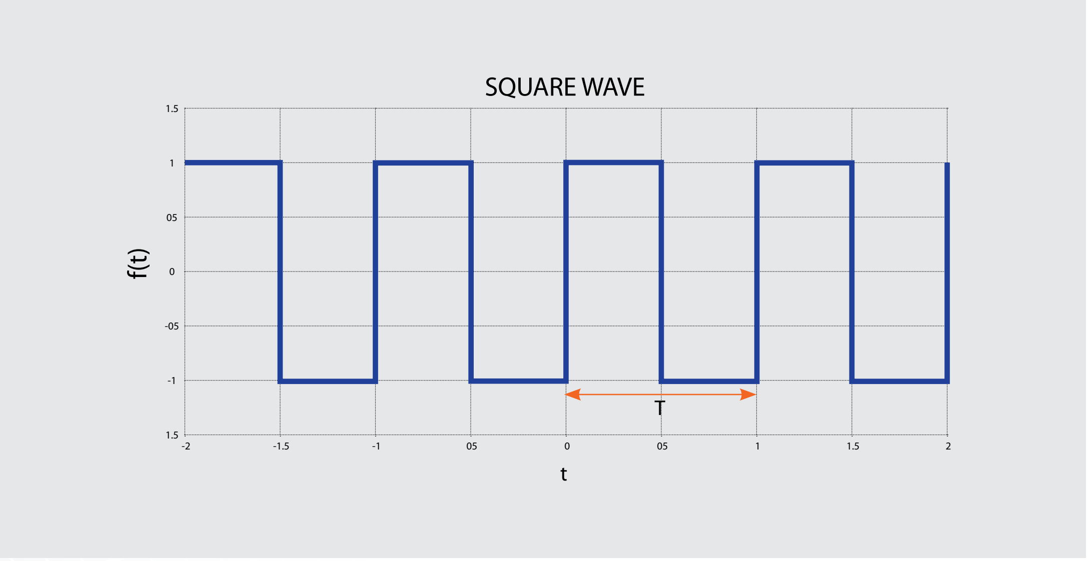


Figure 53: Show Square-wave Inverters.

The (DC – AC Inverter) can be installed in the solar cell system directly from the battery while observing the negative and positive polarity. The cables must be tied tightly.

Figure 54: Show back side of Inverter.

9.3 Protection of Inverters:

Good types of Inverters are normally provided with the following protections:

- Overload protection.
- High battery voltage protection.
- Low battery voltage protection.
- High-temperature protection.
- Reverse polarity protection.

Figure 55: Show front panel of Inverter.

9.4 Technical specifications of the Inverter (terms):

1. Maximum output power in Watts.
2. Instantaneous surge power in Watts.
3. Efficiency (95-98% mod. sine wave, 80-95% sine wave).
4. DC voltage limits (10.5 - 15 V for 12 V model).

9.5 Exercises:

Answer briefly:

1. Write three problems that can happen to the Inverter:

   1.. 2. ....

   3. ....

2. Write three technical specifications of the Inverter:

   1.. 2. ....

   3. ....

3. Write three types of Inverter:

   1.. 2. ....

   3. ....

4. Write three home appliances that benefit from the AC system in operation:

   1.. 2. ....

   3. ....

10. Selected applications of PV solar energy:

Many technologies have been invented to exploit solar photovoltaic energy.

10.1 Examples of solar energy use include:

1. Use of solar energy in street and road lighting.
   The use of solar panels to provide electricity for street lighting is one of the most important uses of solar energy as it provides not only clean and free energy but also saves the cost of wires stretched along the streets and loss of energy due to the long distance.
2. Use of solar energy in irrigation and agriculture (solar power pumping):
   This use is one of the most useful solutions, especially in remote places that do not have electricity instead of electric generator which works with fuel.
3. The use of photovoltaic solar energy in homes (solar panels on the roofs of houses). This use has been very widespread recently after the development of the efficiency of solar panels and solar batteries that have different geometry and sizes.
4. Solar refrigerator particularly for vaccines storage.
5. Telecommunication equipment.

Figure 56: Show street and road lighting.

10.2 Using solar cells in telecommunications:

Electricity is the main source of energy for the operation of wireless communication equipment. In rural areas, batteries are now being used by generators. However, solar panels can be an ideal alternative to solving the problem of supplying electrical equipment in areas where electricity is not available.

The solar energy system required to supply electrical communication equipment consists of the following components:

1. Solar cell panels.
2. Batteries to store energy.
3. Battery charge regulator.

The design of the number of solar panels and the capacity of the storage battery depends on the following:

1. The consumption of the communication device.
2. The number of daily operating hours, especially in the cases of transmission and reception.
3. The voltage difference on which the device works.
4. The amount of solar energy in the site used by the device and other weather factors.

