Handbook:
Designing a Solar-Powered Soilless Irrigation System for Net Houses

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Introduction

The advancement of agricultural practices is crucial in meeting the ever-growing food demand while maintaining sustainable and environmentally friendly methods. One such innovative approach is the integration of soilless cultures in net houses with solar-powered irrigation systems. This handout provides a guide to designing, implementing, and managing a closed hydroponic system powered by solar energy, tailored for small to medium-scale agricultural operations.

Hydroponics, a method of growing plants without soil by using mineral nutrient solutions in an aqueous solvent, is becoming increasingly popular due to its efficiency and ability to produce high yields in controlled environments. Coupled with solar-powered irrigation systems, this method offers a sustainable solution that reduces dependence on non-renewable energy sources and minimizes the environmental footprint of agricultural activities.

Importance of This Handout

The primary purpose of this handout is to serve as a practical guide for farmers, agricultural engineers, and enthusiasts looking to adopt solar-powered hydroponic systems. By following the steps and recommendations provided, users can optimize their resources, improve crop yields, and contribute to sustainable agricultural practices.

Key Benefits:

1. Sustainable Energy Use: Utilizing solar power for irrigation reduces reliance on fossil fuels, leading to lower carbon emissions and a smaller environmental footprint.

2. Efficient Water Use: Closed hydroponic systems recycle water, significantly reducing water consumption compared to traditional soil-based agriculture.

3. Enhanced Crop Production: Controlled environment agriculture, such as net houses, protects crops from adverse weather conditions and pests, leading to more consistent and higher yields.

4. Economic Savings: Over time, the initial investment in solar panels and hydroponic infrastructure can lead to substantial savings on energy and water costs.

Prerequisites

Before using this handout, it is essential that users have a foundational understanding of closed hydroponic systems and solar irrigation components. Familiarity with these concepts will enable users to effectively implement the detailed steps and recommendations provided.

Section 1: Calculating Plant Density, Growing Canals, and Pots.

Step 1: Determine Suitable Plant Density for Cucumber and Tomato in Net House

To determine the suitable plant density for cucumber and tomato crops in a net house, we need to consider the optimal spacing requirements for each plant type. These requirements ensure that plants have enough space to grow properly, receive adequate light, and have sufficient airflow to prevent diseases.

Cucumber Plant Density Calculation

Cucumbers typically require a spacing of about 30-45 cm (0.3-0.45 meters) between plants and 90-120 cm (0.9-1.2 meters) between rows. For simplicity, we'll use an average value for our calculation.

- In-row spacing: 0.4 meters

- Between-row spacing* 1.0 meter

To find the plant density (number of plants per square meter), we use the formula:

$$plant\ density = \frac{1}{\text{In} - \text{row spacing x Between} - \text{row spacing}}$$

For cucumbers:

$$plant\ density = \frac{1}{0.4\text{m x }1\text{m}} = 2.5\ plant/m^2$$

Tomato Plant Density Calculation

Tomatoes generally require a spacing of about 45-60 cm (0.45-0.6 meters) between plants and 90-120 cm (0.9-1.2 meters) between rows. We'll use an average value for our calculation.

- In-row spacing: 0.5 meters

- Between-row spacing: 1.0 meter

For tomatoes:

$$plant\ density = \frac{1}{0.5\text{m x }1\text{m}} = 2.0\ plant/m^2$$

Combining Plant Densities

For a practical approach in a net house, we'll average the densities for cucumbers and tomatoes to find a common suitable density, considering they might share the same growing space.

$$\text{Average plant density} = \frac{2.5\text{ plants}/m^2 + 2\text{ plants}/m^2}{2} = 2.25\text{ plants}/m^2$$

To simplify planning, we can round this to a practical density:

$$practical\ plant\ density \approx 3\ \text{plants}/m^2$$

This value aligns well with the commonly used density of 3 plants per square meter for both cucumber and tomato crops in a net house setting, ensuring optimal growth conditions.

Step 2: Calculate the Total Area of the Net House

To calculate the total area of the net house, we use the formula for the area of a rectangle:

$$Total\ area = \text{Lengh}\ \times \text{Width}$$

Given the common net house size of 8 meters by 30 meters:

$$Total\ area = 30\text{m}\ \times 8\text{m} = 240\ m^2$$

This formula allows you to easily calculate the total area of any rectangular net house by substituting the specific dimensions of length and width.

Step 3: Calculate Optimum Growing Canal Length

When designing the layout for a net house, it is essential to allocate space at both ends of the growing canals for work and walking. This space ensures ease of movement, maintenance, and efficient management of the crops.

Space Requirements

- Front (work area): 2 to 3 meters

- Back (walking path): 1 to 2 meters

For this calculation, we will use the minimum recommended space of 3 meters at the front and 2 meter at the back.

Formula for Canal Length

The formula to calculate the optimum growing canal length is:

$$Optimum\ canal\ lengh = Total\ lenght - (front\ space + Back\ space)$$

Given the net house size of 8 meters by 30 meters:

- Total length of net house: 30 meters

- Space at the front for work area: 3 meters

- Space at the back for walking path: 2 meter

- Optimum growing canal length: 30m – (3m+2m)=25m

This calculation ensures that there is adequate space for working at the front and for walking at the back, while maximizing the length of the growing canals for planting.

