VICTORIA UNIVERSITY OF WELLINGTON
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XMUT204 Electronics Design

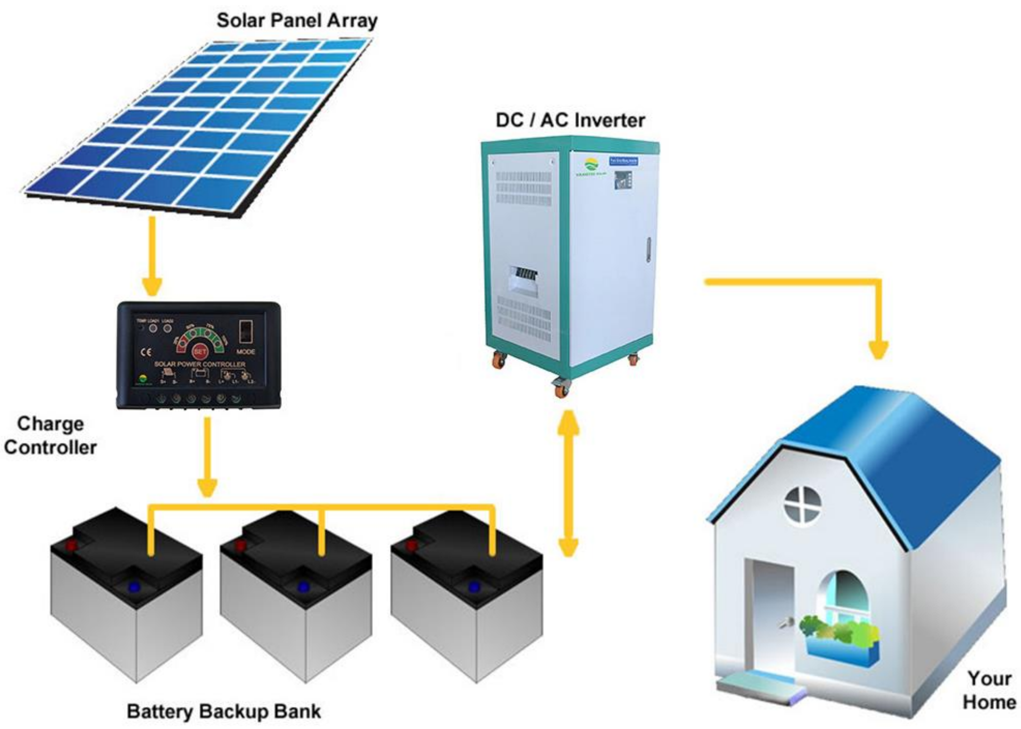
Lecture 2g - Special Purpose Diodes (Solar Cells II)

Overview

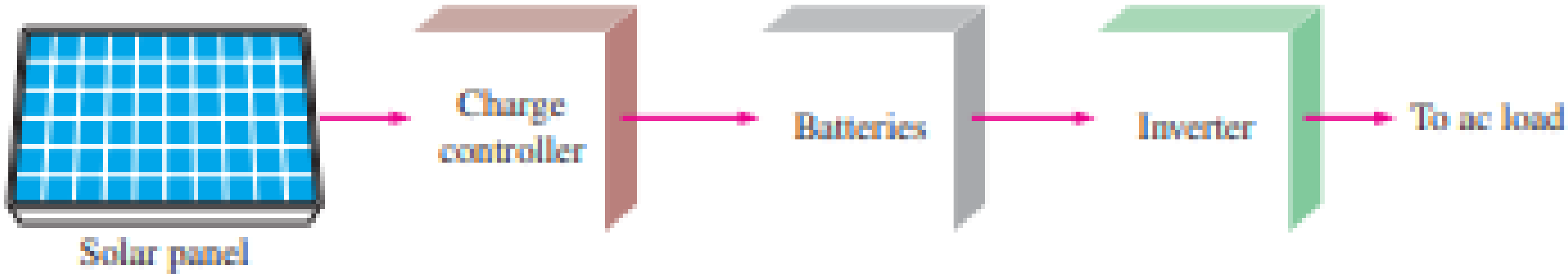
- Solar power systems.
- Controller unit.
- Storage units.
- Inverter system.
- Tracking system.

1. Solar Power System

- A basic solar power system: solar panel, charge controller, batteries, and inverter.
- Three main installation scales: residential, commercial, and utility.



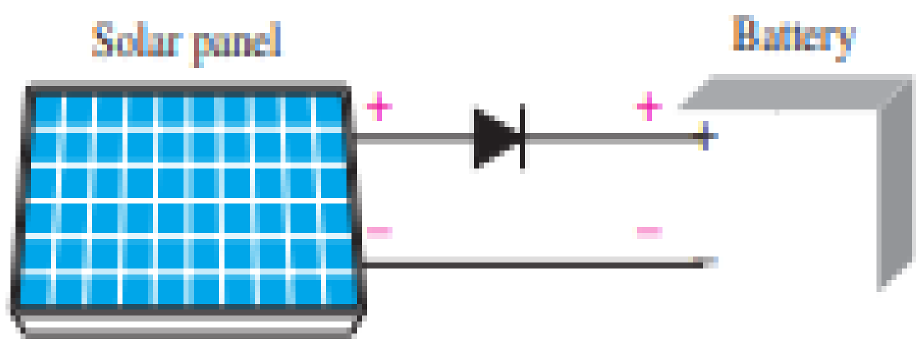
2. Design of Solar Power Systems



- *Solar panel* - collects energy from the sun and converts it to electrical energy through the photovoltaic process
- *Charge controller* - takes the output of the solar panel and ensures that the battery is charged efficiently and is not overcharged.
- *Battery* – Storing electrical energy (e.g. deep-cycle batteries, such as lead-acid) – repeated charge/discharge operations)
- *Inverter* - changes DC voltage stored in the battery to the standard 120-240 Vac used in most common applications such as lighting, appliances, and motors

