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Local Governments for Sustainability

100% RENEWABLES
CITIES & REGIONS ROADMAP

Supported by:

Federal Ministry for Economic Affairs and Climate Action

IKI INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag

Capacity Building Module:
Solar Energy Basics & Solar Photovoltaic Systems

CHAPTER 2:

Establishment of solar PV systems

CONTENTS

Components of Solar PV systems

PV Mounting Systems

Solar PV System Design

PART 1

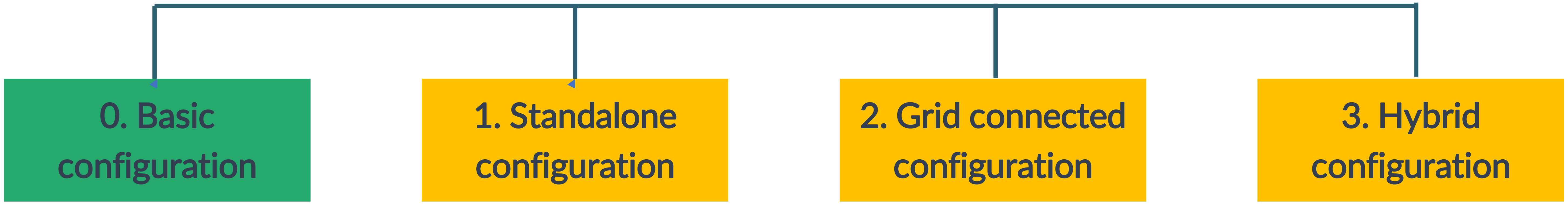
COMPONENTS OF SOLAR PV SYSTEMS

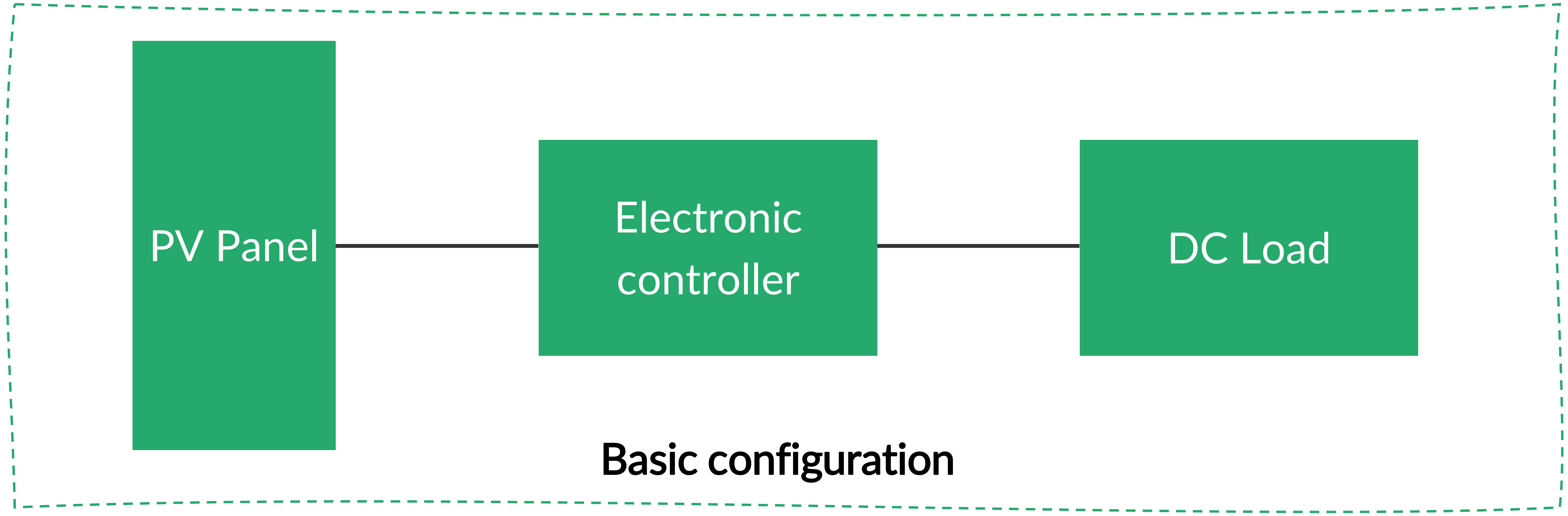
MAJOR COMPONENTS OF SOLAR PV SYSTEM

- PV panels
- Storage battery
- Grid inverter
  (conversion of direct current to alternating current /DC to AC)
- Charger controller
  (Electronic device regulating current and voltage from PV panel to battery)
- Mounting hardware
- Wiring