Step 4: Calculate the Optimum Number of Plants

Calculating the optimum number of plants in a net house involves understanding the balance between plant density and overall plant health. Plant density refers to the number of plants per square meter. For cucumber and tomato crops, a suitable plant density is approximately 3 plants per square meter. The total number of plants can be calculated by multiplying the plant density by the total area of the net house.

$$Optimum\ number\ of\ plants = Plant\ density\ \times Total\ area$$

Given the total area of the net house is 240 square meters:

$$Optimum\ number\ of\ plants = 3\frac{plant}{m^2} \times 240\ m^2 = 720\ plants$$

Impact of Plant Density

Choosing the right plant density is crucial for maximizing yield and maintaining plant health. A higher plant density can lead to overcrowding, which reduces production by increasing competition among plants for light, nutrients, and water. Overcrowded conditions also create a favourable environment for the spread of diseases and pests, potentially leading to higher infection rates.

Conversely, a lower plant density means fewer plants per square meter, which reduces competition and allows each plant to access more resources. While this setup can enhance individual plant health and reduce the risk of disease, it may also result in a lower total yield and, consequently, reduced income. Therefore, finding the optimal plant density is essential to balance the benefits of resource availability and total yield. For cucumber and tomato crops, a density of 3 plants per square meter is often ideal, providing a balance between maximizing production and maintaining plant health.

Step 5: Calculate the Number of Pots

When calculating the number of pots required for planting crops in a net house, several factors should be considered, including the size of the pots, the planting configuration, and the total number of plants. The size of the pot must be sufficient to support the root system of the crops and provide adequate space for growth. Additionally, the configuration of the plants within the pots, such as planting in a V shape, can maximize space efficiency and support optimal plant development.

For cucumber and tomato crops, using pots with dimensions of 25 cm by 25 cm is suitable. The number of plants per pot depends on the space required for each plant to grow. Cucumber and tomato plants typically require 30 to 50 cm of space between them. Planting these crops in a V shape allows for two plants per pot, ensuring that each plant has adequate space to grow without overcrowding. However, it's important to note that larger pot sizes require more volume of growing media, which can increase the cost of production. Conversely, using pots that are smaller than optimal can restrict plant growth, leading to reduced yield and lower overall plant health.

To calculate the total number of pots needed in the net house, we divide the total number of plants by the number of plants per pot:

$$The\ total\ number\ of\ pots = \frac{The\ total\ number\ of\ plants}{\text{Number of plants per pot}}$$

For Cucumber and Tomato crops with V shape planting and given the previously calculated total number of plants (720 plants):

$$The\ total\ number\ of\ pots = \frac{720}{2} = 360\text{ pots}$$

This calculation ensures that each pot accommodates two plants, optimizing space and resources within the net house. By carefully selecting the appropriate pot size and planting configuration, growers can balance the costs associated with growing media and the need for adequate plant growth, ultimately maximizing yield and profitability.

Step 6: Calculate the Optimum Number of Canals

When the number of pots is calculated, the next step is to determine the number of canals required in the net house. This involves calculating how many pots can fit per canal based on the canal length and then determining the number of canals needed to accommodate all the pots.

Considerations for Canal Design

1. Internal Space of Canals: The internal length of the canal should account for the thickness of the walls. Using cement blocks with a thickness of 10 cm, we need to subtract this thickness from the total canal length.

2. Width and depth of the Canals: When cement blocks are used, the pots can sit on the edge of the canal. The width should ensure that there is a 5 cm space between the bottom of the pots and the bottom of the canal for water movement. For 25 cm x 25 cm pots, an internal space of 20 cm is sufficient. Using cement blocks of 10x40x20 cm, the total width of the canals would be:

$$Total\ width = 10\ cm\ (wall) + 20\ cm\ (\ internal\ space) + 10\ cm\ (wall)$$

Step-by-Step Calculation

1. Calculate the Internal Length of Each Canal:

Given the optimum canal length, in our example, is 25 meters (from Step 3), and considering the wall thickness:

$$Internal\ lengh = 25\ meters - (2\ \times 0.1\ meters) = 24.8\ meters$$

2. Calculate the Number of Pots per Canal:

Each pot has a width of 25 cm (0.25 meters)

$$Number\ of\ pots\ per\ canal = \frac{Internal\ lenght}{Width\ of\ one\ pot} = \frac{24.8}{0.25} \approx 99\ pots$$

3. Calculate the Total Number of Canals Required:

To calculate number of canals total number of pots will be divided to number of pots per canal. Given the total number of pots (360 pots) from Step 5:

$$Number\ of\ growing\ canals = \frac{\text{Total number of pots}}{\text{Number of pots per canal}} = \frac{360}{99} = 3.64\ \approx 4$$

Rounding up, we need 4 canals to accommodate all the pots. With 4 canals we will have 396 pots and 792 plants with plant density of 3.3 which is still acceptable.

Impact of Increasing the Number of Canals

Increasing the number of canals beyond the optimum number has several negative impacts on both the initial and running costs of the system:

Higher Initial Costs:

Larger Pump and Irrigation System: More canals require a larger, more powerful pump and a more complex irrigation system to ensure adequate water distribution to all canals. This increases the initial investment.

Extra Pots and Growing Media: Additional canals mean more pots and a greater volume of growing media, which directly raises the cost of materials.

Increased Running Costs:

Maintenance and Operation: A larger system with more canals needs more regular maintenance and monitoring, leading to higher labor and operational costs.

Water and Nutrient Management: More canals increase the complexity of water and nutrient management, potentially leading to inefficiencies and higher resource consumption.

Reduced Space Efficiency:

Spacing Between Canals: Less than 1.2 meters (centre to centre) between canals is not recommended. Insufficient space between canals can lead to overcrowding, poor air circulation, and increased disease risk. It also hampers ease of movement and maintenance within the net house.