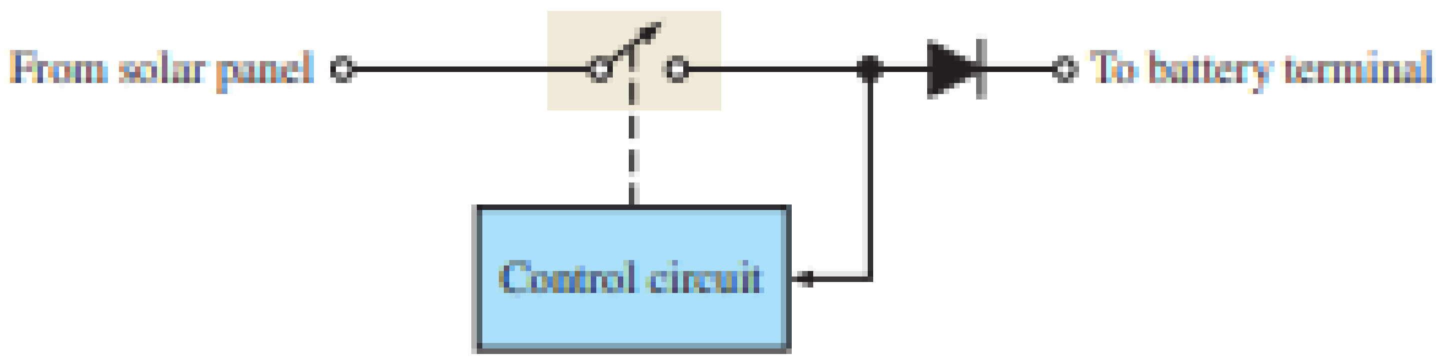
3. Design of Controller Unit

- Solar charge controller regulates the power from the solar panels primarily to prevent overcharging the batteries.
- Overcharging batteries reduce battery life and may damage the batteries.
- Exist if the solar panel produces about two watts or less for each 50 battery amp-hrs (Ah)
- Diode prevents the battery from discharging back through the solar panel when the panel voltage drops below the battery voltage.
- Three basic types of charge controllers are: On/Off, PWM, and MPPT.



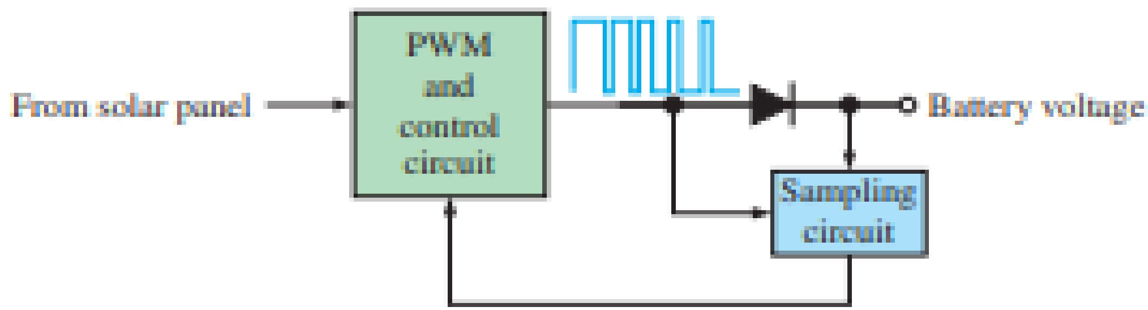
3. Design of Controller Unit (On/Off Charge Controller)

- On/Off is most basic controller - monitors the battery voltage and stops the charging when the battery voltage reaches a specified level in order to prevent overcharging.
- Restart the charging i.e. the battery voltage drops < a predetermined value.
- Switch shown below i.e. a transistor that is turned on and off.
- Voltage of the battery is fed back to the control circuit.
- Diode prevents discharge back to the control circuit i.e. the output of the panel < than the battery.

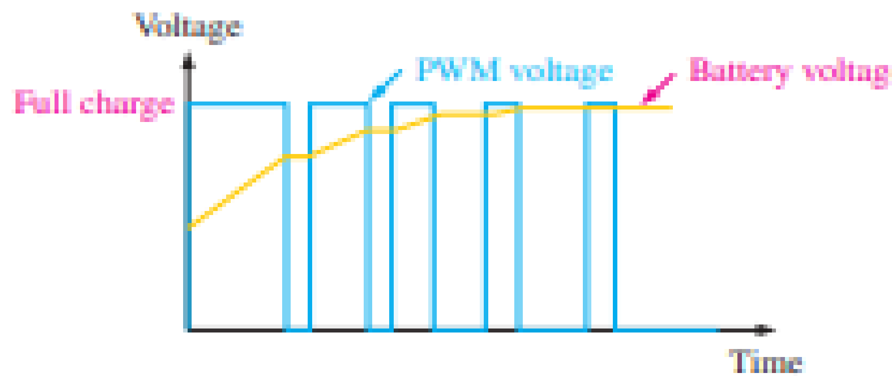


3. Design of Controller Unit (PWM Controller)

- PWM (pulse width modulation) - Produce a series of pulses to charge the batteries instead of a constant charge.
- Gradually reduce the amount of power applied to the batteries as the batteries get closer to full charge.
- Allow the batteries to be more fully charged with less stress on the batteries.
- Extends the life of the batteries and constantly maintains the batteries in a fully charged state (called "float") during sunlight hours.



