



ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY

AUTONOMOUS INSTITUTION

Approved by AICTE & Affiliated to Anna University

NBA Accredited for BE (ECE, EEE, MECH) | Accredited by NAAC with A+ Grade

Anjugramam - Kanyakumari Main Road, Palkulam, Variyoor P.O. - 629 401, Kanyakumari District.

CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 2

SOLAR CONCENTRATING COLLECTORS AND PV TECHNOLOGY

Prepared by:

Mr.Arunpandian.N.

Assistant Professor

Department of Agricultural Engineering

Solar Photovoltaics (PV): Types and Characteristics

Solar photovoltaics (PV) are systems that convert sunlight directly into electricity using the photovoltaic effect. The most common method of harnessing solar energy for electricity production, solar PV technology has become one of the leading renewable energy sources worldwide due to its versatility, efficiency, and low environmental impact. Solar PV systems are used in a variety of applications, ranging from small residential setups to large utility-scale power plants.

Types of Solar Photovoltaics

There are several types of solar PV systems, each with different technologies, applications, and performance characteristics. The main types include:

1. Monocrystalline Solar Panels

- **Description:** Monocrystalline solar panels are made from a single continuous crystal structure. These panels are the oldest and most widely used type of solar cell. They are typically black in color due to the way the silicon is structured.
- **Production Process:** These solar cells are produced from high-purity silicon, which is melted and formed into a single crystal. This is then sliced into thin wafers.
- **Efficiency:** Monocrystalline panels are known for their high efficiency, typically between 18-22%. This is because the single crystal structure allows for better electron movement, resulting in higher electricity output from the same amount of sunlight.
- **Durability:** They have a long lifespan, typically around 25 to 30 years, with minimal degradation in performance over time.
- **Cost:** Monocrystalline panels are generally more expensive to produce due to the more complex manufacturing process, which is reflected in their higher price compared to other types of solar panels.
- **Applications:** These panels are commonly used in residential, commercial, and industrial applications where space is limited, and high efficiency is required.

2. Polycrystalline (Multicrystalline) Solar Panels

- **Description:** Polycrystalline solar panels are made from silicon crystals that are melted together and then cut into wafers. The crystals are not a single continuous structure, but instead consist of multiple smaller silicon crystals, which results in a less uniform appearance compared to monocrystalline panels.
- **Production Process:** The silicon is melted and poured into molds to form blocks, which are then sliced into wafers.
- **Efficiency:** Polycrystalline panels typically have an efficiency range of 15-18%. The efficiency is lower than monocrystalline panels due to the presence of multiple smaller crystals, which can limit the movement of electrons.

- **Durability:** Polycrystalline panels also have a lifespan of around 25 to 30 years, though they might degrade at a slightly faster rate than monocrystalline panels.
- **Cost:** These panels are cheaper to manufacture and, as a result, tend to be less expensive than monocrystalline panels, making them more affordable for large installations.
- **Applications:** Polycrystalline panels are used in both residential and commercial applications, especially where the cost per watt is more important than efficiency, or when space is not limited.

3. Thin-Film Solar Panels

- **Description:** Thin-film solar panels are made by depositing very thin layers of photovoltaic material onto a substrate like glass, metal, or plastic. These panels are lightweight and flexible, which allows them to be used in a variety of applications.
- **Production Process:** Thin-film panels can be made using a variety of materials, including cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium selenide (CIGS). These materials are deposited in thin layers, often only a few micrometers thick.
- **Efficiency:** Thin-film solar panels generally have lower efficiencies than crystalline silicon panels, with typical efficiencies ranging from 10-15%. However, newer technologies, such as CIGS, are achieving efficiencies closer to 20%.
- **Durability:** Thin-film panels typically have a shorter lifespan compared to crystalline silicon panels, with a useful life of around 15-20 years.
- **Cost:** Thin-film panels are cheaper to produce than both monocrystalline and polycrystalline panels, due to the simpler and less energy-intensive manufacturing process. However, because of their lower efficiency, more panels are required to generate the same amount of electricity.
- **Applications:** Thin-film solar panels are often used in large-scale solar farms, building-integrated photovoltaics (BIPV), and portable solar systems. They are also used in applications where flexibility and lightweight features are desired.