By maintaining the optimal number of canals and appropriate spacing, growers can ensure efficient use of resources, minimize costs, and promote healthy plant growth, ultimately leading to higher yields and profitability.

Section 2: Calculate Head Required Based on the Required Flow Rate and Head Loss Due to Irrigation System

Step 1: Determine the Total Flow Rate

The total flow rate in a closed soilless production system depends on the number of drippers and the flow rate of each dripper.

- Flow rate of each dripper: Typically, drippers have a flow rate of 4 or 8 litters per hour (l/h).

- Number of drippers: This depends on the number of pots and plants.

$$Total\ flow\ rate\ (Q) = Number\ of\ Dirppers\ \times Flow\ rate\ per\ drippers$$

For example, if there are 400 drippers (one per pots) with 8 l/h discharge:

$$Total\ flow\ rate\ (Q) = 400\ drippers\ \times 8\frac{l}{h} = 3200\frac{l}{h}$$

Convert the total flow rate to cubic meters per hour (m^3/h):

$$3200\frac{l}{h} = 3.2\ m^3/h$$

Step 2: Calculate Flow Velocity and determine pipe size.

Flow velocity in the pipes is crucial to ensure efficient water delivery without causing excessive pressure loss. The desired flow velocity for irrigation systems typically ranges between 0.5 and 2 meters per second (m/s).

To calculate the flow velocity, use the following formula:

$$v = \frac{Q}{A}$$

Where:

- V is the flow velocity (m/s)
- Q is the flow rate (m^3/s)
- A is the cross-sectional area of the pipe (m^2)

Step-by-Step Calculation

1. **Convert the Total Flow Rate to Cubic Meters per Second (m^3/s):**

$$Q = \frac{3.2\ m^3/h}{3600\ s^h} = 8.89\ \times 10^{-4} m^3/s$$

2. **Determine the Cross-Sectional Area of the Pipe:**

The cross-sectional area A of a pipe can be calculated using the pipe diameter D:

$$A = \frac{\pi D^2}{4}$$

For a pipe with a diameter of 25 mm (0.025 meters):

$$A = \frac{\pi (0.025)^2}{4} = 0.00049087\ m^2$$

3. **Calculate the Flow Velocity:**

Using the flow rate $Q=8.89 \times 10^{-4}\ m^3/s$ and cross-sectional area $A=0.00049087\ m^2$

$$v = \frac{8.89\ \times 10^{-4} m^3/s}{0.00049087\ m^2} = 1.81\ m/s$$

Step 3: Determine pipe size.

The flow velocity in a 25 mm diameter pipe is approximately 1.81 meters per second. This falls within the acceptable range for irrigation systems (0.5 - 2 m/s), ensuring efficient water delivery and minimizing pressure loss.

If a larger pipe diameter (e.g., 50 mm) is used:

$$A = \frac{\pi (0.05)^2}{4} = 0.0019635\ m^2$$

$$v = \frac{8.89\ \times 10^{-4} m^3/s}{0.0019635\ m^2} = 0.45\ m/s$$

This new velocity of 0.45 m/s would be below the desired range, indicating that a 25 mm pipe is more appropriate for maintaining the desired flow velocity.

Step 4: Convert Fitting Equivalent Length to Pipe Length

When designing piping systems, it's important to account for the pressure losses caused by various fittings. These losses can be expressed as an equivalent length of straight pipe. Below are the typical equivalent lengths for various fittings in terms of pipe diameters, including reducers, couplings, and unions.

Common Equivalent Lengths for Fittings:

- **90° Elbow**: 30 pipe diameters
- **45° Elbow**: 16 pipe diameters
- **Tee (Line Flow)**: 20 pipe diameters
- **Tee (Branch Flow)**: 60 pipe diameters
- **Valve**: 10 pipe diameters
- **Concentric Reducer (2:1)**: 20 pipe diameters
- **Eccentric Reducer (2:1)**: 30 pipe diameters
- **Coupling**: 4 pipe diameters
- Union**: 20 pipe diameters**

Equivalent Length Calculation for the Given System with Additional Gate Valves

We will calculate the equivalent lengths for the given fittings and then sum them to find the total equivalent length of the system. The system includes 32 mm and 25 mm pipes with the following fittings:

32 mm Pipe Fittings: 1 Coupling, 2 Elbows 90°, 1 Valve, 1 Tee (Branch), and1 Concentric Reducer (32 mm to 25 mm)

25 mm Pipe Fittings: 3 Tees (Branch), 6 Elbows 90°, 4 Gate Valves,

Pipe Diameters:

32 mm Pipe Diameter: 0.032 meters

25 mm Pipe Diameter: 0.025 meters

Equivalent Lengths for 32 mm Pipe Fittings

1. Coupling: 4 pipe diameters: $L_{coupling}$=4 x 0.032m=0.128 m

2. 90° Elbows: 30 pipe diameters each: L_{elbow}=2 x 30 x 0.032m=1.92 m

3. Valve: 10 pipe diameters: L_{valve}=10 x 0.032m=0.32 m

4. Tee (Branch): 60 pipe diameters: L_{Tee} =60 x 0.032m=1.92 m

5. Concentric Reducer: 30 pipe diameters (assuming an average value for 2:1 ratio): L_{Tee} =30 x 0.032m=1.92 m

Total Equivalent Length for 32 mm Pipe: $L_{total\ 32mm}$ = 0.128 + 1.92 + 0.32 + 1.92 + 0.96 = 5.248 m