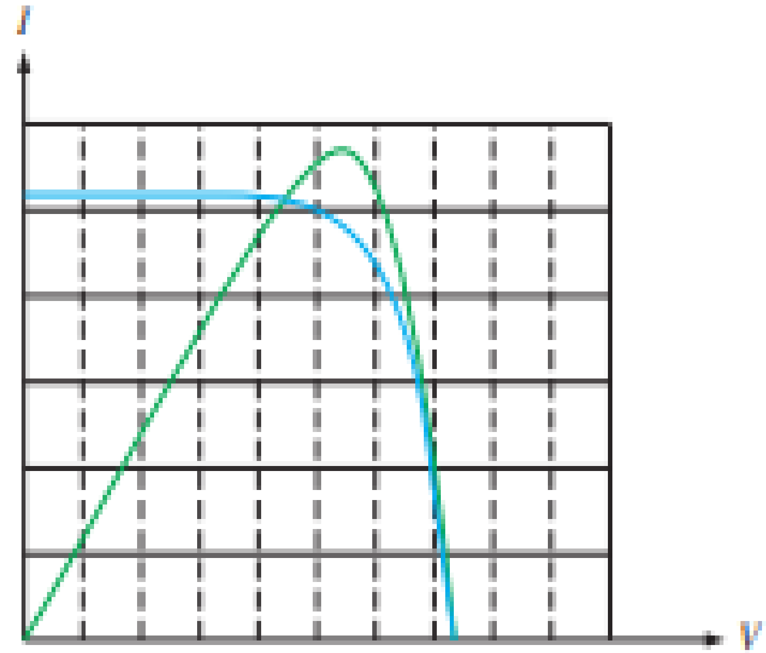
(a) Block diagram



(b) Waveforms

3. Design of Controller Unit (MPPT Controller)

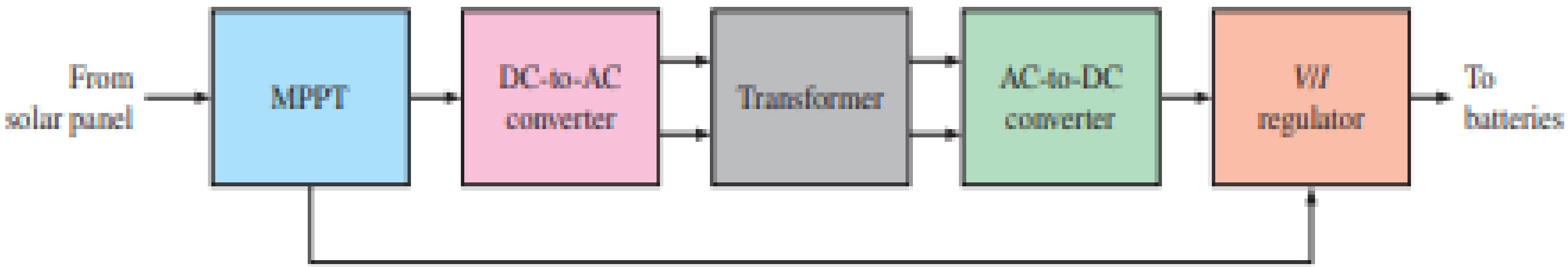
- MPPT (maximum power point tracker) - continuously tracks the input voltage and current from the solar panel to determine when the peak input power occurs and then adjusts the voltage to the battery to optimize the charging.
- Eliminate much of the energy loss found in the other types of controllers and produce much higher efficiencies.
- Result in a maximum power transfer from the solar panel to the battery.



- Blue curve - voltage-current characteristic for a certain solar panel under a specified condition of incident light.
- Green curve - power showing where the peak occurs - the knee of the V-I curve. If the incident light decreases, the curves will shift down.

3. Design of Controller Unit (MPPT Controller)

- MPPT is basically overall a DC-to-DC converter.
- Consist of DC/AC converter, the transformer, and the AC/DC converter.
- Isolate the dc input from the dc output, so the output can be adjusted for maximum power.

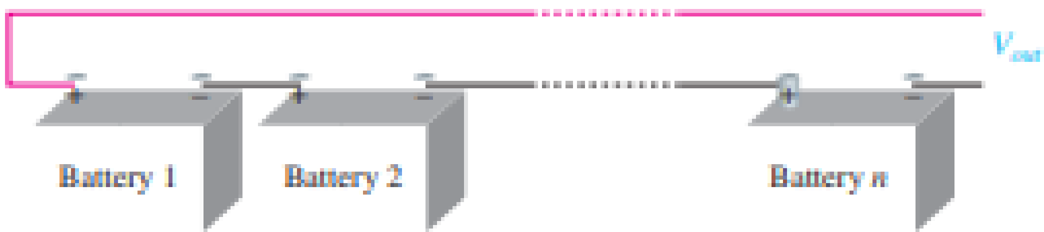


4. Design of Storage Units

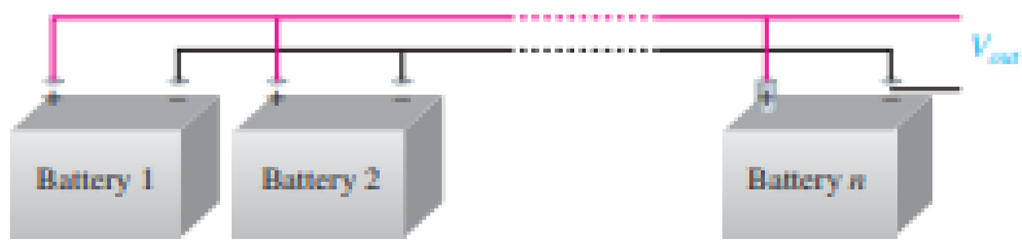
- Deep-cycle batteries are required in solar power systems simply because the sunlight is not at its maximum all of the time - an intermittent energy source.
- Unlike automobile batteries (shallow-cycle batteries).
- Repeatedly discharged by as much as 80 % of their capacity - a longer life if the cycles are shallower.
- Connected in series and in parallel.

4. Design of Storage Units

- Connected in series to increase the output voltage and in parallel to increase the ampere-hour capacity.
- Several series connections of batteries can be connected in parallel to achieve both an increase in amp-hrs and output voltage.



(a) Series batteries



(b) Parallel batteries

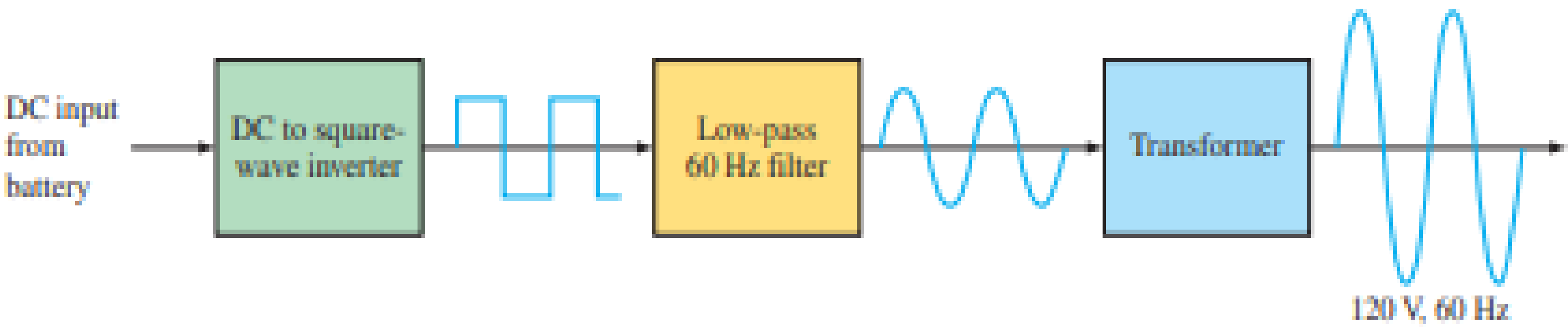
5. Design of Inverter System

- Inverter = dc-to-ac converter - takes the output of the batteries in a solar power system and converts it to a standard 220 V, 50 Hz output voltage.
- An inverter switches the dc output of the storage battery on and off and processes the result to create: a pure sine wave, a stepped wave called a modified or quasi sine wave (sometimes called a modified square wave), or a square wave.

- Most inverters produce a pure sine wave, which is the type that the power company generates.