4. PERC (Passivated Emitter and Rear Contact) Solar Panels

- **Description:** PERC is a type of monocrystalline solar cell technology that improves efficiency by adding a layer of passivation on the rear of the solar cell to capture more light and reduce energy loss.
- **Production Process:** PERC cells are made by modifying the rear surface of a traditional solar cell, enhancing its performance by improving light capture and reducing recombination of electrons.
- **Efficiency:** PERC panels have efficiencies that are generally higher than standard monocrystalline panels, often reaching up to 22% or more.
- **Durability:** PERC panels offer similar durability to standard monocrystalline panels, with a lifespan of 25 to 30 years.
- **Cost:** PERC panels are more expensive to produce than regular monocrystalline panels but offer higher energy output, which can justify the price in applications where space is limited.

- **Applications:** PERC technology is commonly used in both residential and commercial solar installations, as it maximizes energy output in limited spaces.

5. Bifacial Solar Panels

- **Description:** Bifacial solar panels are designed to capture sunlight on both the front and back sides of the panel. This allows the panel to capture reflected sunlight from the ground or other surfaces, improving overall energy generation.
- **Production Process:** These panels are typically made from monocrystalline silicon and are designed with glass on both the front and back, allowing light to be absorbed from both sides.
- **Efficiency:** Bifacial panels can increase energy yield by up to 30% compared to traditional monofacial panels, depending on the reflectivity of the surface underneath the panels.
- **Durability:** These panels have a similar lifespan to monocrystalline panels, typically around 25-30 years.
- **Cost:** Bifacial panels tend to be more expensive than monofacial panels due to their design and the materials used, but the increased energy yield often makes them a cost-effective choice in certain applications.
- **Applications:** Bifacial panels are typically used in commercial and utility-scale solar installations, especially in locations where the ground reflects a lot of light (such as snowy or desert environments).

Characteristics of Solar Photovoltaics

The characteristics of solar PV systems are influenced by the type of panel, as well as environmental factors and the design of the solar power system. The most important characteristics include:

1. Efficiency

- Efficiency refers to the percentage of sunlight that a solar panel can convert into usable electricity. Monocrystalline panels are the most efficient, followed by PERC, polycrystalline, and thin-film panels. Higher efficiency means more electricity can be generated from a given area, making efficient panels ideal for small spaces or applications with high energy demands.

2. Power Output

- Power output refers to the total amount of electrical energy a solar panel can produce under standard test conditions (STC), typically measured in watts (W). Higher-efficiency panels generally have higher power outputs.

3. Durability and Lifespan

- Solar panels are designed to last for many years, with most panels lasting 25-30 years with minimal degradation. Over time, the output of a solar panel will decrease, but well-maintained panels will continue to produce electricity for decades.

4. Temperature Coefficient

- The temperature coefficient indicates how much a panel's efficiency decreases as temperature increases. Solar panels typically lose some efficiency in hot conditions. Monocrystalline panels tend to perform better in high-temperature conditions than thin-film panels.

5. Degradation Rate

- Solar panels degrade over time, meaning their efficiency gradually declines as they age. The degradation rate is typically around 0.5-1% per year for most panels, meaning after 25-30 years, the panel may only produce around 80-90% of its original power output.

6. Cost

- The cost of solar panels varies depending on the type, efficiency, and brand. While monocrystalline panels are the most expensive upfront, they offer the best efficiency and space utilization. Thin-film panels are cheaper but typically require more space to generate the same amount of power.

7. Aesthetic and Design Flexibility

- The design and appearance of solar panels vary by type. Thin-film panels are more flexible and can be integrated into building materials, while monocrystalline panels are typically rigid and may have a more uniform appearance. Bifacial panels are transparent on the back, allowing for architectural integration into both residential and commercial designs.

Applications of Solar Photovoltaics

Solar photovoltaics are used in a wide variety of applications, ranging from small-scale residential use to large-scale utility projects:

1. **Residential Solar Systems:** Solar panels are installed on rooftops or on the ground to provide electricity for homes, reducing reliance on the grid and lowering electricity bills.
2. **Commercial and Industrial Solar Systems:** Businesses and industries install solar panels to reduce energy costs, power large facilities, and contribute to sustainability goals.

3. **Utility-Scale Solar Power Plants:** Large solar farms generate electricity that is fed into the grid, often producing gigawatts of power to supply communities and cities.
4. **Off-Grid Systems:** In remote areas without access to the electricity grid, solar panels provide a reliable, sustainable energy source for homes, businesses, and communication systems.
5. **Solar-Powered Vehicles:** Solar panels are used in some electric vehicles (EVs) to supplement battery charging, improving their overall range and energy efficiency.