Equivalent Lengths for 25 mm Pipe Fittings

1. Tees (Branch): 60 pipe diameters each: L_{Tee} =3 x 60 x 0.025m=4.5 m

2. 90° Elbows: 30 pipe diameters each: L_{elbow}=6 x 30 x 0.025m=4.5 m

3. Gate Valves: 8 pipe diameters each: $L_{gate\ valve}$=4 x 8 x 0.025m=0.8 m

Total Equivalent Length for 25 mm Pipe: $L_{total\ 25mm}$ = 4.5 + 4.5 + 0.8 = 9.8 m

Total Equivalent Length for the System

Sum the equivalent lengths of the 32 mm and 25 mm pipes:

$$L_{total\ system} = L_{total\ 32mm} + L_{total\ 25mm}$$

$$L_{total\ system} = 5.248\ m + 9.8\ m$$

$$L_{total\ system} = 15.048\ m$$

Summary

The total equivalent length of the system, including all fittings, is approximately 15.048 meters. This equivalent length can now be used to calculate the total head loss in the system using methods like the Darcy-Weisbach equation.

Resources

For more detailed information, you can refer to the following sources:

1. [Neutrium - Pressure Loss from Fittings: Equivalent Length Method](https://neutrium.net/fluid-flow/pressure-loss-from-fittings-equivalent-length-method/)

2. [EngineerExcel - Equivalent Lengths of Pipe Fittings](https://engineerexcel.com/equivalent-lengths-of-pipe-fittings/)

3. [ASHRAE Fundamentals Handbook](https://www.ashrae.org/technical-resources/ashrae-handbook) for detailed tables and calculations.

Step 5: Measure Total Pipe Length Including Equivalent Length of Fittings

To accurately calculate the head loss in your irrigation system, you need to determine the total effective pipe length. This includes the actual physical length of the pipes as well as the equivalent length of all fittings. Here's how to calculate it using the given example.

Example Data:

25 mm Pipe:

- Actual Pipe Length: 108 meters
- Equivalent Length of Fittings: 10 meters

32 mm Pipe:

- Actual Pipe Length: 9.8 meters
- Equivalent Length of Fittings: 5.248 meters

Step-by-Step Calculation:

1. Calculate Total Effective Length for 25 mm Pipe

Actual Pipe Length: 108 meters

Equivalent Length of Fittings: 10 meters

Total effective length for 25mm = 108+10=118m

2. Calculate Total Effective Length for 32 mm Pipe

Actual Pipe Length: 9.8 meters

Equivalent Length of Fittings: 5.248 meters

Total effective length for 32mm = 9.8+5.248=15.048m

Next Steps:

Use these total effective lengths in your head loss calculations using the Darcy-Weisbach equation or any other appropriate method. These lengths ensure that the pressure loss calculations account for all the additional friction introduced by the fittings.

Step 6: Calculate Friction Loss Using the Darcy-Weisbach Equation

The Darcy-Weisbach equation provides a method to calculate the friction loss in a pipe due to the flow of fluid. The equation is:

$$h_f = \frac{fLv^2}{2gD}$$

Where:

- hf is the friction loss (meters of water)
- f is the Darcy friction factor (dimensionless)
- L is the length of the pipe (meters)
- v is the flow velocity (m/s)
- g is the acceleration due to gravity (9.81 m/s^2)
- D is the pipe diameter (meters)

Darcy Friction Factor (f) for Different Pipe Materials

PVC and Polyethylene (PE) Pipe:

- Polyethylene pipes are generally smooth, and the friction factor can be similar to that of PVC pipes.
- Approximate value for f: 0.015 - 0.02 for turbulent flow.

Steel Pipe:

- Steel pipes are rougher compared to polyethylene and PVC pipes.
- The friction factor for steel pipes can be significantly higher, especially if the pipes are not new and have accumulated some roughness.
- Approximate value for f: 0.02 - 0.05 for turbulent flow, depending on the roughness.

Using Darcy-Weisbach Equation:

Given:

- Flow velocity for 25mm: 1.81 m/s (as previously calculated)
- Flow velocity for 32mm: 1.11 m/s (as previously calculated)
- Friction factor: 0.02 (for PVC pipe and Polyethylene pipe)
- Pipe diameter D: 0.025 m (for 25 mm pipe) and 0.032 m (for 32 mm pipe)
- Acceleration due to gravity: 9.81 m/s^2

For 25 mm Pipe:

$$h_f = \frac{0.02 \times 118 \times (1.81)^2}{2 \times 9.81 \times 0.025} = 15.76\text{m}$$

For 32 mm Pipe:

$$h_f = \frac{0.02 \times 15.048 \times (1.11)^2}{2 \times 9.81 \times 0.032} = 0.59\text{m}$$

Step 7: Adding Head Loss Due to Filters and Drippers

When designing an irrigation system, it is crucial to account for the head loss due to filters and drippers. These components can significantly impact the overall pressure and flow rate. Here is a step-by-step guide to include these losses in your calculations.

Determine Head Loss Due to Filters

Filters are essential for preventing debris and particles from clogging the drippers and pipes. Both disk filters and mesh filters can be considered for this purpose.

- **Disk Filter**: Assume a head loss of 3 meters.
- **Mesh Filter**: Assume a head loss of 3 meters.

Determine Head Loss Due to Drippers

Drippers, also known as emitters, are designed to deliver water at a specific flow rate and pressure. The pressure loss through drippers depends on their flow rate and design. If specific data is not available, use the following guidelines:

- **Average Normal Drippers (8 l/h)**: Assume a head loss of 15 meters.
- **Ultra-Low Pressure (ULP) Drippers (8 l/h)**: Assume a head loss of 5 meters.