Figure 57: Application of PV solar energy in telecommunication.

10.3 Solar pumping:

Solar water pumping systems generally consist of the following parts:

A. Solar cell panels, which can be selected according to the required energy.
B. Electric motor and pump.
C. A direct current converter to AC in case of using AC power pumps.

There are different types and sizes of solar powered pumps produced by different international companies. There are also direct floating pumps.

The installation of the solar pump requires the presence of a suitable well or water source and sometimes a water storage tank. The amount of water raised by the solar pump depends on the following factors:

A. Pump capacity used.
B. The area of the solar panels and the way they are connected.
C. The depth from which the water is pumped.
D. The amount of solar radiation in the region and weather conditions.

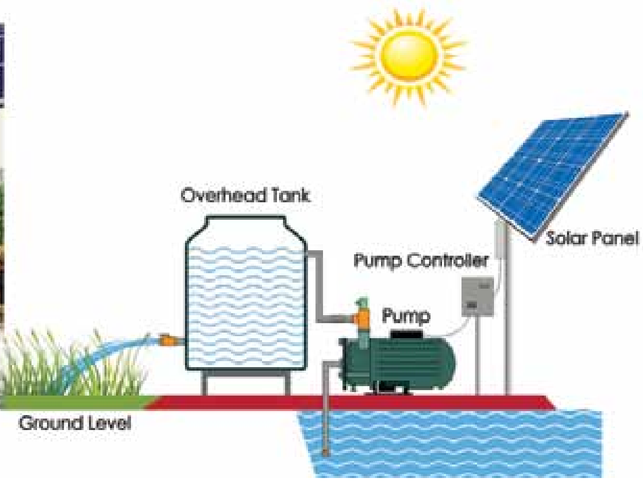


Figure 58: Show solar pump components.

Figure 59: Show solar water pumping in the field.

10.4 PV solar refrigerators for vaccines:

Solar refrigerators are an unavoidable source of sanitary and veterinary vaccines in villages and rural areas where electric refrigerators cannot be used for lack of electricity supply.

As refrigerators require a lot of maintenance and fuel availability and transport to those areas, which makes it safer to store vaccines than solar refrigerators.

Solar refrigerators consist of:

A. **Solar panels:** The refrigerator usually needs between four and six plates, depending on the capacity of the refrigerator.

B. **Batteries:** They are used to store the electrical energy used to operate the refrigerator during the night, and its capacity is determined depending on the refrigerator capacity and the prevailing weather conditions in that area.

C. **Refrigerator compartment:** It has a direct-flow compressor with a capacity of between 40 litres and 160 litres.

D. **Charge regulator:** it regulates battery charging by solar panels and protects batteries from charging and overcharging.

E. **Heat regulator:** It regulates the temperature inside the refrigerator compartment.

10.5 Practical exercise No. 7, on PV systems (demonstration or site visit)

10.5.1 PV solar lighting systems.

10.5.2 Battery charging by PV modules.

10.5.3 PV solar pumping systems.

10.5.4 PV solar refrigerators.

10.6 Exercises:

Answer briefly:

1. Solar water pumping systems generally consist of the following parts:

   1. .... 2. ....

   3. ....

2. Write three components of the solar system needed to supply electrical communication devices:

   1. .... 2. ....

   3. ....

3. Write four components of solar cells. Write four components of decentralised solar lighting systems:

   1. .... 2. ....

   3. .... 4. ....

4. Write four different types of solar cell lighting systems that can be marketed:

   1. .... 2. ....

   3. .... 4. ....

5. Write four components of solar refrigerators:

   1. .... 2. ....

   3. .... 4. ....

6. Write four factors on which the solar pump depends on determining the amount of water it raises:

   1. .... 2. ....

   3. .... 4. ....

7. The design of the number of solar panels and the capacity of the storage battery depends on the following:

   1. .... 2. ....

   3. .... 4. ....

11. Advantages and disadvantages of solar energy:

11.1 Advantages of solar energy:

The advantages of solar energy are as follows:

1. The photovoltaic power source provides clean and environmentally friendly energy, as no harmful gases are emitted during production.
2. Solar energy is the energy provided by nature - and therefore free of charge and widely available, with no reliance on fossil fuels.
3. The available solar energy can be harvested anywhere on the Earth's surface falling down on it by sunlight.
4. Photovoltaic solar technologies have in fact a very promising future in terms of economic viability and environmental sustainability.
5. Photovoltaic panels produce electricity directly through the photoelectric phenomenon.
6. The operation and maintenance costs of photovoltaic units are low and negligible, compared to the costs of other renewable energy systems.
7. Solar panels do not include moving parts, which reduces maintenance requirements, compared with other renewable energy systems (e.g. wind turbines).
8. Solar panels do not produce any noise.
9. Solar is modular, allowing for systems to be sized to needs.