Balance of system components

POSSIBLE PV SYSTEM CONFIGURATIONS



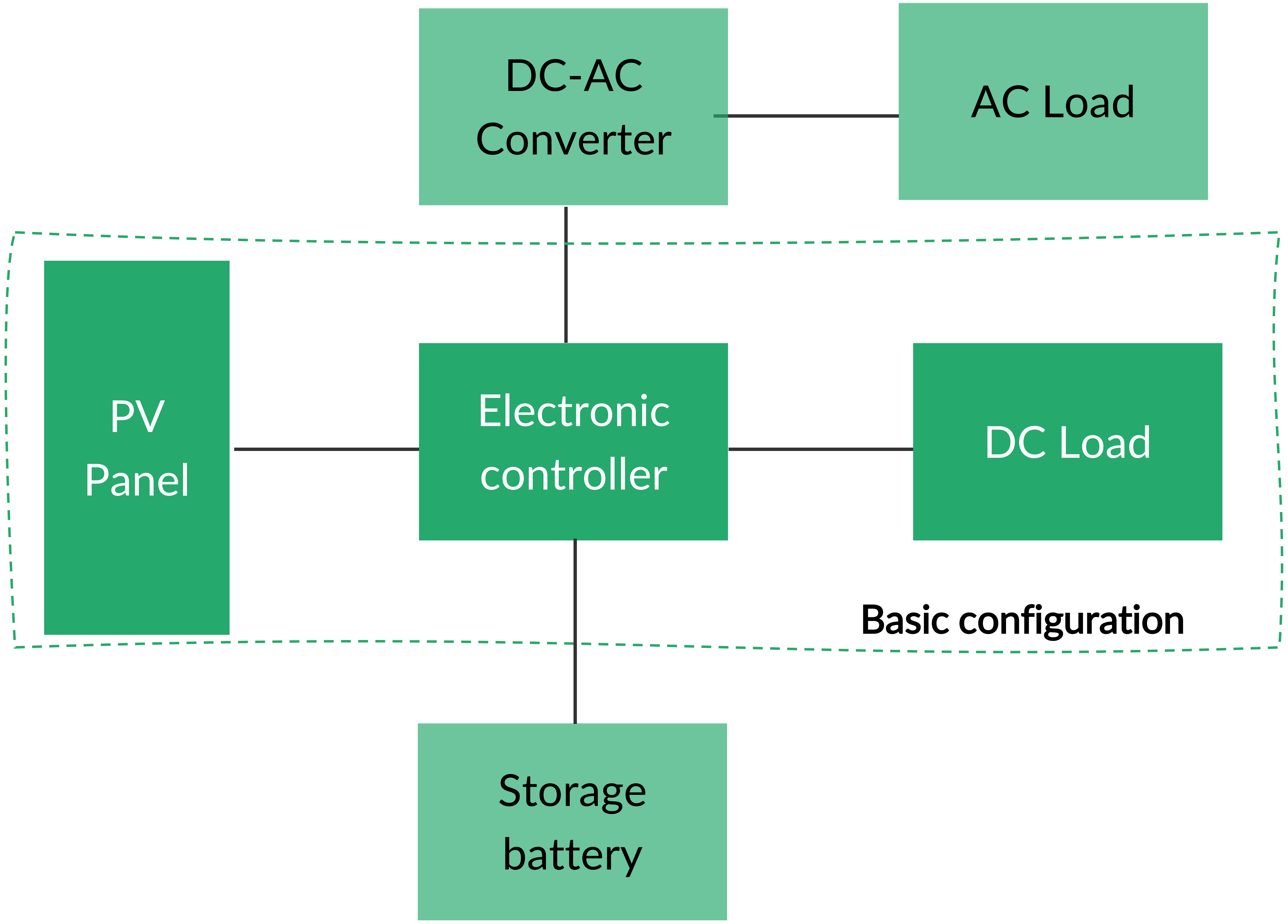


Basic configuration

1. STANDALONE PV SYSTEMS (DECENTRALIZED)

Some applications of DRE include:

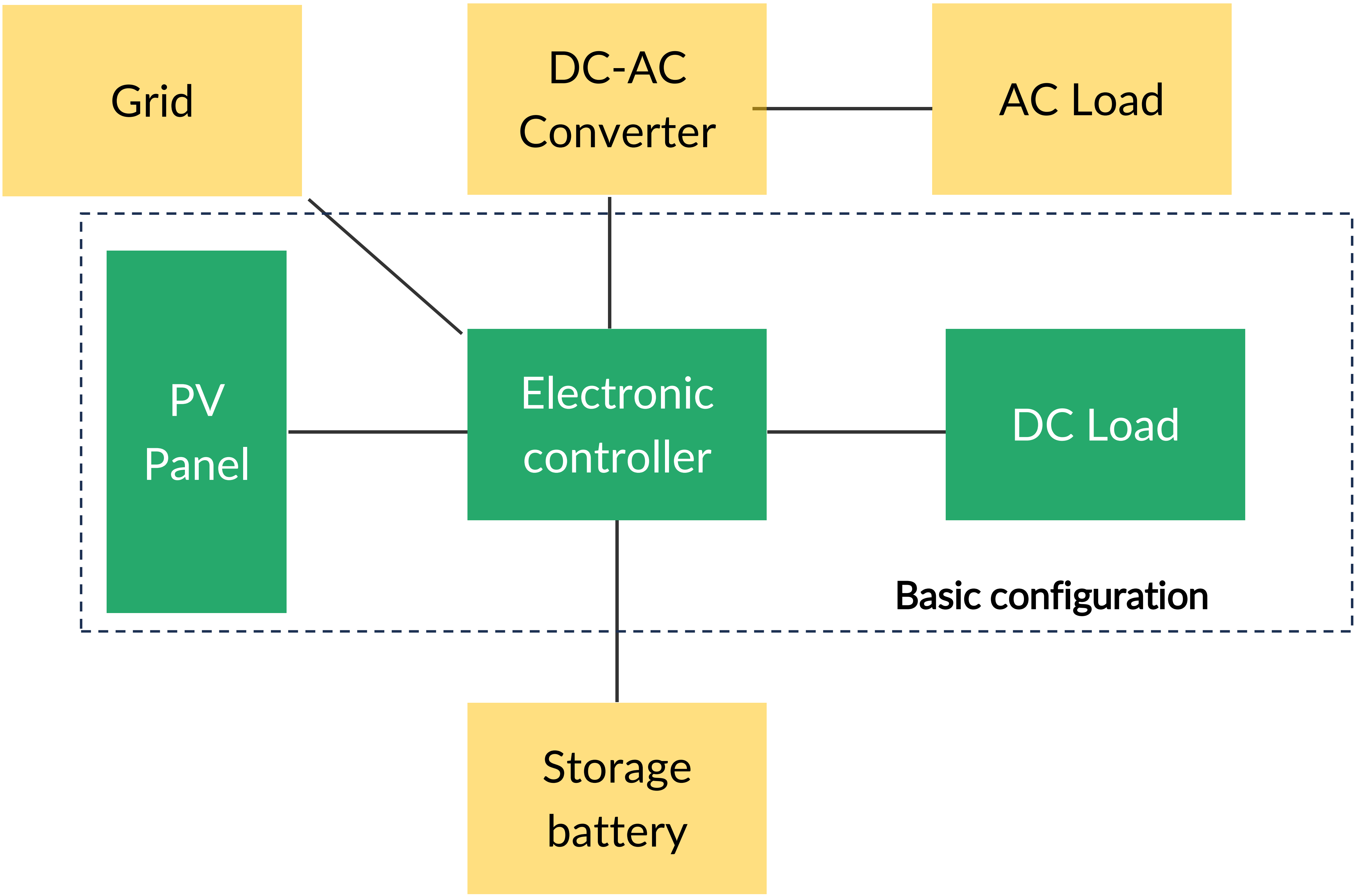
- Remote homes and cabins
- Agricultural and farming operations
- Water pumping
- Telecommunications
- Navigational aids
- Weather stations
- Environmental monitoring
- Recreational vehicles and water boats
- Emergency and disaster relief small business
- Remote lighting
- Off grid resorts and lodges
- Military and defense
- Educational and research
- Hiking and camping