If you have access to specific data for the drippers, use the pressure required to deliver their design capacity. For example, if an 8 l/h dripper requires 10 meters of pressure to deliver 8 l/h, consider a 10-meter head loss.

Step 8: Calculating Total Head Required

Calculating the total head required for an irrigation system involves summing up all the individual head losses from different components, including pipes, fittings, filters, and drippers. This ensures the system has sufficient pressure to operate efficiently.

Example Data:

- 25 mm Pipe: Friction Loss (as previously calculated): 15.76 meters
- 32 mm Pipe: Friction Loss (as previously calculated): 0.59 meters
- Filters: Disk filter or mesh filter: 3 meters head loss
- Drippers: Normal Drippers (8 l/h): 15 meters head loss or ULP Drippers (8 l/h): 5 meters head loss

Calculation: Combine the head losses from filters and drippers with the head losses calculated for the pipes.

With Normal Drippers:

Total Head Loss = 15.76m (25 mm) + 0.59m (32 mm) + 3m (Filter) + 15 m (Drippers) = 34.35m

With ULP Drippers:

Total Head Loss = 15.76m (25 mm) + 0.59m (32 mm) + 3m (Filter) + 5m (Drippers) = 24.35m

Step 7: Calculate the Pump Power Required

To determine the pump power required for your irrigation system, you need to consider the total head, water flow rate, and the efficiency of the pump. This ensures that the pump selected will meet the needs of the system and maintain optimal performance.

The formula to calculate the pump power in watts is:

$$Pump\ Power\ (W) = \frac{\rho \times g \times H \times Q}{\eta}$$

Where:

ρ is the density of water (1000 kg/m^3)

g is the acceleration due to gravity (9.81 m/s^2)

H is the total head (meters)

Q is the flow rate (m^3/s)

η is the pump efficiency (decimal form)

Given Data:

1. Total Head:

- With Normal Drippers: 34.35 meters

- With ULP Drippers: 24.35 meters

2. Flow Rate:

- Assume a flow rate of 3.2 m^3/h (which is 0.00089 m^3/s)

3. Pump Efficiency:

- Assume an efficiency of 70% (0.70)

Step-by-Step Calculation:

1. Calculate Pump Power for Normal Drippers

- Total Head (H): 34.35 meters
- Flow Rate (Q): 3.2 m^3/h = 0.00089 m^3/s
- Pump Efficiency (η):0.70

$$Pump\ Power\ (W) = \frac{1000 \times 9.81 \times 35.35 \times 0.00089}{0.7} = 428.02$$

2. Calculate Pump Power for ULP Drippers

- Total Head (H): 24.35 meters
- Flow Rate (Q): 3.2 m^3/h = 0.00089 m^3/s
- Pump Efficiency (η):0.70

$$Pump\ Power\ (W) = \frac{1000 \times 9.81 \times 24.35 \times 0.00089}{0.7} = 304.63$$

Summary of Pump Power Required:

- Pump Power with Normal Drippers: 428.02 watts
- Pump Power with ULP Drippers: 304.63 watts

Step 8: Water Tank Capacity

In a closed irrigation system, excess water is returned to the tank. Tomato crops require about 1.8 litters per day at full mature stage[1], while cucumber crops require lest than that. Some sources mentioned between 0.2 to 0.8 litters per day[2]. For this calculation, the tank capacity is based on the higher water requirement of tomato crops.

Given Data:

1. Plant Type: Tomato

2. Daily Water Requirement per Plant: 1.8 litters/day in a drip irrigation system

3. Number of Plants: 792 as calculated before

Step-by-Step Calculation:

1. Calculate Daily Water Requirement for All Plants

$$Total\ number\ of\ plant\ \times Daily\ water\ requirment\ prepalnt = Total\ Dailiy\ Water\ Requirment$$

$$792\ \times 1.8 = 1425.6\ \approx 1500\ litter$$

2. Double the Capacity to Ensure Space for Return Water

$$1500\ \times 2 = 3000\ litter = 3m^3 \approx 800\ gallon$$

Additional Considerations:

The tank should be connected to a fresh water source through a floating valve located in the middle of the tank to adjust the water pH as needed.

The floating valve will help maintain the desired water level and quality in the tank by adding fresh water as needed.

[1] Salokhe, V. M., Babel, M. S., & Tantau, H. J. (2005). Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment. *Agricultural water management*, *71*(3), 225-242.
[2] Dombrovsky, A., Elad, Y., Jaiswal, A. K., Koren, A., Lachman, O., & Frenkel, O. (2018). Combined infection with Cucumber green mottle mosaic virus and Pythium species causes extensive collapse in cucumber plants. *Plant disease*, *102*(4), 753-759.

Section 3: Calculate the Solar System Component

Step 1: Calculate the Required Daily Power for the Pump (kWh)

In designing solar-powered irrigation systems, it's crucial to account for potential inefficiencies that can affect overall performance. Adding a 10% buffer to the daily power requirement calculation helps ensure that the system remains reliable and effective under various conditions. This additional capacity addresses several factors:

1. Energy Losses: Solar panels and electrical components are not 100% efficient. Energy losses can occur due to resistance in wiring, inefficiencies in the pump motor, and other electrical losses within the system.

2. Environmental Factors: Variations in sunlight intensity due to weather conditions (cloud cover, rain) can reduce the energy output of solar panels. The 10% buffer helps compensate for these fluctuations.

3. System Wear and Tear: Over time, the efficiency of solar panels and other components can degrade. Including a buffer ensures the system can still meet the required power demands as components age.

