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CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 2

SOLAR CONCENTRATING COLLECTORS AND PV TECHNOLOGY

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PV Powered Water Pumping Systems: Sizing and Optimization

Photovoltaic (PV) powered water pumping systems are a sustainable and efficient solution for water pumping needs in areas without access to a reliable electricity grid. These systems use solar energy to power pumps that can supply water for agricultural irrigation, livestock watering, rural households, and other applications. The main components of a PV-powered water pumping system include solar panels, a pump (typically a submersible or surface pump), an inverter (for systems that need AC pumps), and a control system to ensure efficient operation.

Components of a PV Powered Water Pumping System

1. **Photovoltaic Panels (Solar Modules):**
 - Solar panels convert sunlight into DC electricity. The output of the panels depends on factors like solar irradiance, temperature, and panel orientation.
 - Solar modules are typically rated in watts (W) or kilowatts (kW), and the total power generated is directly related to the amount of sunlight they receive.
2. **Pump:**
 - The pump can be either a submersible pump (for deep wells) or a surface pump (for shallow water sources).
 - The type and size of the pump depend on the water requirements (flow rate, head height, etc.) and the available solar energy.
3. **Inverter (if needed):**
 - If an AC pump is used, an inverter is needed to convert the DC electricity generated by the solar panels into AC power.
 - For DC pumps, the inverter is not required, but a DC-DC controller might be used to regulate voltage and current.
4. **Control and Monitoring System:**
 - These systems help regulate the performance of the pump, monitor the battery (if present), and ensure that the pump operates efficiently under different sunlight conditions.
 - Includes features like MPPT (Maximum Power Point Tracking) to ensure that the system operates at peak efficiency.
5. **Battery Storage (Optional):**
 - In some systems, batteries are included to store excess energy generated during the day for use when sunlight is not available (e.g., nighttime or cloudy periods). However, in many PV pumping systems, batteries are not required, as the system is designed to operate when sunlight is available.

Sizing of a PV Powered Water Pumping System

Sizing a PV-powered water pumping system requires considering the water demand, solar energy availability, and the type of pump being used. The process involves several key steps:

1. Determine Water Requirements

- **Flow Rate (Q):** The flow rate is the volume of water required per unit of time (e.g., liters per minute or gallons per hour). For agricultural irrigation, flow rates can vary depending on the crop needs.
- **Total Head (H):** The head is the vertical distance that the pump needs to lift the water. This can include the depth of the well, the height of the tank, and friction losses in the piping.
- **Operating Hours:** Determine how many hours per day the system will need to pump water. This depends on the application and local conditions, such as irrigation schedule or livestock water needs.

2. Select the Appropriate Pump

- **Type of Pump:** Choose between a submersible pump (for deep wells) or a surface pump (for shallow wells).
- **Pump Characteristics:** Pump selection depends on the flow rate and head requirements. The pump's specifications will indicate its power consumption at different flow rates and heads.
- The pump should be selected to provide the necessary head and flow rate while matching the available solar power.

3. Solar Array Sizing

- **Solar Irradiance:** The amount of sunlight available depends on the geographical location and time of year. Solar irradiance is typically expressed in kWh/m²/day, and local weather data can help determine the average daily solar radiation.
- **Solar Panel Capacity:** The total number of solar panels required can be calculated based on the pump's power consumption. If the pump requires a certain power output (e.g., 1 kW), the total panel output should exceed this value, factoring in efficiency losses due to temperature, shading, and other environmental factors.

$$\text{Required Solar Power (W)} = \frac{\text{Pump Power Consumption (W)}}{\text{Solar Panel Efficiency} \times \text{Safety Factor}}$$

For example, if the pump needs 1 kW of power, and the solar panel efficiency is 80%, the required solar power will be:

$$1 \text{ kW} = 1 \text{ kW} \div 0.8 \approx 1.25 \text{ kW}$$

You will then divide this required power by the wattage of individual panels to determine the number of panels needed.

4. Account for System Losses

- **Efficiency Losses:** Solar power systems have inherent losses due to factors like shading, dirt, temperature, and wiring. Efficiency losses typically range from 15% to 25%, depending on environmental conditions.
- **Pump Efficiency:** The efficiency of the pump is also a crucial factor. Submersible pumps may have efficiencies of around 60-80%, while surface pumps may perform slightly better.