2. GRID-CONNECTED PV SYSTEMS

Applications

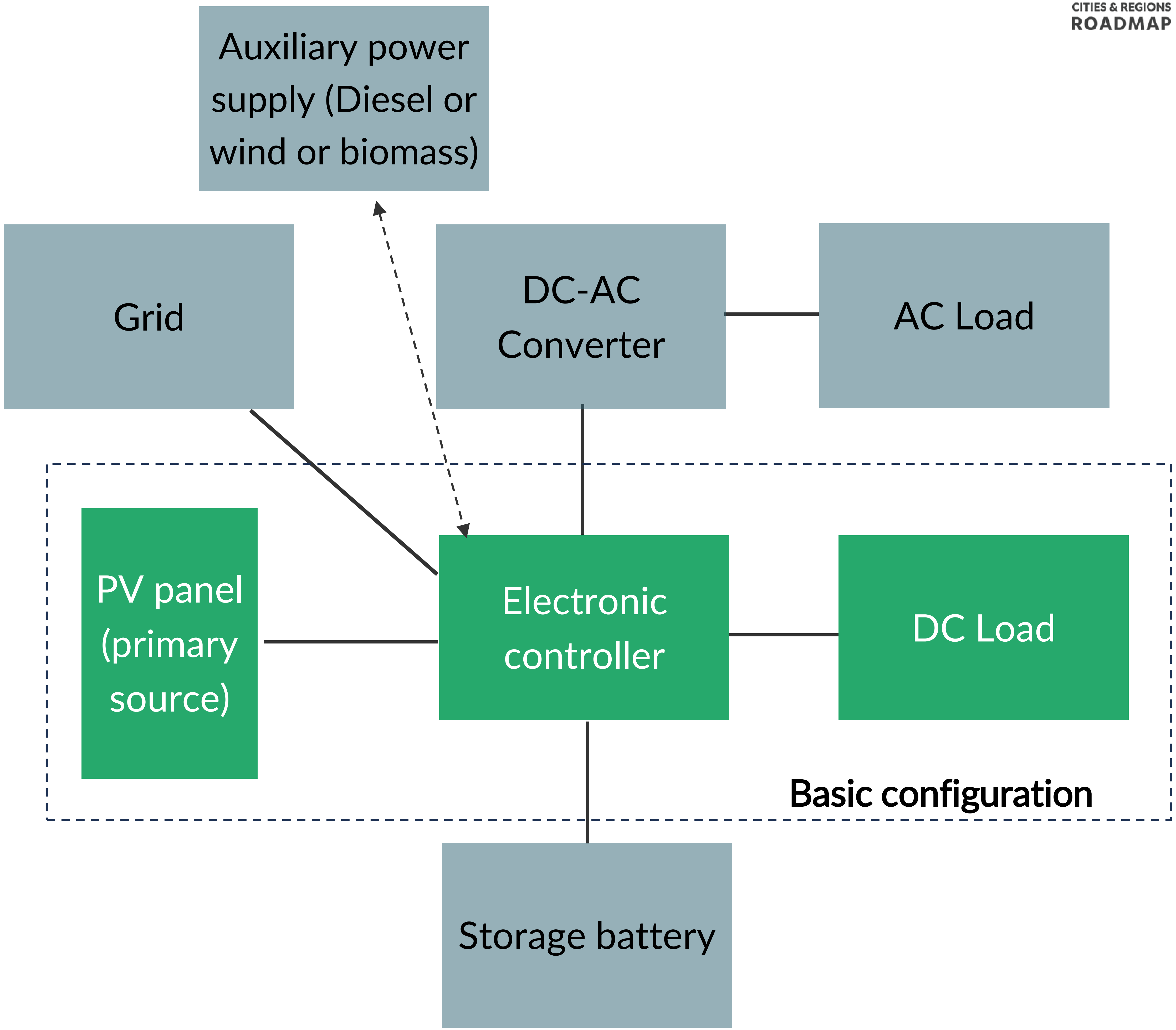
- Residential rooftop solar PV system
- Commercial solar PV systems
- Community solar gardens
- Solar farms
- Floating solar PV systems
- Solar carports
- Solar PV microgrids
- Solar PV mini-grids
- Building integrated solar PV
- Industrial solar PV installations
- Solar canopies
- Utility scale solar projects
- Solar PV power plants with energy storage



3. HYBRID PV SYSTEMS

Applications

- Residential power generation
- Rural electrification
- Island and off-grid systems
- Commercial and industrial buildings
- Agricultural applications
- Telecommunications
- Solar-powered street lighting
- Water pumping
- Mining operations
- Hybrid electric vehicles
- Remote monitoring stations
- Emergency backup power
- Tourism and leisure facilities
- Hybrid microgrids
- Mobile and portable power



EXAMPLES OF PV SYSTEM CONFIGURATION

ROOFTOP

Source: https://www.pxfuel.com/en/free-photo-odctg

POLE-MOUNTED

Source: https://www.pvsolarfirst.com/

GROUND-MOUNTED

Source: https://greentumble.com/types-of-solar-panel-mounting-systems-and-their-installation

BUILDING INTEGRATED PV

Source: https://inhabitat.com/building-integrated-photovoltaics-market-projected-to-quadruple-to-2-4-billion-by-2017/