4. Safety Margin: Providing a safety margin ensures that even if the system experiences unexpected increases in power consumption or minor faults, it will continue to operate without interruptions.

By considering these potential inefficiencies and uncertainties, the 10% buffer enhances the reliability and sustainability of the solar-powered irrigation system, ensuring consistent performance and sufficient power supply for the pump.

To calculate the daily power requirement for a pump, considering system efficiency and adding a 10% buffer, follow these steps:

Given Data:

1. Pump Power Rating: 450 Watts

2. Daily Operating Time: 80 minutes

3. System Efficiency Adjustment: Add 10% to account for inefficiencies

Step-by-Step Calculation:

1. Convert Operating Time to Hours

$$Operation\ Time = 80\ minute = \frac{80}{60} = 1.33\ houres$$

2. Calculate Daily Power Consumption (kWh) Without Efficiency Adjustment

$$power\ (kw) = \frac{power\ (watt)}{1000} = \frac{450w}{1000} = 0.45kW$$

$$Daily\ Power\ Consumption\ (kWh) = \ Power\ (kW) \times Operating\ Time\ (hours)$$

$$Daily\ Power\ Consumption\ (kWh) = \ 0.45\ kW \times \ 1.33\ hours$$

$$Daily\ Power\ Consumption\ (kWh) = \ 0.5985\ kWh$$

3. Add 10% for System Efficiency

$$Adjusted\ Daily\ Power\ Consumption\ (kWh)\} \ = \ Daily\ Power\ Consumption\ (kWh) \ \times \ 1.10$$

$$Adjusted\ Daily\ Power\ Consumption\ (kWh) = \ 0.5985\ kWh \ \times \ 1.10$$

$$Adjusted\ Daily\ Power\ Consumption\ (kWh) = \ 0.65835\ kWh$$

Summary

The adjusted daily power requirement for a 450 Watt pump operating for 80 minutes per day, including a 10% buffer for system inefficiency, is approximately 0.65835 kWh.

This calculation helps in designing the solar system by determining the amount of energy needed from the solar panels to meet the pump's daily energy requirements.

Step 2: Calculate the Required Battery Pack Size

Calculating the required battery pack size for your solar-powered irrigation system involves determining the energy storage needed to power the pump for one day, considering the depth of discharge (DOD) and system voltage. Here's how to do it:

Key Concepts:

1. One-Day Battery Backup (Autonomy):

The battery pack should store enough energy to power the pump for one day without any solar input, providing reliability even on cloudy days.

2. Depth of Discharge (DOD):

DOD represents the percentage of the battery's capacity that can be used. To prolong battery life, it's recommended to use only up to 50% of the battery capacity.

3. System Voltage:

The system operates at a specific voltage, in this case, 24V. The battery capacity required will be calculated based on this voltage.

Given Data:

1. Daily Power Requirement (Adjusted for Efficiency): 0.65835 kWh (or 658.35 Wh)

2. DOD: 50% (0.50)

3. System Voltage: 24V

Step-by-Step Calculation:

1. Calculate the Energy Storage Needed

To ensure the battery pack can supply the necessary power for one day of operation, considering the DOD:

$$Usable\ Battery\ Capacity\ = \frac{Daily\ Power\ Requirement}{DOD}$$

$$Usable\ Battery\ Capacity = \frac{658.35}{0.5} = 1316.7\ Wh$$

2. Calculate the Battery Capacity in Ampere-Hours (Ah)

To find the capacity in ampere-hours (Ah), use the system voltage:

$$Battery\ Capacity\ (Ah)\ = \frac{Usable\ Battery\ Capacity\ (Wh)}{System\ Voltage\ (V)}$$

$$Battery\ Capacity\ (Ah) = \frac{1316.7\ (Wh)}{24\ (V)} \approx 55\ (Ah)$$

Importance of DOD and Choosing 50%

- DOD: Represents the amount of energy that can be safely used from the battery without significantly reducing its lifespan. Using a lower DOD (e.g., 50%) helps extend the battery's life by preventing deep discharges, which can damage the battery and reduce its efficiency over time.
- 50% DOD: This is a common recommendation for lead-acid and many other types of batteries to balance between usable capacity and longevity. It ensures that the battery pack can deliver consistent performance and have a longer service life.

Conclusion

For the solar-powered irrigation system with a 450W pump operating for 80 minutes daily, you need a battery pack with a capacity of approximately 55Ah (54.86 Ah) at 24V, considering a 50% DOD for optimal performance and battery lifespan. This calculation ensures that the system has enough stored energy to operate the pump for one day, with adequate reserve capacity to handle variations in energy production and consumption.

Step 3: Calculate the Required Number of Solar Panels

To determine the number of solar panels needed to charge the battery bank, you must consider the daily energy requirement, the power rating of the available solar panels, and the efficiency factors. This step ensures that the system has sufficient power to meet daily needs.

Given Data:

1. Battery Bank Size: 1.32 kWh (as calculated before)

2. Available Solar Panel Sizes: 250W, 480W, and 550W

Importance of Choosing the Correct Panel Size:

Choosing the correct solar panel size is crucial for optimizing the cost and efficiency of your solar power system. Lower power panels (e.g., 250W) might seem cost-effective individually, but they require more units, increasing installation complexity and overall system cost. Higher power panels (e.g., 480W or 550W) reduce the number of panels needed, simplifying installation and potentially lowering costs despite a higher price per panel.