5. Battery Sizing (if applicable)

- If battery storage is used, you need to estimate the amount of storage required to cover periods without sunlight (e.g., cloudy days or nighttime). The battery storage capacity should be able to meet the water pumping demand during these periods.
- Battery sizing is calculated by multiplying the daily energy consumption of the pump (in watt-hours) by the number of days of autonomy desired.

Example: If the pump requires 1000 Wh per day and 2 days of backup is needed:

Battery Size (Wh) = 1000 Wh/day × 2 days = 2000 Wh
 $\text{Battery Size (Wh)} = 1000 \, \text{Wh/day} \times 2 \, \text{days} = 2000 \, \text{Wh}$

Optimization of PV Powered Water Pumping Systems

Optimizing a PV-powered water pumping system involves improving its efficiency and performance, reducing costs, and maximizing the system's operational lifespan. Several techniques and strategies can be employed to optimize the system:

1. Maximizing Solar Irradiance

- **Panel Orientation:** Solar panels should be oriented to maximize exposure to the sun, typically facing south in the Northern Hemisphere and north in the Southern Hemisphere. The angle of the panels should be adjusted to match the latitude for maximum solar gain throughout the year.
- **Tracking Systems:** Use of solar trackers that adjust the angle of the panels to follow the sun can increase system efficiency by 20-30%. These can be either single-axis (following the sun's movement east to west) or dual-axis (adjusting for both time of day and seasonal changes).

2. Utilizing Maximum Power Point Tracking (MPPT)

- **MPPT Technology:** MPPT is used in solar inverters and charge controllers to continuously adjust the voltage and current to operate at the maximum power point. This ensures the system operates efficiently even as sunlight conditions vary throughout the day.

- **Efficiency Gains:** MPPT can improve the overall efficiency of the system, especially in environments with fluctuating sunlight or partial shading.

3. Optimizing Pump Selection and Operation

- **Choosing the Right Pump Curve:** The pump's performance is directly linked to the system's head and flow rate. Selecting the correct pump based on the system's needs ensures that the pump operates within its most efficient range.
- **Variable Speed Pumps:** These pumps adjust their speed to match the available solar power, ensuring they operate efficiently even when sunlight is variable. By matching the pump speed to the available power, these pumps prevent overloading and optimize water pumping based on sunlight.

4. Energy Management and Control

- **System Controllers:** Advanced controllers can monitor and regulate the entire pumping system, adjusting pump operation according to solar energy availability and water demand. These controllers ensure the system operates efficiently, reducing energy waste and maximizing system uptime.
- **Remote Monitoring:** Modern systems often come with remote monitoring and control capabilities, allowing users to track system performance, identify issues early, and perform optimizations based on real-time data.

5. Minimizing System Losses

- **Low-loss Wiring:** Use high-quality, low-resistance wiring to minimize energy losses in the system. Properly sized wires for both the solar array and pump system ensure minimal energy loss.
- **System Maintenance:** Regular maintenance of the solar panels (cleaning) and the pump (checking for wear and tear, ensuring proper function) helps maintain the efficiency of the system. Dust, dirt, and shading on the panels can reduce their efficiency by up to 25%, so regular cleaning is essential.

6. System Design Adjustments for Local Conditions

- **Local Climate Considerations:** Adjust the design and optimization strategies based on local weather patterns, such as average annual solar radiation, rainfall patterns, and temperature fluctuations. For example, in regions with frequent dust storms, the panels may require more frequent cleaning.
- **Backup Water Supply:** In case of periods of insufficient sunlight (such as during rainy seasons), consider integrating a secondary water source or backup generator to ensure consistent water pumping.

Conclusion

A PV-powered water pumping system provides a sustainable, low-maintenance solution for water pumping in remote areas and for agricultural applications. Proper sizing of the system, including solar panel capacity, pump specifications, and battery storage (if needed), is critical to ensure the system can meet the water demand. Optimization of the system involves selecting the right components, maximizing solar energy capture, and using advanced control technologies like MPPT to ensure the system operates efficiently under varying sunlight conditions.

By carefully designing, sizing, and optimizing the system, PV-powered water pumping can deliver reliable, cost-effective, and environmentally friendly water solutions.