BI-FACIAL MODULE

Source: https://www.greentechmedia.com/

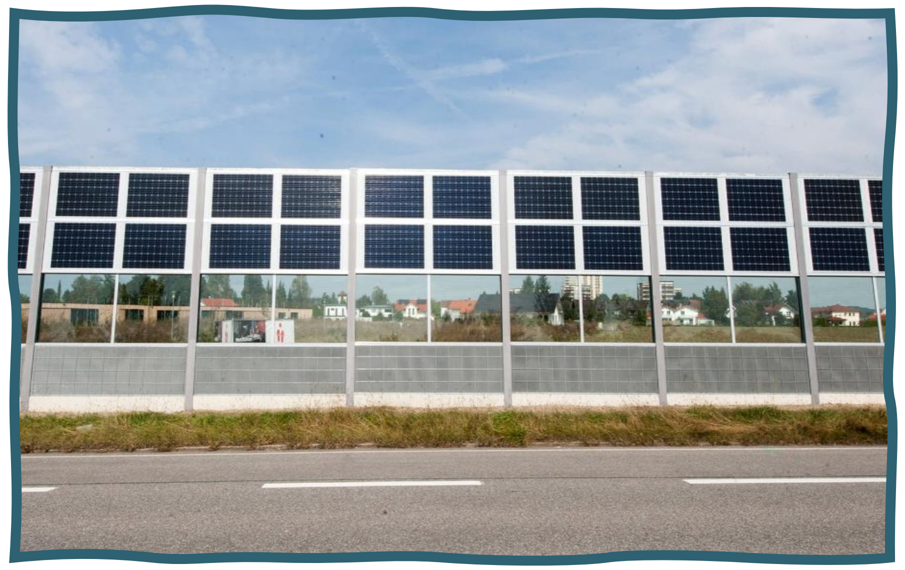
FLOATING SOLAR

Source: https://www.saurenergy.com/solar-energy-news/oriana-power-commissions-1mw-floating-solar-power-project-in-rajasthan

EXAMPLES OF PV SYSTEM CONFIGURATION, PT. 2

RAILROAD TRACKS

Source: https://www.trendwatching.com/innovation-of-the-day/in-between-swiss-railroad-tracks-sun-ways-rolls-out-solar-panels-like-a-carpet



Source: Fraunhofer ISE- R. Kohlhauer GmbH. Noise barrier with integrated PV modules in Neuötting, Germany

Source: https://www.solarpowerportal.co.uk/dft_funding_innovative_solar_rail_roads_and_footways_trials/

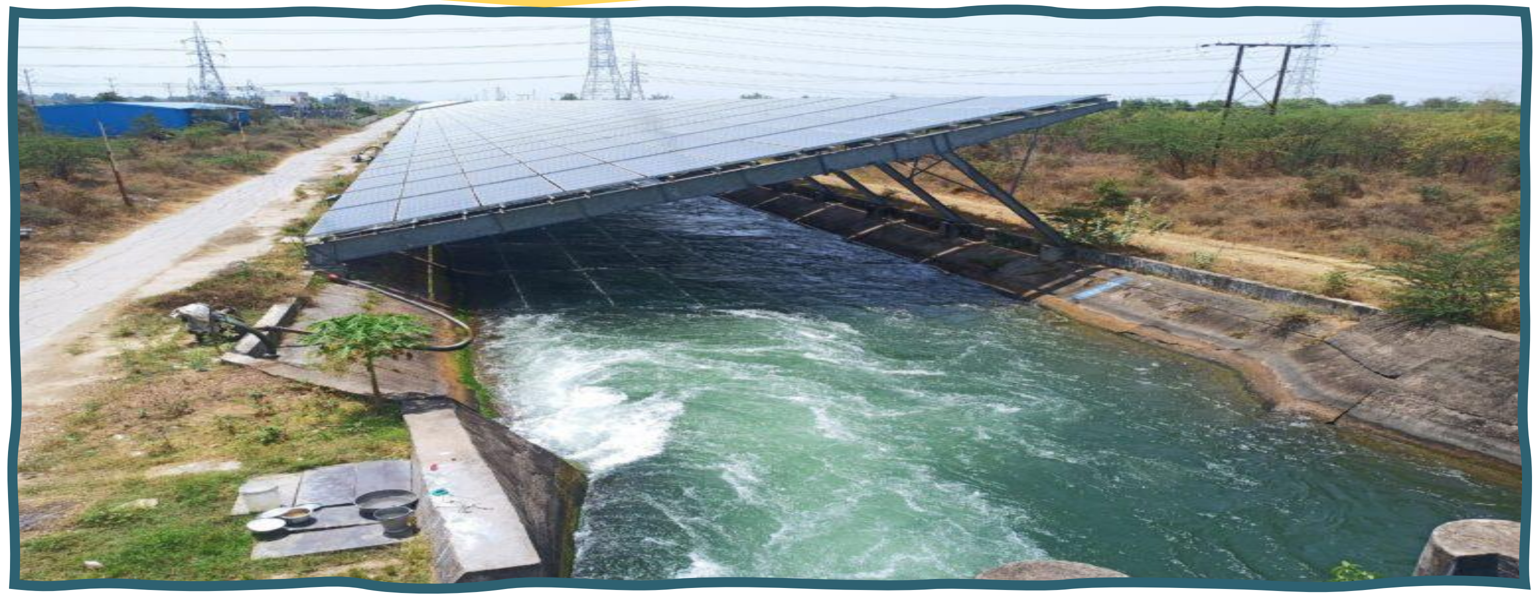
AGRIVOLTAICS

Source: https://www.nsefi.in/

PV SYSTEM CONFIGURATION EXAMPLES, PT. 3

Situating PV panels on water can reduce the use of land and result in more efficient operation due to lower temperatures; however, costs may be higher. It can serve other purposes such as reducing water evaporation.