11.2 Disadvantages of solar energy:

1. As with all renewable energy sources, solar energy is not always available where the sun does not shine at night or on cloudy and rainy days.
2. Energy produced from solar panels is less certain and reliable, due to varying weather conditions.
3. Solar panels require additional equipment after converting solar energy into electric energy, in order to be used on the electricity network.
4. The continuous supply of electric power requires the use of batteries to store energy. Thus, greatly increasing the cost of the solar system.
5. The need for relatively large areas of land to install solar panels.
6. The efficiency of solar panels is relatively low (between 14% -22.5%) compared

to other renewable energy systems.

7. Solar panels are relatively fragile and can be damaged easily, requiring additional insurance.
8. Solar panels or batteries can easily be stolen and used for other purposes.

11.3 Exercises:

Advantages VS disadvantages of solar energy

12. System sizing, installation and maintenance:

1. When you design a solar energy system, you should first define the loads, i.e. how much power and energy is required.
2. During system installation, safety and good wiring technique are your main concerns.
3. Maintenance of photovoltaic systems is not difficult, but it must be consistent to guarantee long life of the equipment.

Practical exercise No. 8, sizing, installation and maintenance of PV system components:

12.1 Different loads on a photovoltaic system:

1. Resistive loads (ex. Incandescent light bulbs or rice cookers).
2. Inductive loads (ex. Fluorescent light ballasts or electric motors).
3. Electronic loads (ex. Radios, TVs and telecommunications equipment).

12.2 PV system design:

12.2.1 The daily energy requirement worksheet:

1. List all possible loads (name, power, type).
2. Consider taking loads off the system (load “shedding”).
3. Consider load reduction (high efficiency).
4. When will the loads be used?
5. How many hours will the loads be used each day (on average)?

12.2.2 Photovoltaic system components choice:

1. AC or DC or AC/DC system?
2. What types of loads are being used?
3. Will you expand at a later date?
4. Will the equipment be mounted in a difficult (marine, dusty, high temp.) or remote area?
5. Can there be temporary "down-times"?
6. What are the safety and security issues?
7. Who will maintain the system and how often?

12.3 Sizing the battery:

- **Battery sizing calculation**

Sizing the Batteries

- Battery Sizing Calculations

Energy required 720 WH per day	÷	System Voltage 24 volts	=	Amps Hours required/Day 30 AH	÷	0.85 Battery Temperature 36 AH/day	x	5 Days of Autonomy 180 AH	+	20% (Max DOD is 80%) 225 AH

System Voltage 24 volts	÷	Battery Voltage 24 volts	=	Batteries In Series 2		Total AH Required 225 AH	÷	Battery Rated AH 230 AH	Batteries in Parallel 1	You need two 12 Volt. 230 AH Batteries for a 36 AH per day load (at 24 volts)

Figure 60: Show battery sizing calculation.

12.4 Sizing the power source, solar modules or array:

1. Will there be a generator or any other power source to assist the photovoltaic modules?
2. What are the peak sun hours (be conservative)?
3. Is the average temperature above 25° C?
4. What is the system voltage?
5. How far is the array from the batteries?

- **Array sizing calculations**

Sizing the photovoltaic Array

- Array Sizing Calculations

AH required by the Batteries		Battery Inefficiency		High module Operating Temperature		Dirt ang Dust on the Module		Controller and Wiring loss		Changing Meteorological Conditions
36 Ah	÷	0.80	÷	0.90	÷	0.96	÷	0.97	÷	0.97

Array AH required		Peak Sun Hours		Array Amps required		Module Amps		Modules in Parallel	System Voltage		Modules Voltage		Modules in Series
56 Ah	÷	5.8 Hours	=	10 A	÷	2.78 A	=	3.59 (4)	24 volt	÷	12 volt	=	2

Figure 61: Show array sizing calculations.

12.5 Sizing the Voltage Controller (regulator):

1. Know your maximum input current (short circuit current).
2. Will the controller voltage set points be set at the factory or will you set them?
3. What type of cabinetry/metering will you use?
4. Will you use circuit breakers or fuses to isolate the controller? (Fuses max current × 1.25).
5. Will you expand at later date?
6. Will you need heat sink or active ventilation?

