Department of Electrical Engineering

Subject: SPIM

Semester: 5th

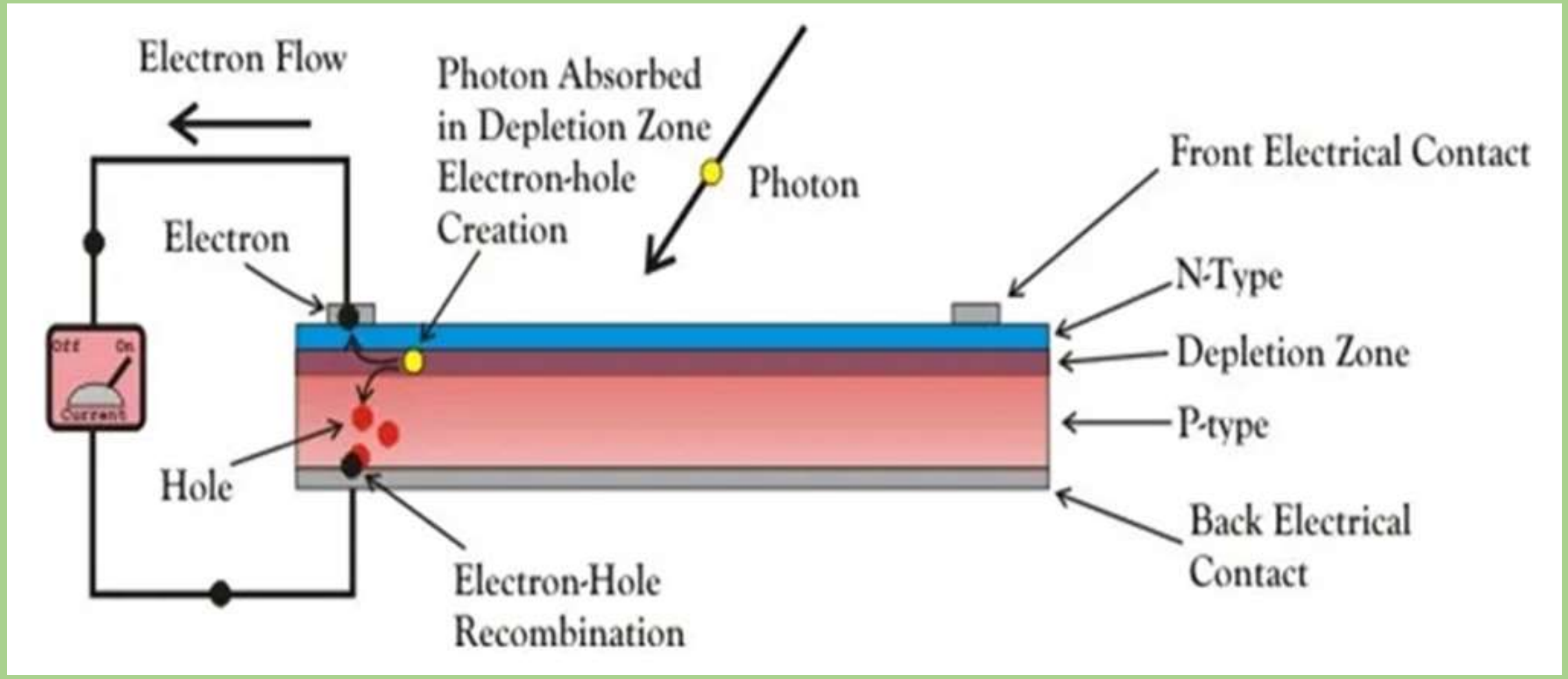
What is a solar cell

A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance– vary when exposed to light.

Individual solar cells can be combined to form modules commonly known as solar panels. The common single-junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn’t much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of solar cell

A solar cell is a junction diode, although its construction is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer. These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer, there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly with thin glass to protect the solar cell from any mechanical shock.