CANAL TOP



Source: https://india.mongabay.com/2023/07/solar-canals-prove-to-be-good-for-the-environment-but-not-for-business/

FLOATING

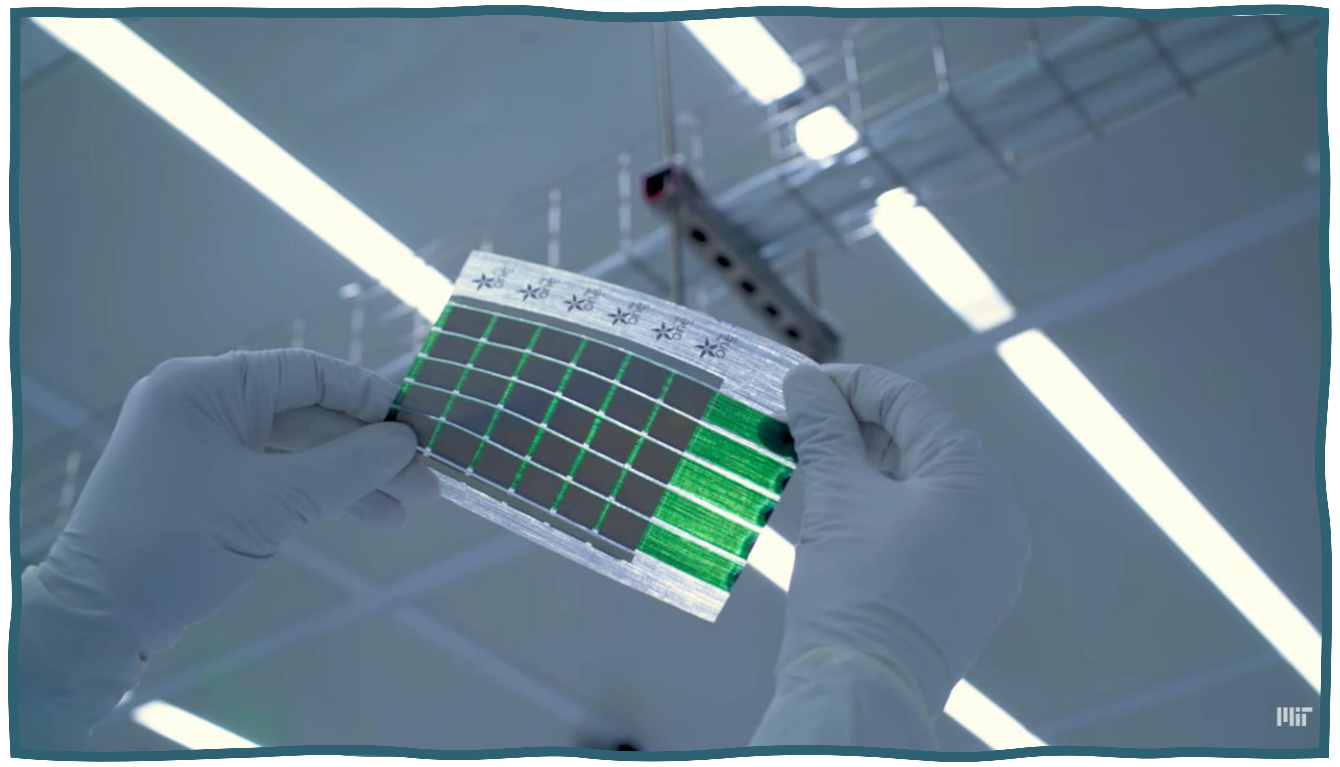
Source: An array of floating panels in Tokushima prefecture, Japan. Credit: Ciel & Terre International

Source: A solar pilot project on a flood control waste pond in Indonesia. Credit: Ciel & Terre International

Source: https://www.conger.solar

PV SYSTEM CONFIGURATION EXAMPLES, PT. 4

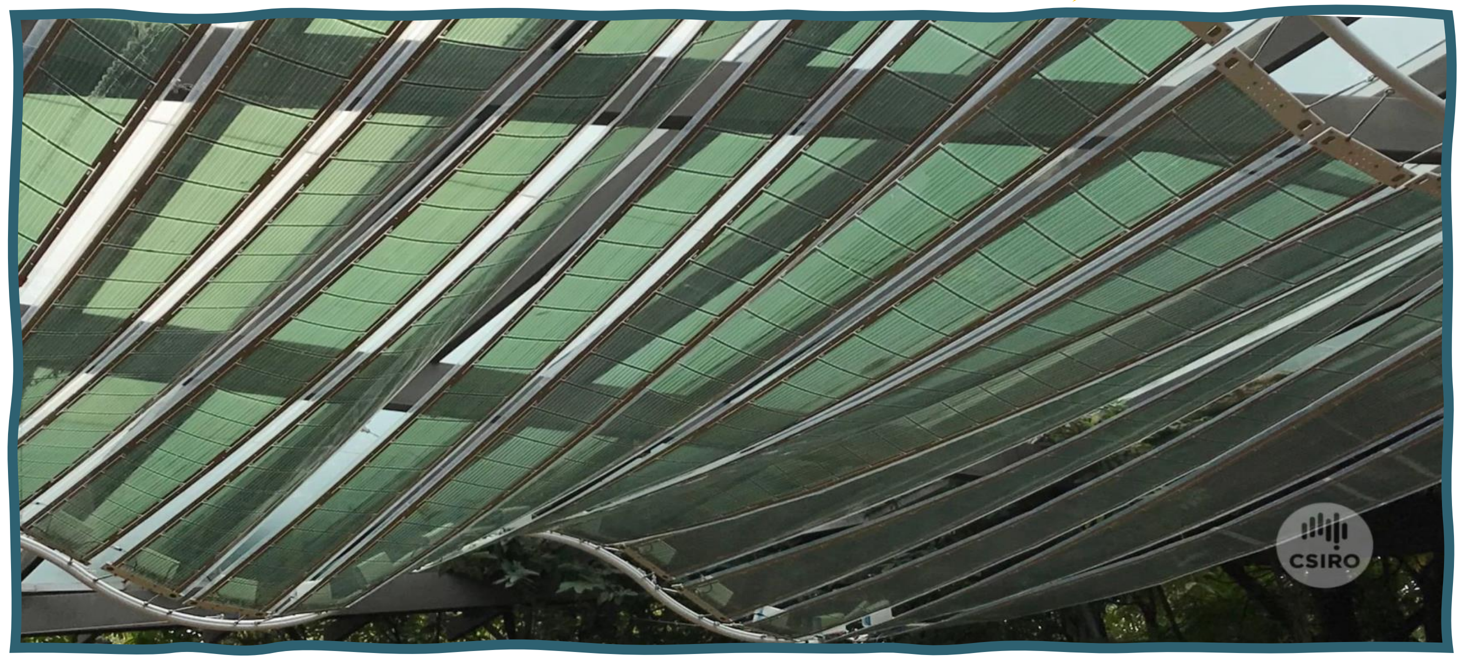
FLEXIBLE



Source: https://news.mit.edu/2022/ultrathin-solar-cells-1209

Source: : https:// swiftsolar.com

While not as cost-effective as standard solar panels, flexible panels can be installed in more 'creative' configurations