Hybrid System Solar Technologies in Green Buildings

A **hybrid solar system** in green buildings integrates multiple sources of renewable energy and conventional power systems to enhance energy efficiency, reduce reliance on the grid, and maximize the sustainability of a building. These systems often combine **solar photovoltaics (PV)**, **solar thermal**, and sometimes **energy storage** solutions, along with a backup power supply (like a diesel generator or the grid). Hybrid systems aim to optimize energy use, reduce operational costs, and increase resilience, ensuring reliable power and minimal environmental impact.

In green buildings, hybrid solar systems are central to achieving sustainable energy goals and aligning with **green building certifications** like LEED (Leadership in Energy and Environmental Design). The adoption of hybrid systems enhances a building's energy efficiency, reduces its carbon footprint, and integrates renewable energy seamlessly into the building's operations.

Here's a detailed explanation of how hybrid solar technologies are used in green buildings, including the types of systems, their components, and benefits:

1. Types of Hybrid Solar Systems

Hybrid solar systems in green buildings typically combine the following technologies:

a. Solar Photovoltaic (PV) + Energy Storage (Batteries)

- **Solar PV Systems:** Photovoltaic systems convert sunlight directly into electricity using semiconductor materials in solar panels. These systems can be grid-tied, off-grid, or hybrid systems.
- **Energy Storage (Batteries):** Battery storage (e.g., lithium-ion or lead-acid batteries) is used to store excess solar energy generated during the day for use at night or during periods of low sunlight. This is critical for providing energy independence in buildings and ensuring continuous power supply without reliance on the grid.

How It Works:

- Solar panels generate electricity, which powers the building's load.
- Excess electricity produced is stored in the batteries.
- During the night or cloudy days, the stored energy is used, ensuring that the building remains powered without relying on grid electricity.
- In some systems, if the stored battery energy is insufficient, grid power or a backup generator is used to meet the building's energy needs.

Benefits:

- Reduces grid dependency.
- Maximizes self-consumption of solar energy.
- Provides backup power in case of grid failures.

b. Solar Thermal + Solar Photovoltaic (PV)

- **Solar Thermal Systems:** Solar thermal collectors capture heat from the sun and transfer it to water or a heat transfer fluid, which can be used for domestic hot water (DHW), space heating, or even for industrial processes. These systems can be integrated into hybrid systems with PV to provide both electricity and thermal energy.
- **How It Works:**
 - Solar PV panels generate electricity to meet the electrical demand of the building.
 - Solar thermal collectors capture solar energy to heat water, which can be used for heating or hot water needs.
 - This combination reduces the demand for electrical energy for heating purposes and provides a more comprehensive solution for energy needs.

Benefits:

- More comprehensive energy solution (both electricity and heating).
- Lower operational costs for heating and hot water.
- Reduced reliance on traditional energy sources for heating.

c. Solar PV + Diesel Generator + Battery Storage (or Grid)

- This hybrid system is commonly used in remote areas or in off-grid applications where solar power alone may not meet all the energy needs of a building.
- **How It Works:**
 - Solar PV systems generate electricity, and excess power is stored in batteries.
 - When solar production is insufficient, the diesel generator can supply additional power.
 - Alternatively, the grid may be used for supplementary power.
- This type of hybrid system ensures a reliable power supply while minimizing fossil fuel consumption and reducing emissions compared to using the diesel generator alone.

Benefits:

- Provides reliable power even in remote or off-grid locations.
- Reduces fuel consumption by using solar energy when available.
- Can be more cost-effective than a fully off-grid diesel system.

d. Solar PV + Wind + Energy Storage

- In some cases, **wind energy** is combined with solar energy and battery storage to form a hybrid system. Wind turbines can generate electricity when solar production is low, such as during the night or on cloudy days.
- **How It Works:**
 - The wind turbine generates electricity when wind conditions are favorable.
 - Solar panels provide energy during daylight hours.
 - Batteries store excess energy from both sources, and the system uses this energy when the production from either source is low.
- This combination can provide a more consistent power supply, as wind and solar energy are often complementary.

Benefits:

- Provides energy generation in both sunny and windy conditions.
- Reduces reliance on the grid or backup generators.
- Enhances energy security and reliability.