Electron Flow
Photon Absorbed
in Depletion Zone
Electron-hole
Creation
Photon
Front Electrical Contact
Electron
N-Type
Depletion Zone
P-type
Hole
Back Electrical
Contact
Electron-Hole
Recombination

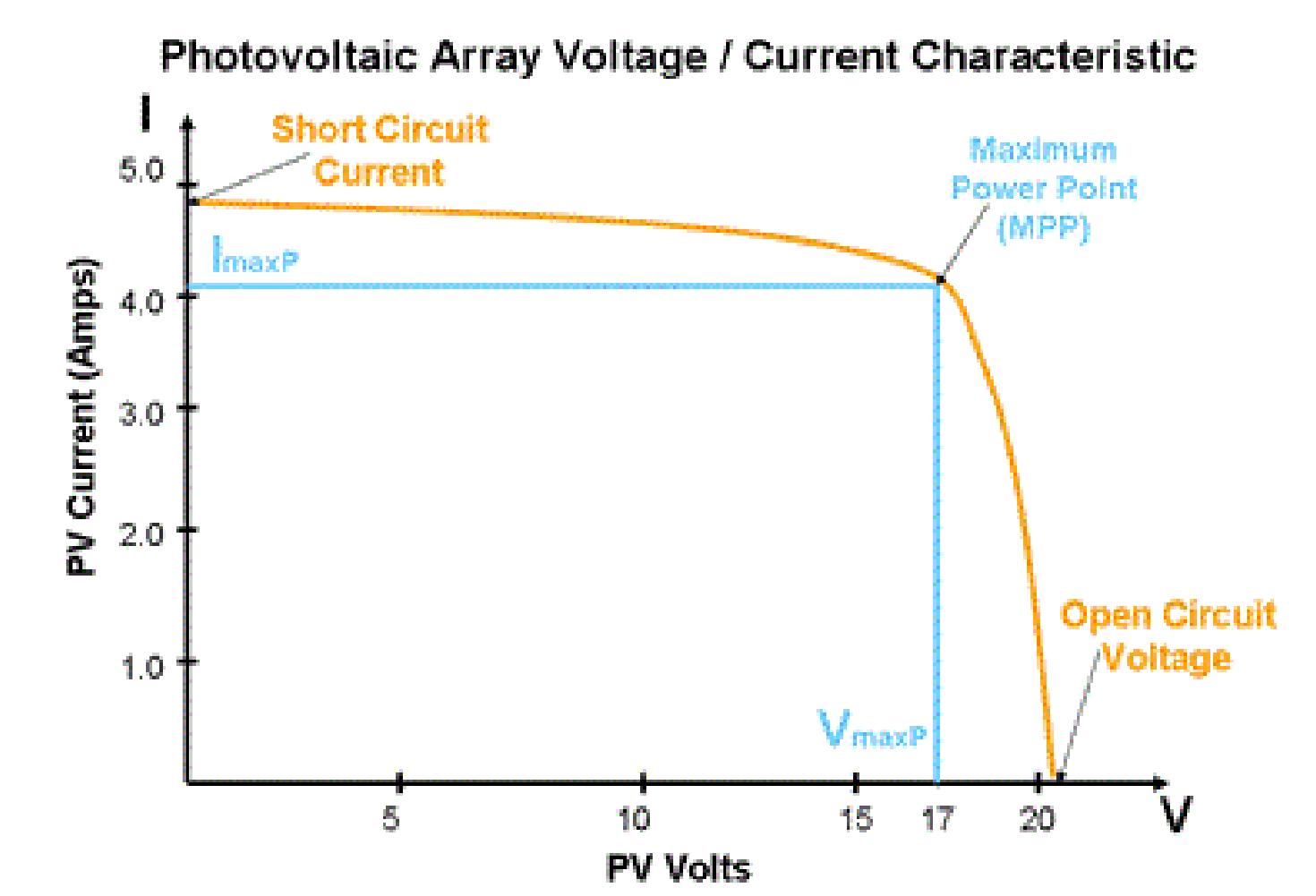
Working principle

When light reaches the p-n junction, the light photons can easily enter the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction.

Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.

Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e., n-type side of the junction and concentration of holes becomes more in another side, i.e., the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

V-I Characteristics of a Photovoltaic Cell



Materials Used in Solar Cell

The materials which are used for this purpose must have band gap close to 1.5ev.

Commonly used materials are-

1. **Silicon**
2. **GaAs (Gallium arsenide)**
3. **CdTe (Cadmium telluride)**
4. **$CuInSe_2$ (Copper Indium selenium)**

Criteria for Materials to be Used in Solar Cell

1. Must have band gap from 1ev to 1.8ev.
2. It must have high optical absorption.
3. It must have high electrical conductivity.
4. The raw material must be available in abundance and the cost of the material must be low.

Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

Disadvantages of Solar Cell

1. It has high cost of installation.
2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of Solar Generation Systems

1. It may be used to charge batteries.
2. Used in light meters.
3. It is used to power calculators and wrist watches.
4. It can be used in spacecraft to provide electrical energy.

Conclusion:

Though **solar cell** has some disadvantage associated it, but the disadvantages are expected to overcome as the technology advances, since the technology is advancing, the cost of solar plates, as well as the installation cost, will decrease down so that everybody can effort to install the system. Furthermore, the government is laying much emphasis on the solar energy so after some years we may expect that every household and also every electrical system is powered by solar or the renewable energy source.

Use and handling procedure of solar panels

1. Lifting and Handling Solar Panels

Solar panels are heavy and awkward to lift and carry. Loading and unloading panels from trucks and onto roofs can cause strains, sprains, muscle pulls and back injuries as well as cumulative trauma that stresses the spine. The panels can also heat up quickly when exposed to sunlight, causing burns if not handled safely.

Safety measures for solar workers:

1. Lift each solar panel with at least two people while applying safe lifting techniques.

2. Transport solar panels onto and around the work site using mobile carts or forklifts.

3. Never climb ladders while carrying solar panels. To get solar panels onto rooftops, use properly inspected cranes, hoists or ladder-based winch systems.

4. Once unpackaged, cover panels with an opaque sheet to prevent heat buildup.

5. Always wear gloves when handling panels.

2. Ladder Safety

Solar installations often involve working on roofs from ladders. So, having the right type of ladder and using it correctly is essential to worker safety.

Select the ladder that best suits the need for access. This can include a **stepladder, straight ladder or extension ladder**.

Choose the right ladder material. Aluminum and metal ladders are commonly used, but they are a hazard near power lines or electrical work. **Instead, a fiberglass ladder with non-conductive side rails may be a better option near power sources**.

Place the ladder on dry, level ground.

3 Trips and Falls

Trips and falls are the second most common nonfatal injury in the construction industry.

A trip is the result of a foot striking or colliding with an object, which causes a loss in balance, and usually a fall.

To help keep workers safe while installing solar panels and systems:

- Keep work areas **dry and clear** of obstructions.
- If employees are working six feet or higher, use **safety nets** may be a good idea.
- Provide workers with a body **harness anchored** to the rooftop to stop a potential fall.
- Cover holes on rooftops, including skylights, as well as ground-level work surfaces.

4. Solar PV Safety

Some of the ways you can keep workers safe include:

- Covering the solar array with an opaque sheet to block the sun’s light.
- Treating wiring **coming from a solar PV system** with the same caution as a **utility power line**. That means assume **all wires are live**.
- Using a meter or circuit test device to ensure circuits are de-energized before working on them.
- Never disconnecting PV module connectors or other associated PV wiring when it is under load.

5 Personal Protective Equipment for Solar Workers

Personal protective equipment (PPE) is essential during every solar installation. Employers have to assess workplaces for hazards and make sure they provide workers with the necessary PPE for their safety. This can include:

1. Hard hats
2. Gloves
3. Steel-toed shoes with rubber soles
4. Eye protection, like glasses or goggles
5. Vests
6. Harnesses

Make sure employees know how to use the PPE, as well as how to maintain it so it is kept in safe and reliable condition.

Energy storage, control and conversion

What is Energy storage?

“Storage” refers to technologies that can capture electricity, store it as another form of energy (chemical, thermal, mechanical), and then release it for use when it is needed.

Lithium-ion batteries are one such technology.

Although using energy storage is never 100% efficient; some energy is always lost in converting energy and retrieving it.

Storage allows the flexible use of energy at different times from when it was generated. So, storage can increase system efficiency and resilience, and it can improve power quality by matching supply and demand.

Storage facilities differ in both **energy capacity** and **power capacity**,

Energy capacity, which is the total amount of energy that can be stored usually in **kilowatt-hours (kWh)** or **megawatt-hours (MWh)**.

Power capacity, which is the amount of energy that can be released at a given time usually in **kilowatts (kW)** or **megawatts (MW)**.