Source: https://https://research.csiro.au/printedpv/

PV SYSTEM CONFIGURATION EXAMPLES, PT. 5

TRANSPARENT

Source: https://www.euronews.com/next/2022/11/12/electricity-generating-windows-swiss-scientists-design-more-efficient-transparent-solar-pa (, dye-sensitised solar cells (DSCs)

Source: : Tubesolar AG

Source: https://insolight.ch/solution/

Source: https://efahrer.chip.de/

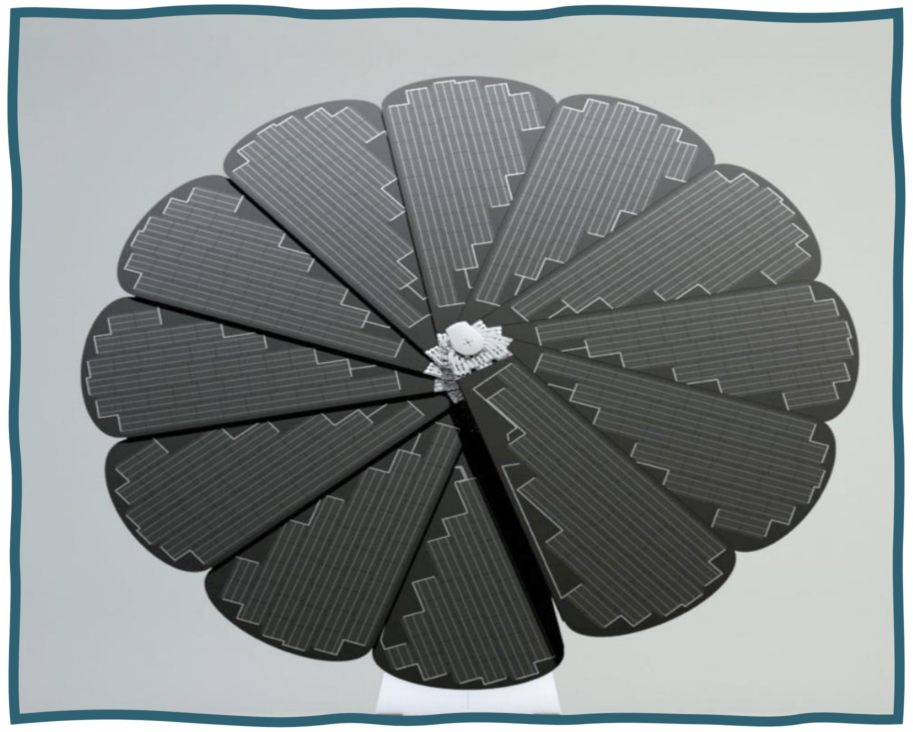
PV SYSTEM CONFIGURATION EXAMPLES, PT. 6

BUILDING-INTEGRATED

Source: https://www.pv-magazine.com/2020/05/19/bipv-solar-modules-with-varying-transparency/

Source: https://www.giesers.de/referenz/grunewald-bocholt/

Source: https://www.maysunsolar.com/bipv-in-one-article//



Source: https://smartflower.com/commercial/

Building-integrated panels can be installed in a variety of configurations, reducing the use of land and providing other benefits such as shading.