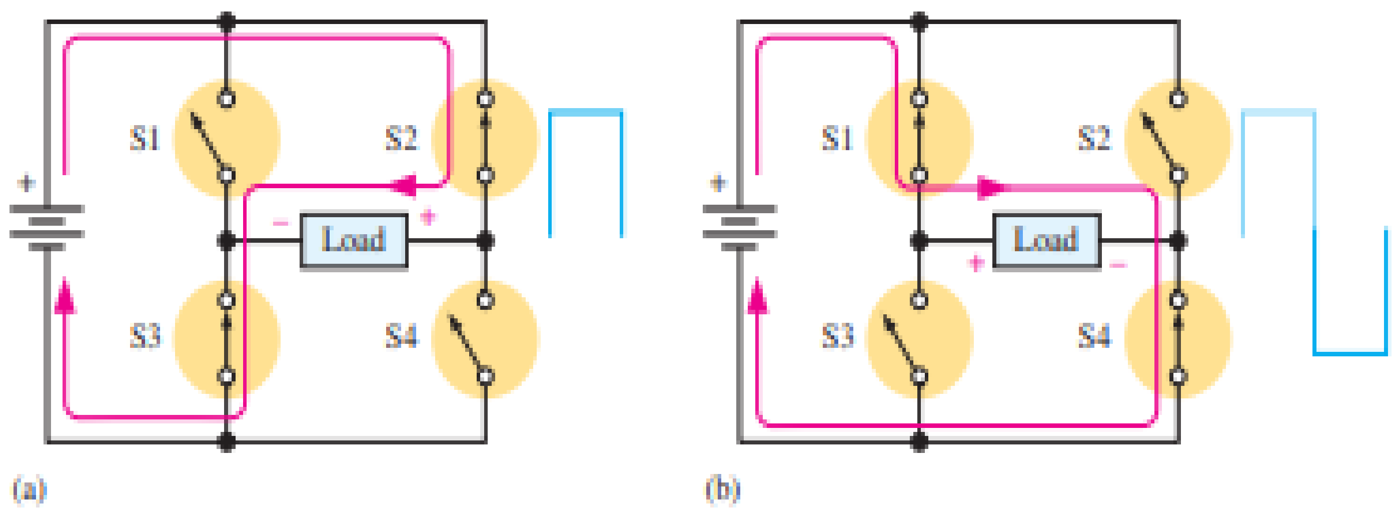
5. Design of Inverter System

- A relatively pure sine wave inverter uses a dc to square wave inverter.
- A filter system to eliminate all of the odd harmonics, leaving only the fundamental sine wave
- A step-up transformer is used to produce the required 220 V, 50 Hz sine wave.



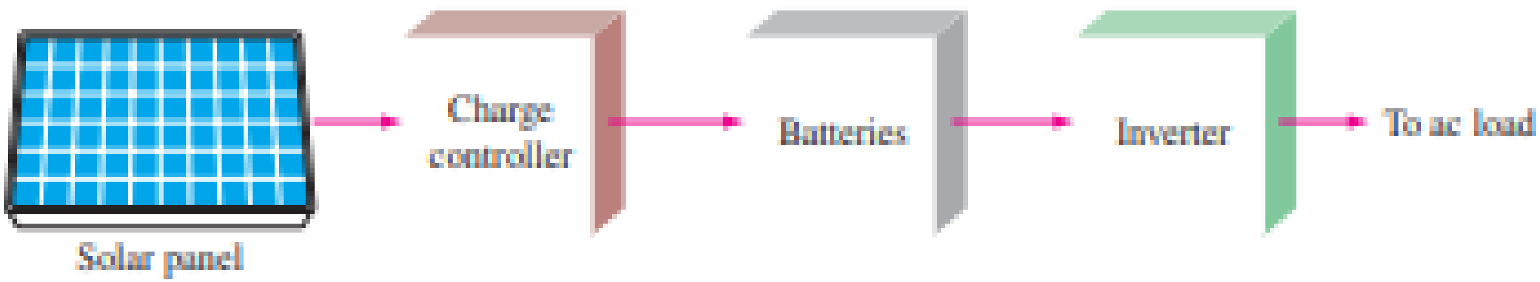
5. Design of Inverter System

- In part (a), switches S2 and S3 are on for a specified time and S1 and S4 are off - direct current is in the load creating a positive output voltage.
- In part (b), opposite switches are on and off - current is in the opposite direction in the load and the output voltage is negative.
- The complete on/off cycle of the switches produces an alternating square wave.
- The transistors are switched by a timing control circuit.



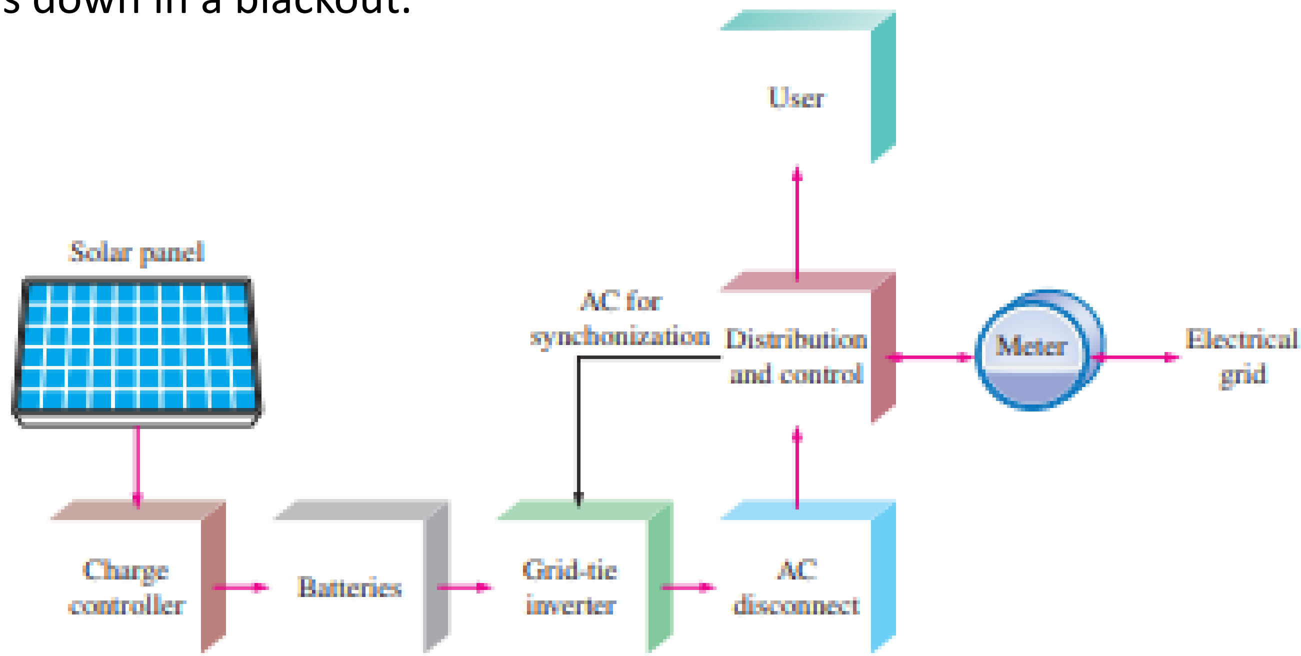
5. Design of Inverter System

- Inverters can have two types of interface: stand-alone and grid-tie.
- The stand-alone inverter is used in applications where all of the output power is used for a specified load, such as lighting, appliances, and motors, and is independent of the electrical power grid.