Battery Energy Storage for the PV System:

Batteries store and produce energy as needed. In PV systems, they capture surplus energy generated by your PV system to allow you to store energy for use later in the day.

A battery converts chemical energy to electrical energy.

Batteries can provide power when electrical loads require more power than the PV panels are generating. This can be due to the generation of less electricity due to adverse weather conditions.

Battery Types:

There are many types of batteries that can be used in PV systems. The **lead-acid type** of the most common, but **lithium-ion batteries** are becoming more popular.

Table 1: Two Most Common Types of Batteries for PV System Storage.

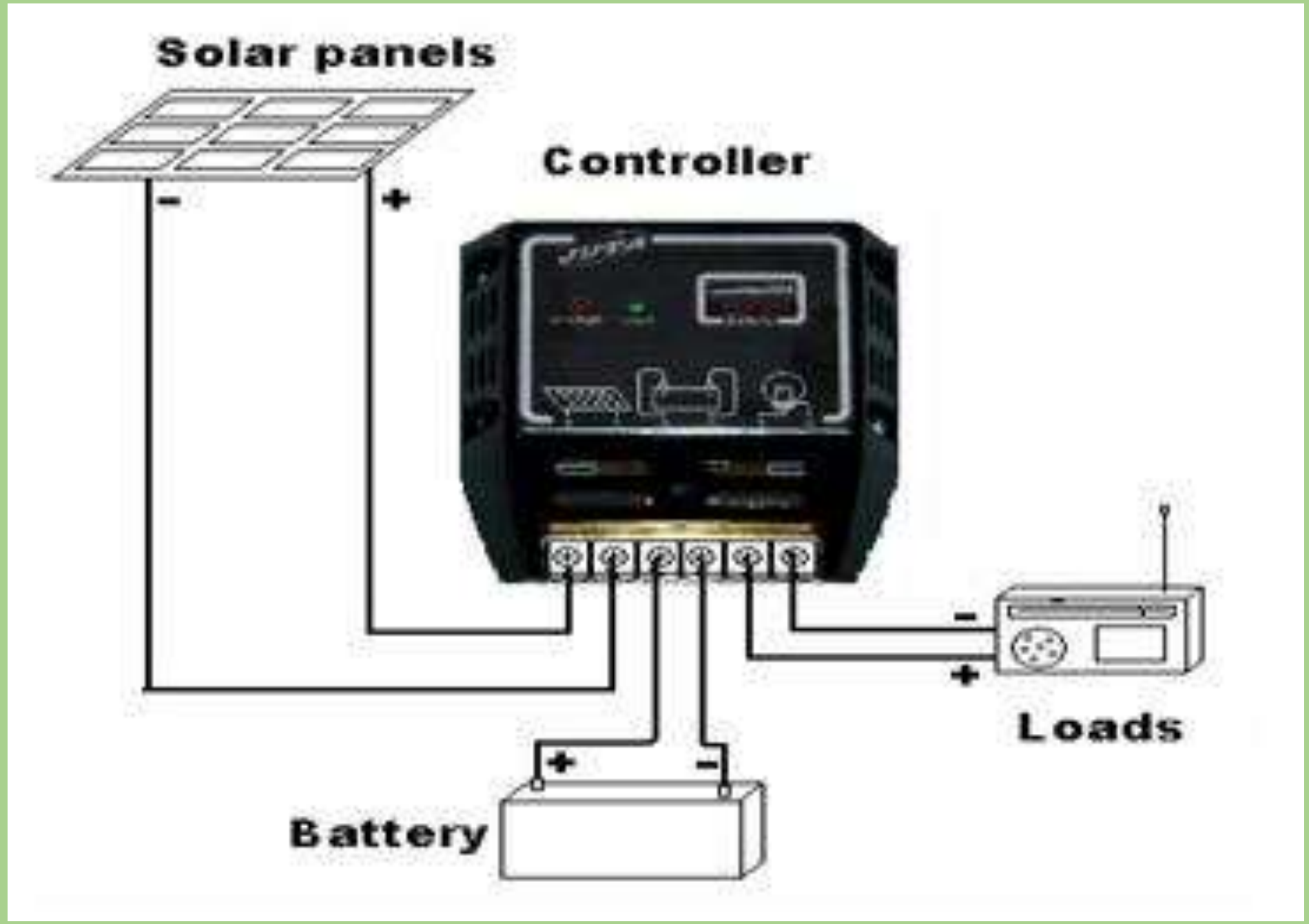
S.No.	Lithium-ion Batteries	Lead-acid Batteries
1	Becoming more common in domestic grid-connected solar PV storage systems	Used for off-grid storage systems where additional storage is required.
2	More expensive	Less expensive
3	Lighter and smaller	Heavier and larger
4	Requires integrated controller to manage charging and discharging	Requires good charging and discharging process to maintain battery health
5	More efficient	Less efficient
6	Longer expected lifetime	Shorter expected lifetime