Step-by-Step Calculation:

1. Calculate the Energy Generated by Each Panel in One Day

Assume an average of 5 hours of peak sunlight per day (this can vary based on location).

$$Daily\ Energy\ per\ Panel\ (kWh) = \frac{Panel\ Power\ (W)}{1000} \times Peak\ Sunlight\ Hours\ (h)$$

For each panel size:

- 250W Panel: $Daily\ Energy\ per\ Panel\ (kWh) = \frac{250W}{1000} \times 5(h)$ =1.25kWh/day

- 480W Panel: $Daily\ Energy\ per\ Panel\ (kWh) = \frac{450W}{1000} \times 5(h) =$ 2.4kWh/day

- 550W Panel: $Daily\ Energy\ per\ Panel\ (kWh) = \frac{550W}{1000} \times 5(h) =$ 2.75kWh/day

2. Calculate the Number of Panels Needed

$$Number\ of\ Panels = \frac{Daily\ Energy\ Requirement\ (kWh)}{Daily\ Energy\ per\ Panel\ (kWh)}$$

For each panel size:

- 250W Panels: $Number\ of\ Panels = \frac{1.32\ kWh}{1.25\ kWh} \approx 1.056$

Since you cannot have a fraction of a panel, you would need 2 panels.

- 480W Panels: $Number\ of\ Panels = \frac{1.32\ kWh}{2.4\ kWh} \approx 0.55$

You would need 1 panel.

- 550W Panels: $Number\ of\ Panels = \frac{1.32\ kWh}{2.75kWh} \approx 0.48$

You would need 1 panel.

Summary

- 250W Panels: 2 panels

- 480W Panels: 1 panel

- 550W Panels: 1 panel

Conclusion

Selecting the appropriate panel size is vital for optimizing the solar power system's cost and efficiency. While lower power panels may appear cheaper, they require more units, increasing the overall cost and installation complexity. Higher power panels reduce the number of panels needed, simplifying installation and potentially lowering costs despite a higher initial price. Furthermore, higher power panels are beneficial because after a day with not enough sunshine, the system should produce enough energy for both recharging the batteries and running the pump. For this system, using one 480W or one 550W panel is the most efficient choice.

Step 4: Selecting an Appropriate Charge Controller for a Solar System

When choosing a charge controller for a solar power system, it is crucial to match the controller's specifications with the system's voltage and current requirements. This ensures efficient charging and protection for the batteries and other components.

Acceptable Voltage

The voltage rating of the charge controller must match the voltage of the battery bank and the solar panel array. Common system voltages are:

-12V

- 24V

- 48V

Most charge controllers are designed to work with these standard voltages. Some advanced controllers are capable of automatically adjusting to different system voltages (e.g., 12/24V or 24/48V).

Acceptable Current

The current rating of the charge controller should be higher than the maximum current output from the solar panels to prevent overheating and potential damage. The current rating is determined by the total wattage of the solar array and the system voltage.

Example Calculation:

Assuming a solar array power of 480W and a system voltage of 24V:

$$Current\ (I)\ = \frac{Power\ (W)}{Voltage\ (V)}$$

$$Current\ (I) = \frac{480\ (W)}{24\ (V)} = 20$$

In this example, you would need a charge controller that can handle at least 20A. It is advisable to choose a controller with a higher current rating for safety and future expansion. A typical recommendation is to have a buffer of around 25-30% above the calculated maximum current.

Example Specifications:

1. Voltage Compatibility:

- Should support the system voltage (12V, 24V, or 48V).

2. Current Rating:

- Should be higher than the maximum current calculated from the solar array.

- For a 480W system at 24V, a charge controller rated for at least 25A is recommended.

Common Types of Charge Controllers:

1. PWM (Pulse Width Modulation):

- Simpler and cheaper.

- Suitable for smaller systems.

- Fixed voltage settings (e.g., 12V, 24V).

2. MPPT (Maximum Power Point Tracking):

- More efficient, especially for larger systems.

- Can handle a wider range of voltages.

- Adjusts to maximize power extraction from solar panels.

Conclusion

When selecting a charge controller, ensure it matches the system voltage and can handle the maximum current output from the solar panels. For a 480W system at 24V, a controller rated for at least 25A is recommended. Opting for a higher current rating and using an MPPT controller can improve efficiency and provide room for future expansion.

Step 5: Panel Setup

When setting up solar panels, it's crucial to configure them correctly in series or parallel to match the required voltage and current for the system and ensure compatibility with the charge controller. This step ensures that the solar array operates efficiently and safely within the acceptable range of the charge controller.

Series and Parallel Setup

Series Setup

- Voltage Increase: Connecting panels in series increases the total voltage while the current remains the same.
- Use Case: Series configuration is useful when you need to increase the voltage to match the battery bank and charge controller requirements.

Example:

- Three 250W panels (each 24V, 10.42A) in series:

$$Total\ Voltage = 24V + 24V + 24V = 72V$$

$$Current = 10.42A$$

Parallel Setup

- Current Increase: Connecting panels in parallel increases the total current while the voltage remains the same.
- Use Case: Parallel configuration is useful when you need to increase the current to match the system's power requirements without increasing the voltage.

Example:

- Three 250W panels (each 24V, 10.42A) in parallel:

$$Voltage = 24V$$

$$Total\ Current = 10.42A + 10.42A + 10.42A = 31.26A$$

Setting Up Panels Based on Required Voltage and Current

To set up the solar panels based on the system requirements, follow these steps:

1. Determine the Required System Voltage and Current:

From previous steps, ensure the system voltage matches the battery bank and charge controller. For example, if the system operates at 24V and requires 20A, configure panels to achieve these values.