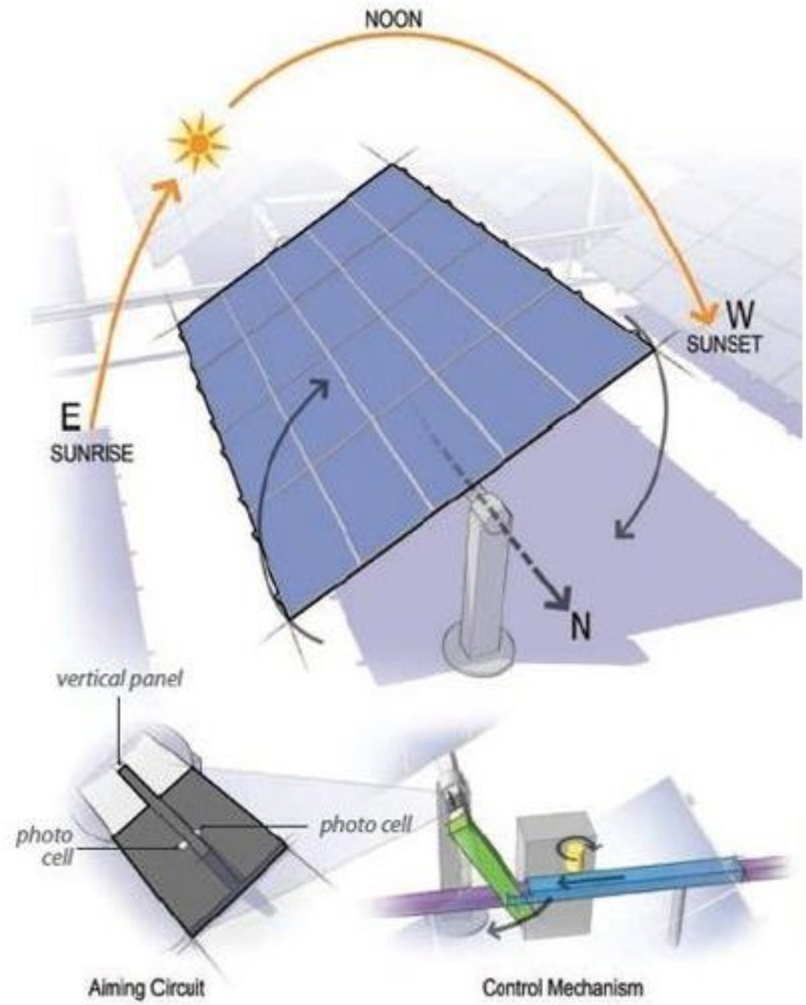
5. Design of Inverter System

- The grid-tie inverter is used in applications where all or part of the output power is provided to the electrical gird.
- A grid-tie inverter (GTI) must synchronize its ac output frequency and phase with that of the grid, limit its amplitude for compatibility with the grid, and adjust its power factor to unity (voltage and current in phase).
- For safety reasons, grid-tie inverters have to disconnect from the grid if the grid goes down in a blackout.



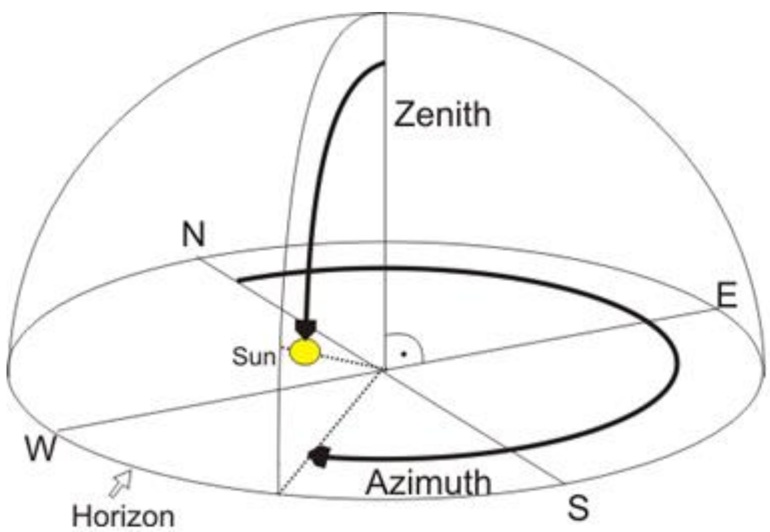
6. Design of Tracking System

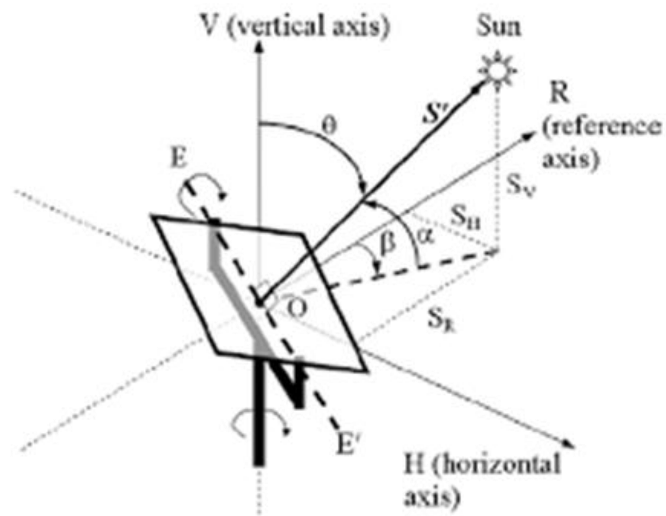
- Solar tracking - process of moving the solar panel to track the daily movement of the sun and the seasonal changes in elevation of the sun in the sky.
- Purpose - increase the amount of solar energy that can be collected by the system.
- For flat-panel collectors, an increase of 30% to 50% in collected energy can be realized with sun tracking compared to fixed solar panels.