Solar Charge Controllers:

Solar Charge Controller is an electronic device that manages the power going into the battery bank from the solar array.

The main purpose of charge controller in this system is to prevent the battery from being overcharged and deeply discharged.

Generally, charge controllers stop charging a battery when they exceed a set high voltage level, and re-enable charging when battery voltage drops back below that level.


Solar panels
Controller
-
+
-
+
Loads
+
-
Battery

A solar charge controller is available in two different technologies:

1. PWM (Pulse Width Modulation)
2. MPPT (Maximum Power Point Tracking)

PWM Solar Charge Controller:

A PWM solar charge controller stands for "**Pulse Width Modulation**".

These operate by making a connection directly from the solar array to the battery bank. A 12V solar panel can charge a 12V battery. A 24V solar panel or a solar array is needed for a 24V battery bank, and 48V array is needed for 48V bank.

MPPT Solar Charge Controller:

An MPPT solar charge controller stands for "**Maximum Power Point Tracking**".

It will measure the V_{mp} (Volts at max. Power) voltage of the panel and down-converts the PV voltage to the battery voltage. When the voltage is dropped to match the battery bank, the current is raised, with a 20V solar panel, you can charge a 12V battery bank.

The Key Features of a Solar Charge Controller are:

1. **Multistage charging of battery bank -** changes the amount of power set to the batteries based on its charge level, for healthier batteries.
2. **Reverse current protection** - stops the solar panels from draining the batteries at night when there is no power coming from the solar panels.
3. **Low voltage disconnects** - turns off the attached load when the battery is low and turns it back on when the battery is charged back up.
4. **Lighting control** - turns attached light on and off based on dusk and dawn. Many controllers are configurable, allowing settings for a few hours or all night, or somewhere in between.
5. **Display**- may show the voltage of battery bank, state of charge, amps coming in from solar panel.

Conversion:


Energy from the Sun
Solar Panel(s)
Electric Current
Charge Controller
Inverter
Battery
Home appliance

Inverter

An inverter converts the available battery’s DC voltage to the main AC voltage in order to operate the loads. Therefore, the inverter helps us to run home appliances, computers or other electronic devices.

Maintenance procedure of equipment

What maintenance is required on solar panels?

Solar panels generally require very little maintenance in order to function. The only thing they need is a periodic light cleaning to make sure dirt, leaves, and other debris aren't obstructing the sun's rays.

Processes involved in the maintenance of solar power systems:

Popular packages encompass processes involved in the maintenance of solar panels and solar power plants; such as:

1. The timely and regular cleaning of solar cells and PV panels
2. Regular maintenance of all thermal-based components
3. Servicing of HT side equipment on an annual basis
4. Diagnosis and tests pertaining to low solar power production
5. Testing and upkeep of circuits.
6. Tracing of IV curves and thermal imaging
7. Measure of earth value
8. Retro-commissioning
9. Management of warranties
10. System checks pertaining to data acquisition, etc.

What to avoid when cleaning solar panels:

Certain cleaning products can damage the solar panels and should therefore be avoided:

• **Hard water-** It can leave white residue that diminishes photovoltaic output.

• **Abrasive sponges-** They may scratch the panels.

• **Very cold water** Using very cold water on a warm panel can result in thermal shock and permanently damage the solar panel.

• **Very high-pressure water-** This can damage the joints in the panel frame. High-pressure cleaners must therefore be avoided.

• **Solvents and detergents-** Such products may damage the surface of the solar collectors.