PV SYSTEM CONFIGURATION EXAMPLES, PT. 7

VEHICLE-INTEGRATED

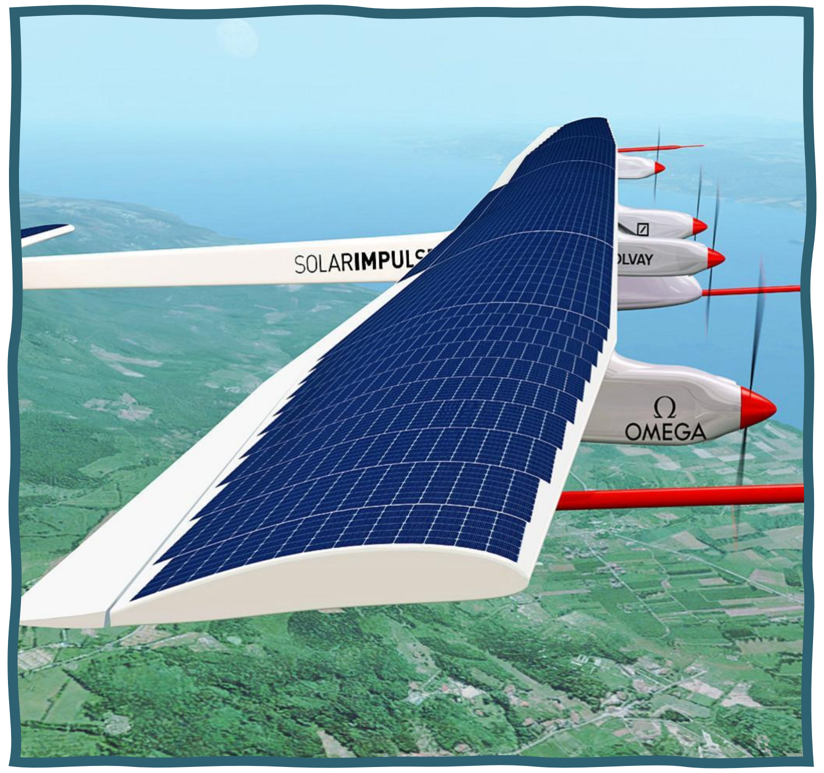
Source: https://navaltboats.com/

Source: Sono Motors

Source: Sono Motors

Power generated onboard results in extended range

Source: Solar Impulse



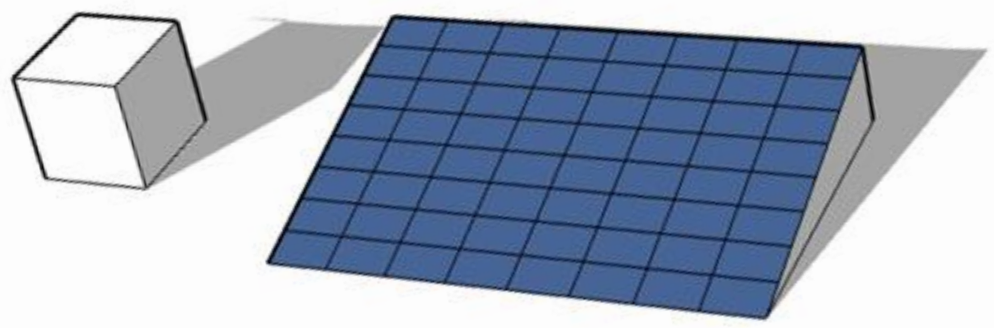
PART 2

PV MOUNTING SYSTEMS

PV MOUNTING STRUCTURE

Mounting structures

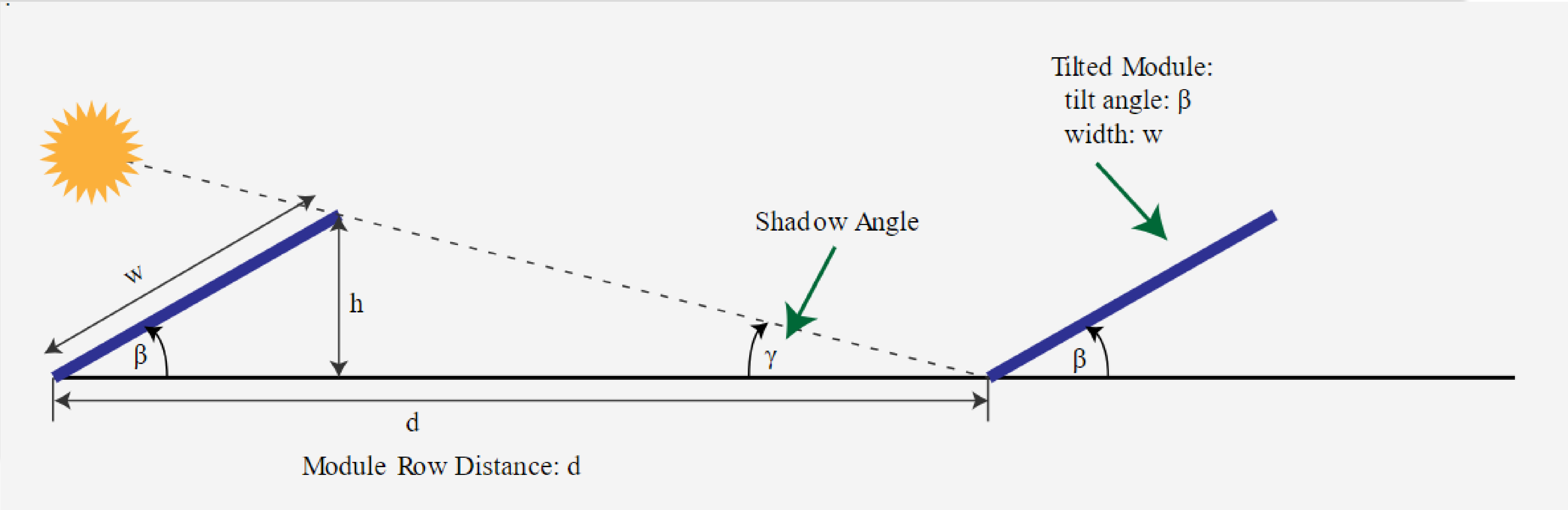
- Fixed tilt
- Tracking
  - Single-axis tracking
  - Dual-axis tracking



When sun's rays are perpendicular, the length of the shadow is zero.

Finding the perfect alignment is challenging due to the sun's movement.
Essentially, sunlight falling directly on panels results in the maximum energy output.

TILT ANGLE



A panel produces the most energy when the sun's rays are perpendicular (zero shadow).

Tilt Angle (β)

- The tilt angle is crucial for optimal energy yield.
- Aligning the PV module so that the tilt angle maximizes sun's energy capture enhances overall performance.

Quick calculations:

Latitude < 25°:
Tilt angle = (latitude × 0.87)
Latitude 25° to 50°:
Tilt angle = (latitude × 0.87) + 3.1°
Latitude > 50°:
Tilt angle ≈ 45°

MODULE MOUNTING STRUCTURES

Fixed structures: Static panel orientation, and so limited optimization for energy production.