Conclusion

Solar photovoltaics are an essential part of the global transition to renewable energy. The technology has advanced significantly in recent years, with numerous types of solar panels available to meet a variety of needs. From residential applications to utility-scale solar farms, PV technology is becoming more efficient, affordable, and versatile. As the demand for clean energy continues to rise, solar photovoltaics will play an increasingly important role in meeting global energy needs.

Load Estimation, Battery, Inverter, and Control Systems in Solar Power Systems

In solar power systems, proper load estimation, battery storage, inverter selection, and control systems are crucial to ensuring efficient and reliable energy management. These components work together to optimize energy production, storage, and consumption. Let's explore each of these elements in detail:

1. Load Estimation

Load estimation refers to the process of determining the energy consumption needs of a building, facility, or device over a given period. This is a critical first step in designing a solar power system because it ensures that the system is appropriately sized to meet the energy demands.

Steps in Load Estimation:

- **Identify Energy Demand:** The first step is to identify all the electrical loads (devices, appliances, and systems) that will be powered by the solar energy. This includes lights, air conditioning, computers, refrigerators, etc.
- **Measure Power Consumption:** Each load has a power rating, typically given in watts (W). For each device, you need to determine:
 - **Wattage (W):** The power consumption of the device, typically listed on the appliance's label.
 - **Usage Duration (hours):** How long each device is used during the day or month.
- **Calculate Daily and Monthly Load:** Multiply the wattage of each device by the hours of usage to estimate the energy consumption (in watt-hours, Wh) for each load:

$$\text{Energy Consumption (Wh)} = \text{Power (W)} \times \text{Duration (h)}$$

$$= \text{Power (W)} \times \text{Duration (h)}$$

Sum up the energy consumption of all devices to get the total energy requirement.

- **Consider Peak Load and Growth:** Estimate the peak load (maximum power demand at any given moment) and plan for any future load increases. This ensures the system can handle occasional surges in power demand without failure.

Example:

If you have the following devices:

- **LED lights:** 10 watts, used for 5 hours/day
- **Refrigerator:** 100 watts, used for 24 hours/day
- **Air conditioner:** 1000 watts, used for 4 hours/day

The energy consumption will be:

- LED lights: $10 \text{ W} \times 5 \text{ h} = 50 \text{ Wh/day}$
- Refrigerator: $100 \text{ W} \times 24 \text{ h} = 2400 \text{ Wh/day}$
- Air conditioner: $1000 \text{ W} \times 4 \text{ h} = 4000 \text{ Wh/day}$

Total daily energy requirement = $50 + 2400 + 4000 = 6450 \text{ Wh/day}$

By estimating your load accurately, you can then select the appropriate size for the solar panels, battery storage, and inverter.

2. Batteries in Solar Power Systems

Batteries are used in solar systems to store excess energy generated during the day so that it can be used at night or during periods of low sunlight. Battery storage enables off-grid systems or provides backup power for grid-tied systems during power outages.

Key Considerations for Batteries:

- **Battery Capacity (Ah or Wh):** The capacity of a battery is typically measured in amp-hours (Ah) or watt-hours (Wh). It indicates how much energy the battery can store. For instance, a 12V battery rated at 100Ah can store $12 \times 100 = 1200 \text{ Wh}$
- **Depth of Discharge (DoD):** This refers to how much of the battery's capacity can be used before recharging is required. For example, if a battery has a DoD of 80%, only 80% of its capacity is usable. Higher DoD means more usable energy but potentially shorter battery life.

- **Efficiency:** Batteries have an efficiency rating, typically around 85-95%. This means some energy is lost during charging and discharging. Choose batteries with a higher efficiency to reduce losses.
- **Battery Life:** Batteries degrade over time, losing capacity after a certain number of charge cycles (typically 3,000 to 5,000 cycles for high-quality batteries). The battery's lifespan is also influenced by temperature, depth of discharge, and usage patterns.
- **Types of Batteries:** Common types of batteries used in solar power systems include:
 - **Lead-Acid Batteries:** Traditional, cheaper, and widely used, but with a shorter lifespan and lower efficiency.
 - **Lithium-Ion Batteries:** More expensive, but they offer better efficiency, longer lifespan, and are compact.
 - **Nickel-Cadmium (NiCd) Batteries:** Less commonly used due to environmental concerns but offer durability and performance in extreme temperatures.