Site survey, design and evaluation of various parameters

Site Survey for Solar PV:

Things carried out during a Site survey are:

1. **Roof Orientation and Shading Analysis-** Helpful in in identifying the suitable location for Solar Panel installation.
2. **Roofing Details –** Study the roofing details to install the right solar PV system.
3. **Load Analysis** – Helpful to understand the energy needs of the building.
4. **Solar PV System usability check –** To assess the accessibility of the solar panels by the user.
5. **Financial Analysis –** To understand the financial viability of the project

Various parameters are:

1. Short-circuit current (I_{sc}):

The short-circuit current, I_{sc}, is the current that flows through the external circuit when

the electrodes of the solar cell are short circuited.

2. Open circuit voltage (V_{oc}):

The open-circuit voltage (V_{oc}) is the voltage at which no current flows through the external

circuit. It is the maximum voltage that a solar cell can deliver.

3. Fill factor (FF):

The fill factor is the ratio between the maximum power ($P_{max} = J_{mp} * V_{mp}$) generated by a solar cell and the product of $V_{oc} * J_{sc}$

4. Conversion efficiency:

The conversion efficiency is calculated as the ratio between the maximal generated power (P_{max}) and the incident power (I_{in}).

$\eta = P_{max} / I_{in}$

Installation procedure of solar panel:

Here are the simple steps to install solar panels

Step – 1: Mount Installation

Step – 2: Installation of Solar Panels

Step – 3: Electrical Wiring

Step – 4: Connection between Solar Panel and Solar Inverter

Step – 5: Connection between Solar Inverter and Solar Battery

Step – 6: Connection between Solar Inverter and Grid

Step – 7: Start Solar Inverter through Solar Panel & Grid

Step – 1: Mount Installation

The first step is to fix the mounts that will support he Solar Panels. This base structure provides support and sturdiness.

A typical mounting structure is made up of **aluminium**. (Sometimes GIA)

The performance of the solar panels depends upon the direction in which these panels are placed.

The **best direction** to face solar panels is **south**, since here they **receive** the **maximum sunlight**.

East and West directions also work well.

North is the only direction that we **should not** want to put our panels on.

Since **India lies in Northern Hemisphere**, **south** direction works **best** here.

The mounting structure must be **slightly tilted**.

Angle of the tilt could be between **18 to 36 Degree.**

Step – 2: Installation of Solar Panels

Once the solar structure is fixed accurately, we will connect it with solar modules. We should ensure that all nuts and bolts of solar modules are fixed with solar structure so that it is properly secured and lasts long.

Step – 3: Electrical Wiring

MC4 connectors are used to connect solar panels. These are universal connectors and can be connected with any type of solar panels. The solar array wiring becomes simpler and faster using MC4 connectors.

These panels can be electrically connected with each other in following series:

Series Connection: In this case, the Positive (+) Wire is of one PV module is connected to the Negative (–) Wire of another module. This type of wiring increases the voltage match with the battery bank.

Parallel Connection: In this case, Positive (+) to Positive (+) and Negative (–) to Negative (–) connection is done. This type of wiring voltage of each panel remains same.

A parallel connection maintains the voltage of each panel while a series connection increases the voltage in order to match it with the battery bank.

Step – 4: Connection between Solar Panel and Solar Inverter

In the picture given below, the backside of an inverter is shown where solar panel wire is connected. Connect the positive wire from the solar panel with the positive inverter terminal and the negative wire with negative terminal of the inverter. Make sure the inverter is turned off while the connections are being done.

Step – 5: Connection between Solar Inverter and Solar Battery

In an off grid solar system, Battery is mandatory where it is used to store power backup. This battery is connected with solar inverter to recharge it with solar panel and grid. The positive terminal of the battery is connected with the positive of the inverter and vice versa.

Step – 6: Connection between Solar Inverter and Grid

In order to connect the inverter to the grid simply plug it in in the main power switch board, so that it gets power from the grid. The output wire is also connected with board that is supplying electricity in home.

In order to calculate the **excess energy generated** from the solar system we need to install a metering device. We need to connect the positive wire from the metering device with the line terminal and the negative wire to the neutral terminal of the inverter.

Step – 7: Start Solar Inverter through Solar Panel & Grid

Now when all the electrical wiring and connections are done, it is time to start the inverter switch ON the Main Switch of the Home. Most solar inverters will have digital display to show you stats regarding generation and usage of solar unit.

How Is Solar Energy Harnessed?

Solar energy can be collected:

Passively or **Actively**

If solar energy gets used **passively**, it means there's nothing to process that energy. So, the heat from the sun is used directly.