2. Choose the Configuration (Series, Parallel, or Combination):

Series Configuration: If the required voltage is higher than a single panel's voltage, connect multiple panels in series to increase the voltage.

Parallel Configuration: If the required current is higher than a single panel's current, connect multiple panels in parallel to increase the current.

Combination: For large systems, you may need a combination of series and parallel configurations to match the required voltage and current.

3. Check Charge Controller Specifications:

Ensure the total voltage and current from the solar array fall within the charge controller's acceptable range.

Example Configurations for a 24V System

Using 250W Panels:

- Voltage: 24V
- Current: 10.42A

Required System Voltage and Current: 24V, 20A

Configuration:

Series: Connect two panels in parallel to maintain 24V but double the current.

$$24V \times 10.42A = 250W$$

$$Two\ panels\ in\ parallel = 24V, 20.84A$$

Using 480W Panels:

- Voltage: 24V
- Current: 20A

Configuration: Single Panel: One panel provides 24V and 20A.

$$24V \times 20A = 480W$$

Using 550W Panels:

- Voltage: 24V
- Current: 22.92A

Configuration: Single Panel: One panel provides 24V and 22.92A.

$$24V \times 22.92A = 550W$$

Conclusion

Properly configuring solar panels in series or parallel is essential to match the required voltage and current of your system while ensuring compatibility with the charge controller. Choosing higher power panels can simplify installation and reduce the number of panels needed, ensuring the system can generate enough energy to recharge batteries and run the pump even after a day with insufficient sunlight.

Step 6: Calculate the Number of Batteries Required and Their Setup

To calculate the number of batteries needed for your solar system, you need to determine the total battery bank capacity in amp-hours (Ah) and then configure the batteries to meet the required system voltage and capacity. Here's how to do it:

Given Data:

1. Required Battery Bank Current: 55 Ah

2. System Voltage: 24V

3. Available Battery Sizes: 18 Ah, 55 Ah, and 100 Ah

Step-by-Step Calculation:

1. Calculate Total Battery Bank Capacity (Ah)

To maintain a 24V system with a capacity of 55 Ah, the total energy storage required is:

$$Total\ Capacity\ (Wh)\ =\ Voltage\ (V) \times Current\ (Ah)$$

$$Total\ Capacity\ (Wh) =\ 24\ (V) \times 55\ (Ah) = 1320\ (Wh)$$

Since 1 Ah at 24V is equivalent to 24 Wh, you need 1320 Wh, which is the same as 55 Ah at 24V.

2. Determine Number of Batteries Required

To achieve the required capacity and voltage, you can use the available battery sizes to form the battery bank. Here's how to do it for each battery size:

Using 18 Ah Batteries:

- Calculate Number of Batteries in Series: To achieve 24V, you need 24V/12V = 2 batteries in series (assuming each battery is 12V).
- Calculate Number of Series Strings in Parallel: To achieve 55 Ah, you need $\frac{55Ah}{18\ Ah\ per\ battery} = 3.06$ strings. Round up to 4 strings for safety and capacity margin.
- Total Number of Batteries: 2 batteries/series x 4 series strings = 8 batteries.

Using 55 Ah Batteries:

- Calculate Number of Batteries in Series: To achieve 24V, you need 24V/12V = 2 batteries in series.
- Calculate Number of Series Strings in Parallel: To achieve 55 Ah, you need 55 Ah/55 Ah per battery = 1 string.
- Total Number of Batteries: 2 batteries/series x 1 series string = 2.

Using 100 Ah Batteries:

- Calculate Number of Batteries in Series: To achieve 24V, you need 24V/12V = 2 batteries in series.
- Calculate Number of Series Strings in Parallel: To achieve 55 Ah, you need 55 Ah\100 Ah per battery = 0.55 strings. Round up to 1 string for simplicity.
- Total Number of Batteries: 2 batteries/series x 1 series string = 2 batteries.

Battery Configuration

Using 18 Ah Batteries:

- Series Configuration: Connect 2 batteries in series to make one string of 24V.

- Parallel Configuration: Connect 4 such series strings in parallel to achieve the required capacity.

- Total Configuration: 8 batteries (2 in series and 4 such series in parallel).

Using 55 Ah Batteries:

- Series Configuration: Connect 2 batteries in series to make one string of 24V.

- Parallel Configuration: Only 1 string is required.

- Total Configuration: 2 batteries (2 in series).

Using 100 Ah Batteries:

- Series Configuration: Connect 2 batteries in series to make one string of 24V.

- Parallel Configuration: Only 1 string is required.

- Total Configuration: 2 batteries (2 in series).

Best Battery Size Selection

The best battery size (Ah) is within the range of 5% above or below the system's total battery bank amp-hours required (Ah). If the battery capacity is significantly lower than this range, the number of batteries needed increases significantly, leading to higher costs and more complex installation. Conversely, if the battery capacity is significantly higher, the entire system needs to be scaled up to charge the larger battery bank effectively.

Conclusion

Selecting the appropriate battery configuration ensures that the system can deliver the required power while maintaining the desired voltage. Here are the setups based on different battery sizes:

- 18 Ah Batteries: Use 8 batteries (4 series strings in parallel, each string having 2 batteries in series).
- 55 Ah Batteries: Use 2 batteries (1 series string with 2 batteries).
- 100 Ah Batteries: Use 2 batteries (1 series string with 2 batteries).

Choosing the correct battery size and configuration is essential to ensure the system's efficiency and longevity. Proper configuration helps to balance the load, optimize charging cycles, and maintain a stable power supply.