Battery Sizing:

The size of the battery system is calculated based on the daily energy consumption and how many days of autonomy (backup power) are needed. For example, if you need to store 6,450 Wh for 1 day of autonomy, and the battery has a 12V, 100Ah rating, you can calculate the number of batteries needed:

Number of Batteries = $\frac{\text{Total Energy Requirement (Wh)}}{\text{Battery Capacity (Wh)}}$

For a 12V, 100Ah battery:

Battery Capacity = $12 \times 100 = 1200 \text{ Wh}$

So for 6,450 Wh:

Number of Batteries = $\frac{6450}{1200} \approx 5.38$

You would need 6 batteries to provide sufficient storage for one day's worth of energy.

3. Inverters in Solar Power Systems

Inverters are devices that convert the DC (direct current) electricity produced by solar panels and stored in batteries into AC (alternating current) electricity, which is used by most household appliances and the grid.

Types of Inverters:

- **String Inverters:** These are the most common type used in residential solar systems. A string inverter converts the DC electricity from a series of solar panels (a "string" of panels) into AC. While cost-effective, they are less efficient because if one panel in the string is shaded or malfunctions, it can affect the performance of the entire system.

- **Microinverters:** These are installed on each individual solar panel and convert DC to AC at the panel level. Microinverters are more efficient than string inverters because they avoid performance issues caused by shading or dirt on individual panels. They also allow for better optimization of each panel's performance.
- **Hybrid Inverters:** These are a combination of a standard inverter and a charge controller for the battery. Hybrid inverters manage both the solar panels and the battery storage, providing seamless energy conversion, storage, and management.
- **Off-Grid Inverters:** These inverters are used in off-grid systems and can operate independently of the grid, providing power to the home or facility directly from the battery storage or solar panels.
- **Grid-Tied Inverters:** These inverters are used in grid-tied solar systems and allow excess solar energy to be fed into the electric grid. They are designed to synchronize with the grid's frequency and voltage.

Inverter Sizing:

The inverter size depends on the solar array's capacity. Typically, the inverter should be rated for at least the peak power of the solar panels. A general guideline is to choose an inverter that can handle 20-30% more than the total peak output of the solar panels to accommodate fluctuations in sunlight.

For example, if your solar array is rated for 5 kW, you would choose an inverter rated between 6 kW and 7 kW to ensure that the inverter can handle peak power loads.

4. Control Systems in Solar Power Systems

Control systems are essential for managing the operation and efficiency of the solar power system, ensuring safe operation and optimizing energy production. These systems include:

a. Maximum Power Point Tracking (MPPT)

- MPPT is a technique used by inverters to continuously adjust the voltage and current from the solar panels to find the "maximum power point," which is the most efficient operating point under varying sunlight conditions.
- MPPT increases the overall efficiency of the system by ensuring that the solar panels are always operating at their optimum voltage and current, regardless of changing environmental conditions (e.g., cloud cover, temperature).

b. Battery Management System (BMS)

- The BMS is responsible for monitoring the state of charge (SoC), voltage, temperature, and health of the battery. It ensures safe charging and discharging, preventing overcharging, deep discharging, and thermal runaway in the battery.
- BMS is particularly important in systems using lithium-ion batteries, as these batteries are sensitive to overcharging and overheating.

c. Charge Controller

- A charge controller is used in off-grid systems to regulate the voltage and current coming from the solar panels to the batteries. It prevents the battery from overcharging and ensures proper charging based on the battery's needs.
- In hybrid or off-grid systems, the charge controller is often integrated with the inverter, as in hybrid inverters.

d. Energy Management System (EMS)

- An EMS is a more advanced control system that manages energy flows between the solar panels, batteries, grid, and load. It optimizes when to store energy in the battery, when to use solar power directly, and when to draw power from the grid. This ensures maximum cost savings, energy independence, and system efficiency.

Conclusion

The success of a solar power system depends on the careful integration of various components: load estimation, batteries, inverters, and control systems. Proper load estimation ensures that the system can meet the energy needs of the building or facility. Batteries provide storage to ensure reliable power availability, while inverters convert DC to AC for use by household appliances or the grid. Control systems, including MPPT, BMS, and charge controllers, ensure the system operates safely, efficiently, and optimally.

By carefully selecting and sizing each of these components, solar power systems can deliver reliable, sustainable, and cost-effective energy solutions for a wide range of applications.