When you use machinery or technology, like an inverter, to turn energy into power, it's considered **active solar energy**.

#Avoid Common Mistakes People Make When Installing Solar

Solar panels effectively produce electricity for a period of 25 years from the day of installation. However, solar panels should be installed properly to churn out the benefits in the long run.

There are **5 major common mistakes** generally Solar Installers happen.

1. **Solar panel mounting structure should be made of GIA**. The normal iron stand will not have a longer life as they are not rust-proof. So, we recommend to use GIA Stand for solar panel installation.

2. Proper Fixing of Solar Panels is important. Solar panels laid and fixed on mounting structure so that it doesn’t tilt or sway. Solar panel mounting structure should be grounded with civil work; general civil work involves 4x4-inch foundation work. Fasteners, preferably top brand like Anchor should be used for structure fastening.

3. Wiring of solar panel with MC4 Connector. MC4 connectors should be used for connecting solar panels, instead of connecting solar panels with tapes. MC4 connectors can be joined together manually, however, they will not unjoin unless a tool is applied, hence it ensures circuit does not breakup.

4. 30 Degree Installation of solar panels. Solar panels should be installed always at 30-degree angle to extract maximum efficiency. Angle of installation results in maximum power generation. Also, solar panels should be installing facing south-west direction.

5. Earthing stands for solar systems. Earthing protects your solar system, protects against overload, directs excess electricity to ground, voltage is stabilised and prevents mishaps.

Tools involved in installation of system

The Most Essential Tools for Solar Installation

1. Digital Multi-meter
2. Battery Operated Drill
3. Hack Saw
4. Flat Pry Bar
5. Caulk Gun
6. Conduit Bender
7. Screwdrivers
8. Wire Stripper/Cutter
9. Tape Measure
10. Solar Panel Hanger

1. Digital Multi-meter:

The solar panel uses a photovoltaic system to convert light into electricity using semiconductors. The right multi-meter can help you confirm the quality of power being emitted by each cell.

A digital multi-meter combines the testing capabilities of an ohmmeter, ammeter, and voltmeter. This tool can also help with the maintenance and repairing of the solar panels.

2. Battery Operated Drill:

Battery-operated drills may be simple. A powerful and efficient battery operated a drill is a must-have tool for any solar worker.

3. Hack Saw:

Remember, the solar panels will rest on some rails which you will install on your roof. Therefore, you will need to cut the rails before installing them or after you have finished installing the panels. A hack saw is affordable and easy to use.

4. Flat Pry Bar:

One of the less common, but very helpful tools for installing solar panels is the flat pry bar. Since most roofs have shingles, you will need a flat pry bar to help you slide the flashing under it.

5. Caulk Gun:

Since the mounts and rails must be installed on your roof, you will have to drill numerous holes on your roof after removing the shingles. Fill the hole with roofing caulk and then screw the mount into the holes using. Therefore, you will need a caulk gun to help you apply the sealant safely and accurately. The roof sealant will prevent leakages in the future and help protect your ceiling.

6. Conduit Bender:

Another crucial tool that you must have when installing a solar system is a conduit bender. In fact, the most commonly used conduit for protecting electric wiring is the EMT (Electrical metallic tubing) conduit. So, make sure you get the right conduit bender. This tool can come in handy when you need to make a few odd angles when installing solar panels. You will also need some channel locks for tightening your conduit joints.

7. Screwdrivers:

Your set of screwdrivers is actually an essential tool that you will require during the installation process. And that is because the entire solar panel will be held in place on your roof by screws. So, the first things you will need to tighten are the big screws locking the mounts onto the roof safely.

8. Wire Stripper/Cutter:

Once your panels are installed on the roof, you will have to either hire an electrician to help you with the wiring or do it yourself. So, make sure you have the right wires stripper and cutter to help you with the wiring task. With the right stripper and cutter, you can finish the wiring job within the shortest time possible.

9. Tape Measure:

One of the biggest challenges every first-time solar installer face is ensuring that the solar panels are leveled on the roof. So, you need a tape measure to help you determine the number of panels that your roof can comfortably accommodate. The tape measure can also help you determine the exact place where you will install the mounts which you will mark using your chalk.