2. Key Components of Hybrid Solar Systems

A hybrid solar system includes several key components that allow it to function optimally:

a. Solar Panels (Photovoltaic Modules)

- Solar panels are the core of the system and are responsible for converting sunlight into electricity. In a hybrid system, the number of solar panels should be sufficient to meet the building's electricity needs while also considering peak demand and storage capacity.

b. Inverter

- The inverter converts the DC electricity generated by the solar panels into AC electricity, which is used to power appliances in the building.
- **Hybrid Inverters:** These inverters are capable of managing both the solar PV and the battery storage system. They intelligently balance the flow of energy between the solar panels, batteries, and the grid to ensure that the system operates efficiently.

c. Battery Storage System

- **Battery Storage** is used to store excess energy generated during the day for use at night or during cloudy days. The batteries are typically lithium-ion or lead-acid, with lithium-ion being more common in modern systems due to its higher efficiency and longer lifespan.
- The battery storage system can be sized based on the building's energy consumption and the desired level of energy independence.

d. Charge Controller

- The charge controller manages the charging and discharging of the batteries, ensuring that they do not overcharge or discharge beyond safe limits. This prevents damage to the batteries and ensures optimal performance.

e. Backup Generator (Optional)

- A backup generator (typically a diesel or gas-powered generator) is used as a last resort when solar and battery power are insufficient. Hybrid systems with generators are often used in remote areas or locations where grid power is unreliable.

f. Energy Management System (EMS)

- An Energy Management System (EMS) is responsible for monitoring the system's performance and optimizing energy use. It tracks solar production, battery storage levels, and energy consumption, and intelligently controls the flow of energy to reduce waste and ensure the building's energy needs are met.

3. Sizing a Hybrid Solar System for Green Buildings

Proper sizing of a hybrid solar system is crucial for ensuring that the system meets the building's energy needs and operates efficiently. Here's how the system is typically sized:

1. **Calculate Energy Demand:**
 - Estimate the building's energy consumption (in kWh per day or month). This includes both electrical loads (lighting, appliances, HVAC systems, etc.) and any thermal energy needs (heating water, space heating).
2. **Solar Panel Size:**
 - Based on the estimated daily energy consumption, determine the number of solar panels required. Consider the average solar irradiance for the region to calculate how much energy the panels will produce.
3. **Battery Size:**
 - The battery size is determined by how much energy storage is needed to meet demand when solar production is insufficient (e.g., at night or on cloudy days). A typical rule of thumb is to size the battery storage based on 1-2 days of autonomy.

4. **Inverter Selection:**

- The inverter should be able to handle the peak power demand of the building, including both the solar output and any additional power requirements (e.g., from the grid or backup generator).

5. **Backup Power (if applicable):**

- If a backup generator is included, size it based on the building's critical load and ensure it can handle the peak load during extended periods of low solar production.

4. Benefits of Hybrid Solar Systems in Green Buildings

1. **Energy Independence:**

- Hybrid solar systems reduce or eliminate dependence on the grid, providing more reliable power, especially in remote or off-grid locations.

2. **Cost Savings:**

- Over time, hybrid solar systems can significantly reduce energy costs by reducing reliance on grid electricity, especially when paired with energy storage systems. The integration of solar thermal systems can further reduce heating costs.

3. **Sustainability:**

- Hybrid solar systems are a clean and renewable source of energy, helping buildings achieve sustainability goals by minimizing their carbon footprint and reducing greenhouse gas emissions.

4. **Resilience:**

- With battery storage or backup generators, hybrid solar systems ensure that buildings can continue to function during grid outages or periods of insufficient sunlight.

5. **Flexibility:**

- Hybrid solar systems can be adapted to suit the needs of different building types, climates, and energy requirements. They provide flexible energy solutions, allowing buildings to optimize energy production and consumption.

Conclusion

Hybrid solar systems in green buildings combine solar PV, solar thermal, energy storage, and sometimes backup power sources to create highly efficient, sustainable, and reliable energy solutions. These systems optimize the use of renewable energy while reducing grid reliance and providing backup power during emergencies. By integrating various energy technologies, hybrid systems ensure that green buildings meet their energy needs sustainably and cost-effectively while contributing to environmental conservation.