6. Design of Tracking System (Single-Axis Solar Tracking)

- Most economical and generally most practical solution to tracking is to follow the daily east-west motion.
- There are two basic single-axis systems: polar and azimuth.





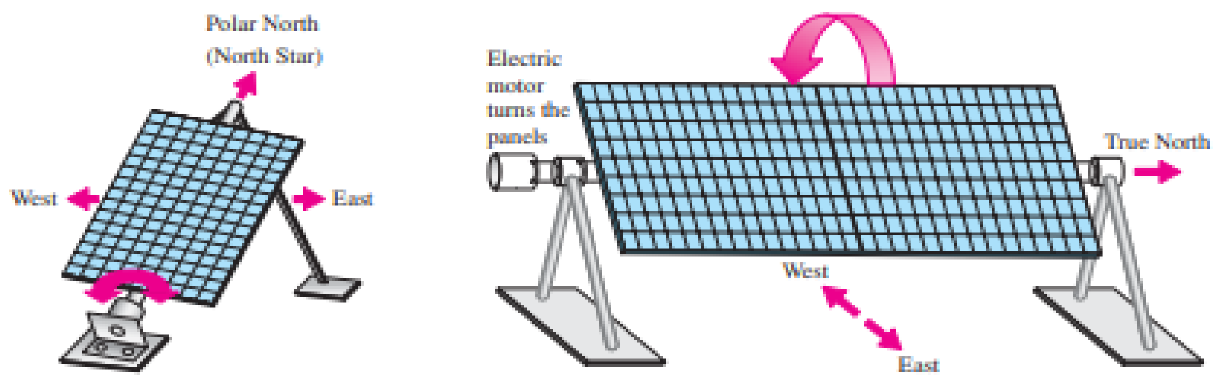
6. Design of Tracking System (Single-Axis Solar Tracking)

- Polar tracking system - the main axis is pointed to the polar north (North Star) as in part (a).

  Advantage - solar panel is kept at an angle facing the sun at all times because it tracks the sun from east to west and is angled toward the southern sky.

- Azimuth tracking system - the motor drives the solar panel and frequently multiple panels. Panels can be oriented horizontally but still track the east-to-west motion of the sun.

  Part (b) shows a solar array that is oriented horizontally with the axis pointing to true north and uses azimuth tracking (east to west).

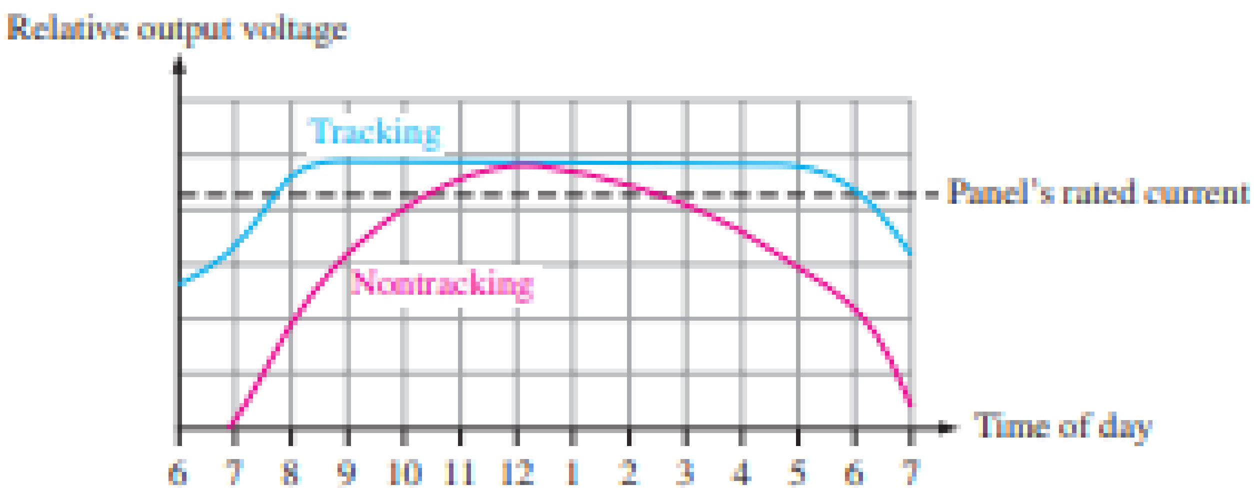


(a) A single-axis polar-aligned tracker

(b) Single-axis azimuth tracker

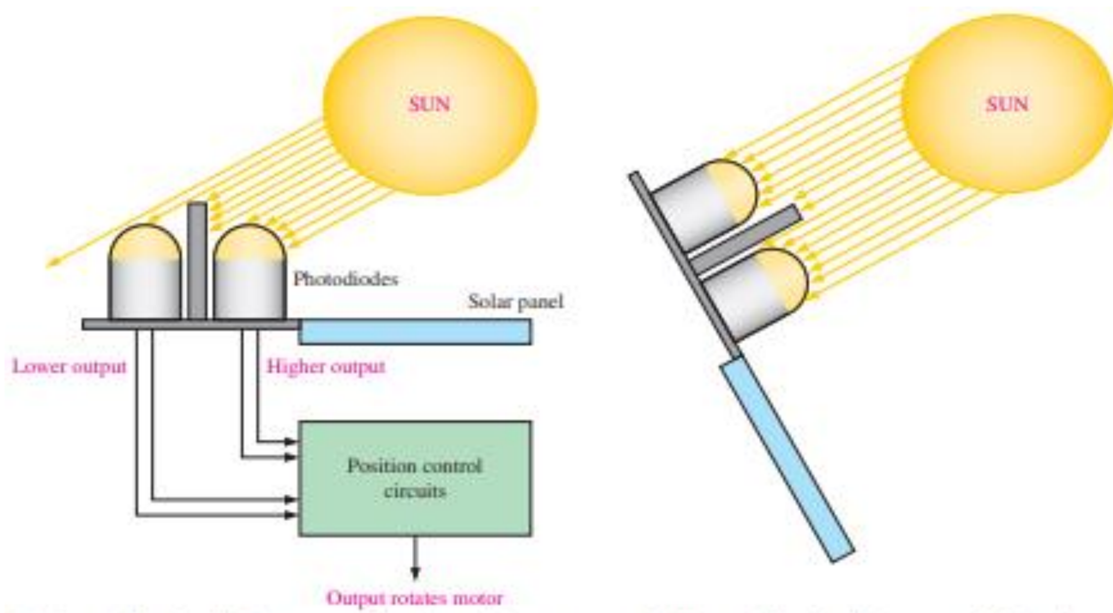
6. Design of Tracking System (Dual-Axis Solar Tracking)

- Both the azimuth and the elevation tracking, which is known as dual-axis tracking.
- Annual north-south motion of the sun can be followed in addition to the daily east-to-west movement.
- Improvement in energy collection of a typical tracking panel versus a non-tracking panel for a flat solar collector.