10. Solar Panel Hanger:

As one of the latest additions to the industry, this is a unique invention that provides a straightforward and seamless solution for holding and positioning the panels while they are on the rail. Solar panel hangers are a must-have tool for anyone who plans on installing panels. This tool sits on the tracks and allows you to place the panels safely on the rail.

Quality and process standards:

Quality Criteria:

1. The guarantee
2. Price
3. Manufacturer
4. Solar panel Technology
5. Efficiency of the Solar Panel
6. Power tolerance
7. Temperature Coefficient
8. The frame of the solar panel
9. The by-pass Box and the cable
10. The Protective film

The guarantee:

A solar panel with a minimum guarantee of 25 years must be offered by the manufacturer.

Price:

Low-cost solar panels are frequently a sign of low-quality equipment with questionable guarantees.

Request several quotations from different distributors or installers to compare.

Manufacturer:

Investigate the reputation of the solar panel manufacturer using search engines. How long has it been in the photovoltaics field, look at the website design and warranty aspects.

Solar panel Technology:

What is the difference between polycrystalline, monocrystalline, and amorphous materials? Which solar cell technology did you opt for, and why? Verify that the solar panel technology meets your requirements and expectations, as well as that it is appropriate for the production context of your solar power plant.

Efficiency of the Solar Panel:

This is a criterion to consider depending on your installation context, the rate expressed in percentage will tell you the relationship between the production produced and the power of radiation captured by solar panels. The performance of photovoltaic solar panels varies according to several determining factors, but generally it is between 12 and 20%.

Power tolerance:

This is the amount of power output from your solar panel.

For example, a 165W module with a tolerance of +/- 5% could actually produce 156.75W up to 173.25W.

The best photovoltaic solar panels have a **"positive only"** power tolerance, which means that you are guaranteed to get at least the specified output power of the panel.

***For example*:** a 200W solar panel with a tolerance of **+ 5% / – 0%** will produce a minimum of 200W and a maximum of 210W.

Temperature Coefficient:

The temperature coefficient tells you the electrical behavior of your solar panel from a standard operating temperature of 25 °.

The **unit** of this coefficient is expressed in **“% by ° C”**, so the lower the coefficient, the better the solar panel is. ***On the other hand***, the higher the number, the less the photovoltaic module will produce in case of strong heat or at the beginning of the afternoon.

A high temperature coefficient is a sign of a lower quality solar panel. A reasonable number is around 0.5%, also the best solar panels down to 0.3% while 0.7% indicates a poor coefficient in terms of performance and thus photovoltaic equipment not very reliable.

The frame of the solar panel:

A high-quality solar panel frame should have a stunning appearance. To ensure corrosion protection, angled contacts must be connected and anodized. Finally, for aesthetic integration on a roof, the edges must not be sharp and the design must be refined.

The by-pass Box and the cable:

Turn the module over to examine the Bypass box's finish. It must be silicone-coated and have the correct cable diameter. Examine the bypass diodes, which will allow the solar panel to continue to produce even if part of it is shaded.

The Protective film:

Check for air bubbles and that the protective layer is absolutely flat on the back of the module; the contrary would indicate poor quality.

Standards generally used in photovoltaic modules:

The manufacture of photovoltaic modules is governed by several standards required by the **IEC (International Electrotechnical Commission).**

IEC 61215 (crystalline),

IEC 61646 (amorph)

IEC 61730 (all modules, safety),

IEC 61853 (Photovoltaic module performance testing & energy rating)

(International Organization for Standardization):

ISO 9488 Solar energy

(Underwriters Laboratories):

UL 1703, Photovoltaic Flat-Plate Modules

UL 1741, Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources

UL 2703, Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels

CE mark: (On commercial products, the letters CE (as the logo CЄ) mean that the manufacturer or importer affirms the good's conformity with European health, safety, and environmental protection standards)

Electrical Safety Tester (EST) Series (EST-460, EST-22V, EST-22H, EST-110).

Electrical safety testing is essential to ensure safe operating standards for any product or establishment that uses electricity.

What Does Occupational Health and Safety (OHS) Mean?

Occupational health and safety (OHS) relates to health, safety, and welfare issues in the workplace.

OHS includes the laws, standards, and programs that are aimed at making the workplace better for workers, along with co-workers, family members, customers, and other stakeholders.

Improving a company's occupational health and safety standards ensures good business, a better brand image, and higher employee morale.