- **Voltage Controller calculations**

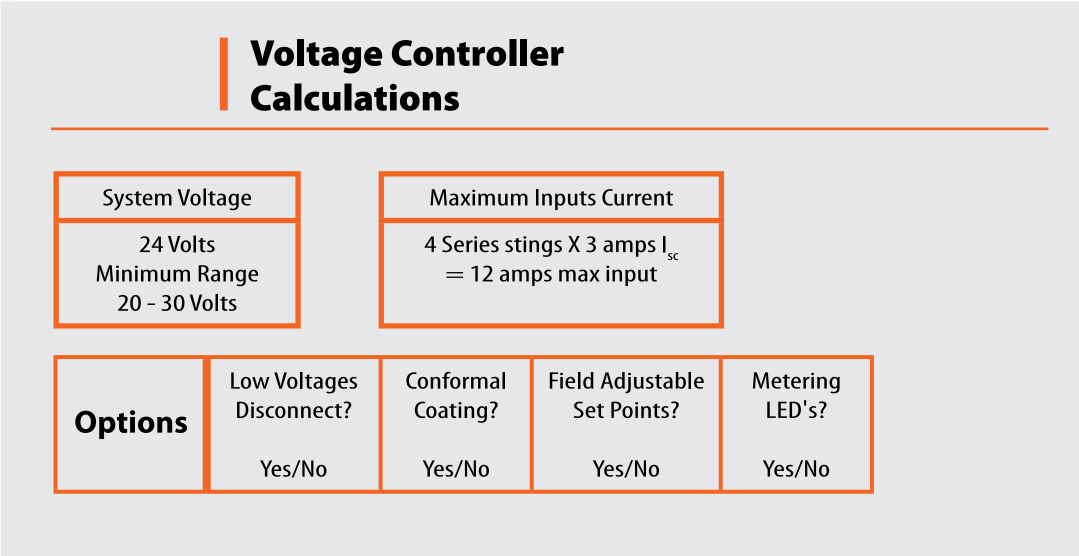


Figure 62: Show Voltage Controller calculations.

12.6 Sizing the Inverter:

1. Know your maximum inputs and outputs.
2. What types of loads will you be using?
3. Are there surge loads? (Surge capacity).
4. Are loads non-continuous? ("Sleep" mode).
5. Marine environment? (Conformal coating).
6. Will you expand later?

Will you use a generator set with the PV system?

- **Inverter calculations**

Inverter Calculations

System Voltage	Maximum Connected Watts Nominal	Max Surge Watts
24 Volts Minimum Range 20 - 30 Volts	2062 Watts	4122 Watts

Options	Sine Wave?	Conformal Coating?	Include a Battery Charger?	«Sleep» Mode?
	Yes/No	Yes/No	Yes/No	Yes/No

Figure 63: Show Inverter calculations.

12.7 Choosing the right site for your solar array:

1. Peak sun hours.
2. Shading and wind.
3. Safety.
4. Lightning.
5. Cement or civil work.
6. Electrical grounding.

12.8 Mounting modules to support a structure:

1. Pay attention to shading and wind load.
2. Mount at least 20 cm above any roofing material to allow for airflow behind the module to keep it cool. The distance can be reduced due to the high temperatures in Sudan reduce airflow behind the panel and this will reduce its efficiency.
3. Get the module direction and tilt angle correct.
4. (Use the latitude, or latitude +/- 15°).
5. In the Northern Hemisphere, face the modules to the South. In the Southern Hemisphere (below the Equator), face the modules to the North.
6. Use ground rods, lightning arrestor, SS hardware, aluminium frames and good cement.

12.9 Wiring modules together:

1. Cut module interconnects to appropriate length.
2. Use the proper wire terminals.
3. Crimp carefully (make a "lifetime" connection).
4. Seal junction box ingress and egress properly.
5. Be careful with the junction box screws.
6. Pay attention to your "drip loops".
7. Do series wiring first and parallel wiring second.
8. Cover modules while you work during the day.

12.10 A place for Power-Conditioning equipment:

1. Keep equipment documentation nearby.
2. Label battery, array and load disconnects.
3. Vent the batteries away from electronics.
4. Make sure space is clean and dry.
5. Use plastic insect screen over cabinet vents.
6. Mount meters, system disconnects at eye level.
7. Mount electronics at least › meter off the ground.
8. Use a drip loop at the service entrance.