6. Design of Tracking System (Sensor-Controlled Solar Tracking)

- Sensor control tracking uses photosensitive devices such as photodiodes or photoresistors.
- Two light sensors for the azimuth control and two for the elevation control. Each pair senses the direction of light from the sun and activates the motor control to move the solar panel to align perpendicular to the sun’s rays.
- Two photodiodes with a light-blocking partition between them are mounted on the same plane as the solar panel.

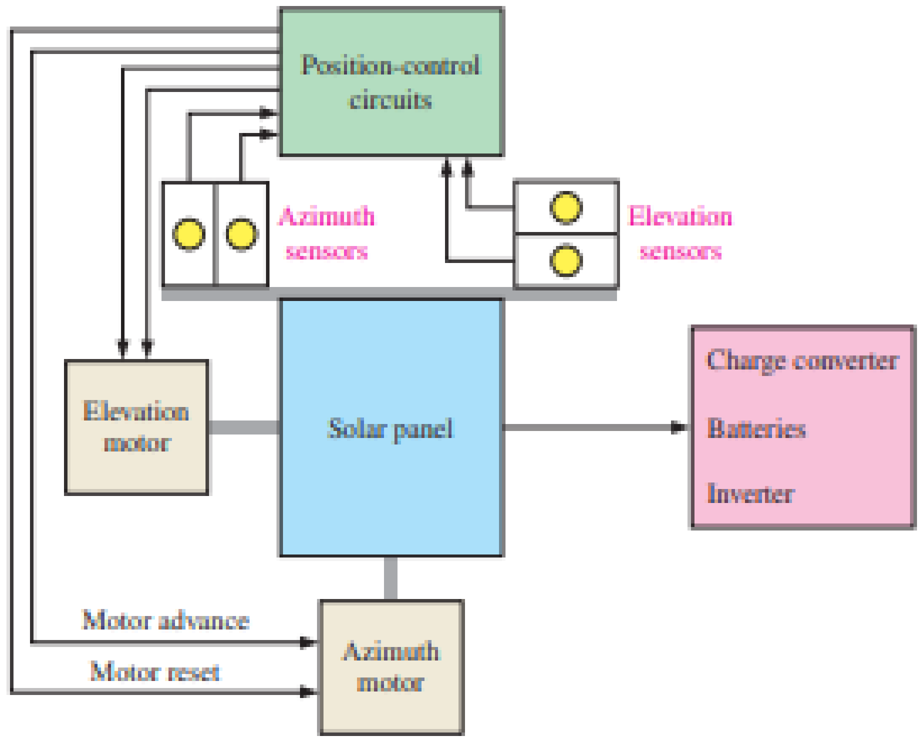


(a) Outputs of the photodiodes are unequal if solar panel is not directly facing the sun.

(b) Outputs of the photodiodes are equal when solar panel orientation is optimum.

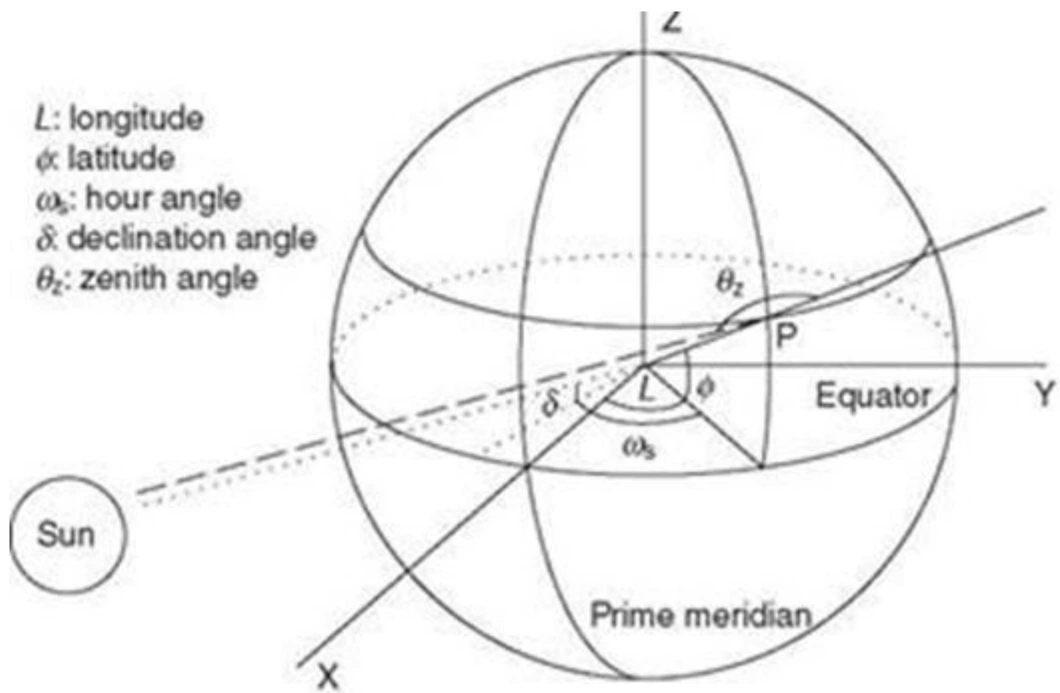
6. Design of Tracking System (Sensor-Controlled Solar Tracking)

- A circuit detects the differential between the two azimuth sensor outputs. If the differential is sufficient - the azimuth motor is advanced westward until a balance occurs between the two sensors.
- Similarly, another circuit detects the differential between the two elevation sensor outputs and. It advances the elevation motor to rotate the solar panel either up or down until a balance occurs between the two sensors.
- A drawback - its sensitivity requirement for cloudy days or a passing cloud, when the differences in detected light are much smaller.