12.11 Wiring Power-Conditioning equipment together:

1. Size wire for 3% maximum voltage drop on all DC lines (array, battery, inverter, DC loads).
2. "Twist" positive and negative DC conductors (RF reduction).
3. Use DC rated equipment and ground the system according to code.
4. Use cable raceways or conduit wherever possible.
5. Connections (best to worst) solder, split bolt, wire nut.
6. Do not tighten equipment pressure terminals too much.
7. Follow manufacturer's recommended sequence for connections. Pay close attention to polarity.
8. Use consistent wire insulation colours.
9. Use anti-corrosion spray (or grease) liberally.
10. Use DC rated battery and array disconnects.

12.12 Wiring the Inverter:

1. Mount no further than 4 meters from the battery in a dry, well-ventilated area. Case and AC output are grounded.
2. Positive and negative DC cables are twisted together, as thick as possible (welding cable) and are the same length.
3. ENSURE THAT DC POLARITY IS CORRECT!
4. Use fast blow, no-arc fuses to protect the inverter.

Options include:

2. "Sleep" mode.
3. Battery charger.
4. Meters and LEDs.

12.13 Battery safety:

1. Water and baking soda (a chemical base to neutralise any spilt acid) should be kept nearby.
2. Sulfuric acid can cause severe burns. Wash electrolyte off your skin or out of your eyes immediately.
3. Batteries produce hydrogen gas, which is highly flammable. Vent the battery room and do not use a lighter or candle to check electrolyte levels.
4. Batteries can hold a lot of energy, and short circuits across your tools can cause severe burns or death. Use insulated tools and be careful handling batteries.

12.13.1 Adding electrolyte to batteries:

2. Wear old clothes, rubber gloves and eye goggles when working with sulfuric acid.
3. Electrolyte should be at 1.25 specific gravity (s.g.) at 25° C. It may be different in warmer climates.
4. If you must mix electrolyte or adjust electrolyte, use clean 7.0 pH water only.
5. Clean the tops of the cells first.
6. Add electrolyte, wait one hour (with the cell caps off!), then top up the cells.
7. Don't overfill the cells (look for fill lines on battery case) and wait an hour before charging.

12.13.2 Wiring batteries together:

1. Check polarity with multi-meter before wiring.
2. Use as thick a wire as possible for cell or battery interconnects.
3. Do not tighten the terminal connections too much.
4. Use insulated tools.
5. Put batteries on a level, stable rack. Make sure you can see and add electrolyte easily.
6. Use anti-corrosion spray on all connections.

12.14 System maintenance:

Minimum required tools include logbook, multi-meter, fuses, hydrometer, screwdrivers, nut drivers (wrenches), linesman pliers, flashlight, wire strippers/ crimpers, utility knife, cloth rag, manufacturer's literature, battery terminal cleaner. Obtain permission to disconnect loads.

For telecommunications systems, maintenance is usually performed two times a year (once a year at a minimum).

System maintenance

1. When you arrive, check for any security problems.
2. With disconnect switches closed, record all system meters and status indicators.
3. With the multi-meter, check array and battery voltage (check current between controller and battery if you have a clamp-on amp meter).
4. Check for open circuit breakers or blown fuses. Use your ears and your nose. Are controller relays chattering or do you smell burning plastic?
5. Open system disconnects and use multi-meter to confirm that the power is actually cut off.
6. Check for loose wires or connections at the controller.
7. Use your eyes. Remove cabinet covers and visually inspect all equipment wiring.

Battery maintenance

1. Clean tops of batteries before removing cell caps.
2. Check electrolyte level, add only distilled water (pH 7.0).

3. Check flame arrestor or recombination caps on the batteries.
4. Repair corroded or burnt connections. Pull on the wires a little to see if they are loose.
5. Inspect battery rack or container and ensure it is in good condition and level.

Photovoltaic array maintenance

1. Check module glass and module support structures for any damage. Clean the modules.
2. Remove connection box covers and check wiring and wire connections for damage. If repairs are necessary, cover the modules.
3. If possible, measure open circuit voltage and short circuit current of each array string at 13:00 hours on a sunny day. If you find a fault, open module junction boxes and check each module.

Load maintenance

1. Close all disconnect switches and make sure loads are operating as designed.
2. Clean and lubricate loads as required.
3. Confirm that no new loads have been added to the system and that loads are operating for the specified number of hours per day.

Troubleshooting

1. Get permission to disconnect the loads.
2. Other than oversize loads and poor wiring connections, most photovoltaic repair operations are replacement operations. "Troubleshooting by replacement" (ex. with a new charge controller) is a valid method.
3. Seek the cause, not the symptom. Sometimes components fail but there may be another defect in the system that is causing repeated failures.
4. Don't stop with one problem. Always check the entire system.
5. Test the replaced components after it has been taken out of the field. Try to determine what went wrong with the component.
6. Keep records so you can review previous service operations.

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