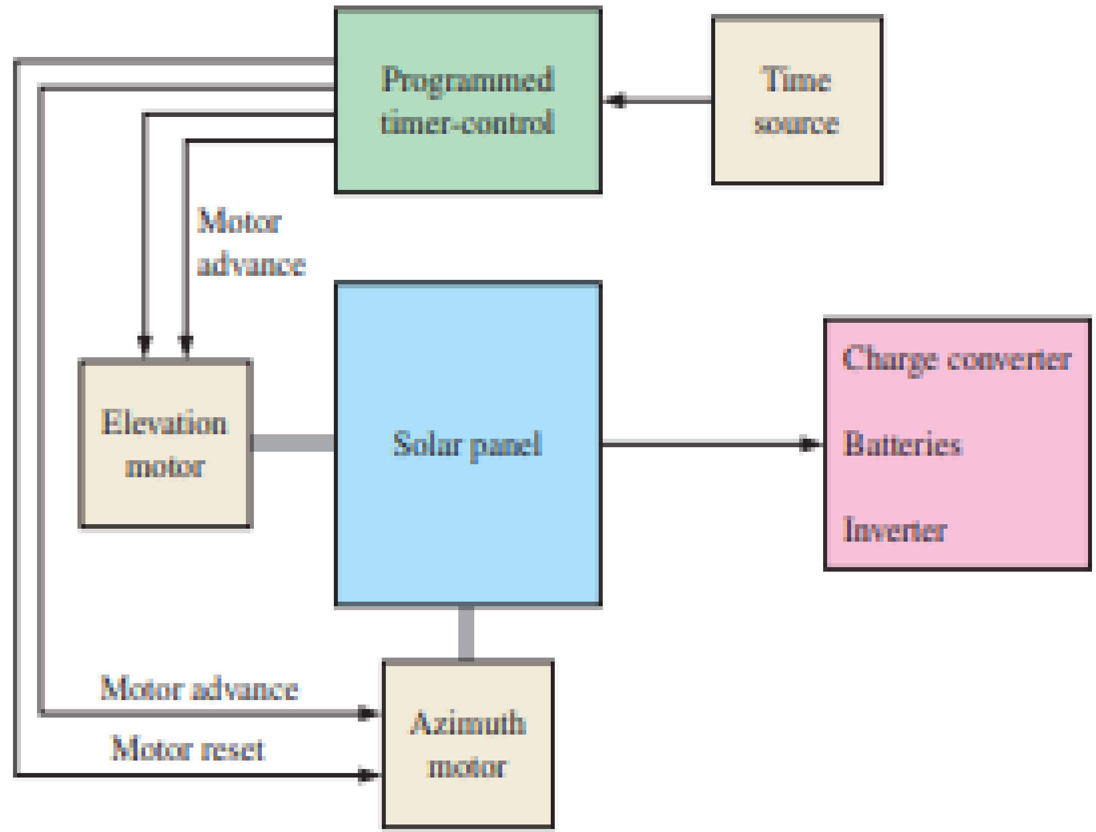
6. Design of Tracking System (Timer-Controlled Solar Tracking)

- Use an electronic timer that causes the motors to move incrementally in azimuth and elevation.
- During the day the sun moves from east-to-west and this takes approximately 12 hours at summer solstice.
- Sun moves at a rate of approximately 15° per hour.



6. Design of Tracking System (Timer-Controlled Solar Tracking)

- A timer-controlled tracking system designed to follow the sun at desired increments.
- Use an accurate time source, such as a crystal oscillator, a microprocessor with associated timing and control circuits, and motor interface circuits.
- Advantage - independent of the amount of sunlight that is striking the solar panel.



Example for Tutorial – Solar Power Installations

1. You are tasked to work on an engineering project installing a solar panel system for smart off-grid bus shelters in a city.

   Given in the table below is the estimated energy used in the shelter that has its energy provided by a solar panel on its roof.

Appliance	Appliance Categories	Quantity	Watts (V*A) Multi* 1.5 for AC	Estimated Operation Hours/day
LED Lights	Night use	2	2.85	14
High Flux LED	Night use	6	12	14
Cell phone charger	Average use	2	5	15
WI-FI router	24 hours use	1	20	24
Solar charger controller	24 hours use	1	1	24
Sensor	24 hours use	1	1	24

For the given solar panel system, assumes on average 3 hours sun hour per day, 20% energy losses, and 30 days per month.

a. Calculate the total energy usage. [10 marks]

b. Calculate overall power consumption (in kWh/month). [5 marks]

c. Calculate wattage of the solar panels. [5 marks]

d. Determine the size of the battery. [5 marks]

e. Determine the rating of the inverter. [2.5 marks]

f. Suggest type of charge controller and its rating. [2.5 marks]

Answer

a. Calculate energy usage of the bus shelter as outlined in the table below.

Appliance	**Appliance Categories**	**Quantity**	**Watts (V*A) Multi* 1.5 for AC**	**Estimated Operation Hours/day**	**Watts Hours/day**
LED Lights	Night use	2	2.85	14	80
High Flux LED	Night use	6	12	14	1008
Cell phone charger	Average use	2	5	15	150
WI-FI router	24 hours use	1	20	24	480
Solar charger controller	24 hours use	1	1	24	24
Sensor	24 hours use	1	1	24	24
Total Watt Hours per day					1770.00

b. Calculate overall power consumption (in KWh/month):

1770 Wh/day ÷ 3 sun hours/day = 590 W

590 W ÷ 0.8 (system losses) =737.5 W

Wh = 737.5 W x 30 days Wh = 22,125 Watt-hours (22.125 kWh/month)

The project will be dealing with lower voltage devices, hence a 12 V system is chosen.

c. Calculate wattage of the solar panels:

1770 Wh/day ÷ 3 sun hours/day = 590 W

590 W ÷ 0.8 (system losses) =737.5 W

737.5/250 = 2.95 (e.g. 3 Solar panels 250 Watts)

For the project, we would be using 3 panels of 250 Watts each.

d. Battery sizing is determined from the following formulae:

Battery Capacity (Ah) = Total Watt-hours per day used by appliances x Days of autonomy (0.85 x 0.6 x nominal battery voltage)

For this project, the daily average energy consumption per day is 1770 (W-h/day) for the month of December.

Battery Capacity (Ah) = 1770 x 2 (0.85 x 0.6 x 12) = 578.4 Ah

As a result, a 578.4 Ah battery capacity is required for the system.

e. Inverter sizing:

As per part (b), the inverter size should be based on the wattage and voltage level of the system. This project employs a 12 V, 2 kW system, hence the inverter that should be used should be of similar rating.

f. Charge controller sizing:

For this project, a PWM charge controller is to be used. Following steps will enable us to size the required charge controller.

- Voltage level of the system: 12V
- Maximum amperage: 10 A

There a PWM controller should be used with 12 V and 10 A with rated voltage and current specifications.