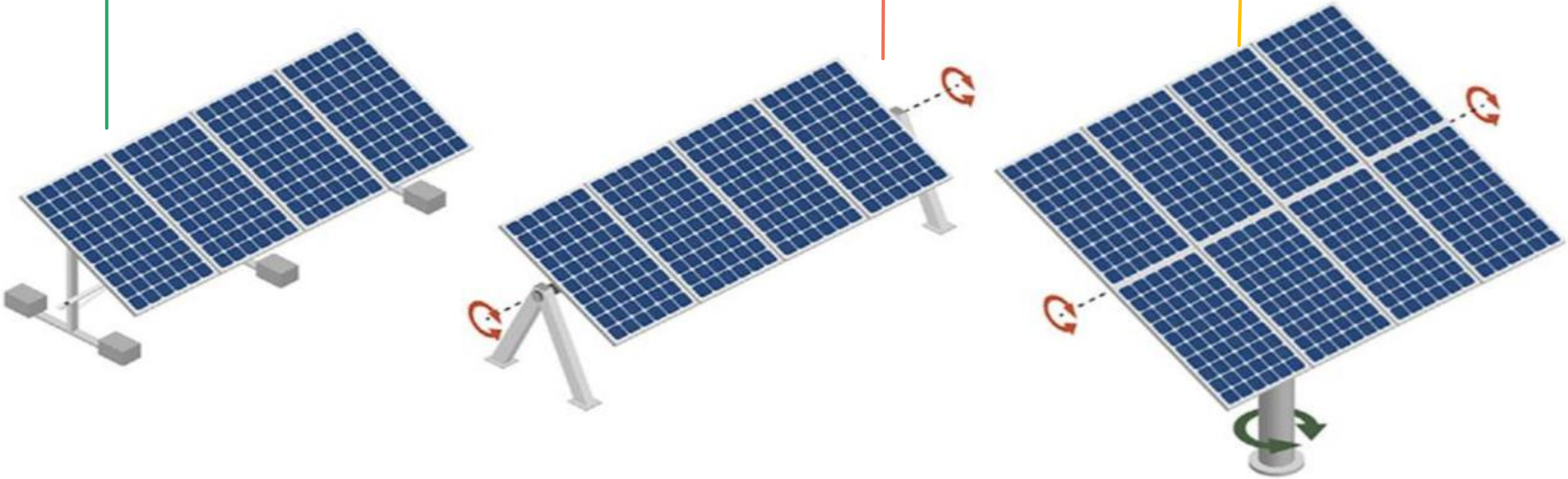
Tracking dynamic adjustment: Follows the sun's path so and optimizes energy capture throughout the day.

Fixed tilt

Single axis tracking

Dual axis tracking

Tracking



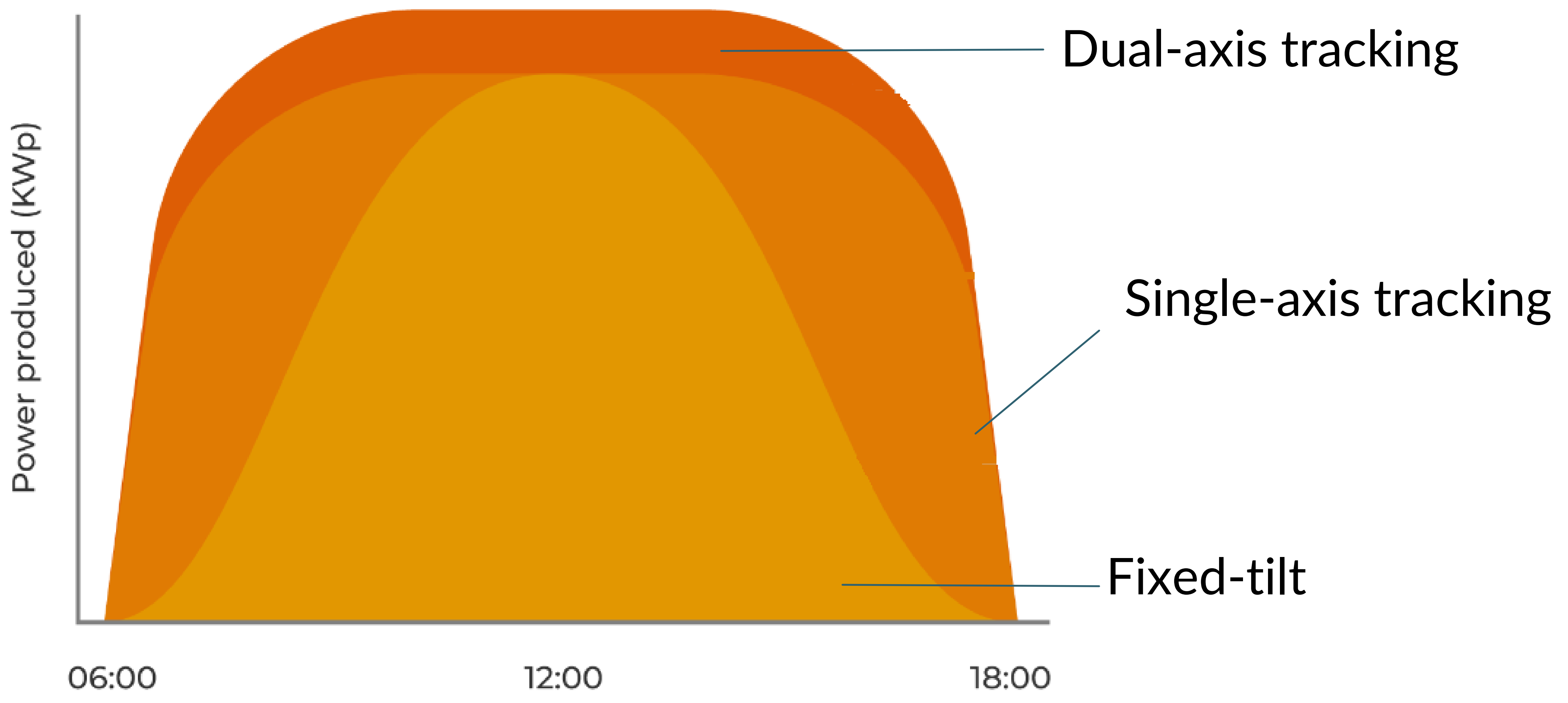
Source: https://solar-energy.uq.edu.au/facilities/gatton/gatton-solar-research-facility/dual-axis-

BENEFITS OF TRACKING SYSTEMS

Deciding factors for choice of tracking

- Location and solar resources
- Size of project
- Financial considerations
- Available space
- Maintenance and reliability
- Environmental conditions
- Regulatory and permitting requirements

Dual-axis tracking results in the highest power output; however costs are also higher



Power generation/energy yield over one day for fixed-tilt, single-axis tracking, & dual-axis tracking

PART 3

SOLAR PV SYSTEM DESIGN

TYPE OF GRIDS FOR DECENTRALIZED RENEWABLE ENERGY APPLICATIONS

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TABLE : TYPES OF GRIDS

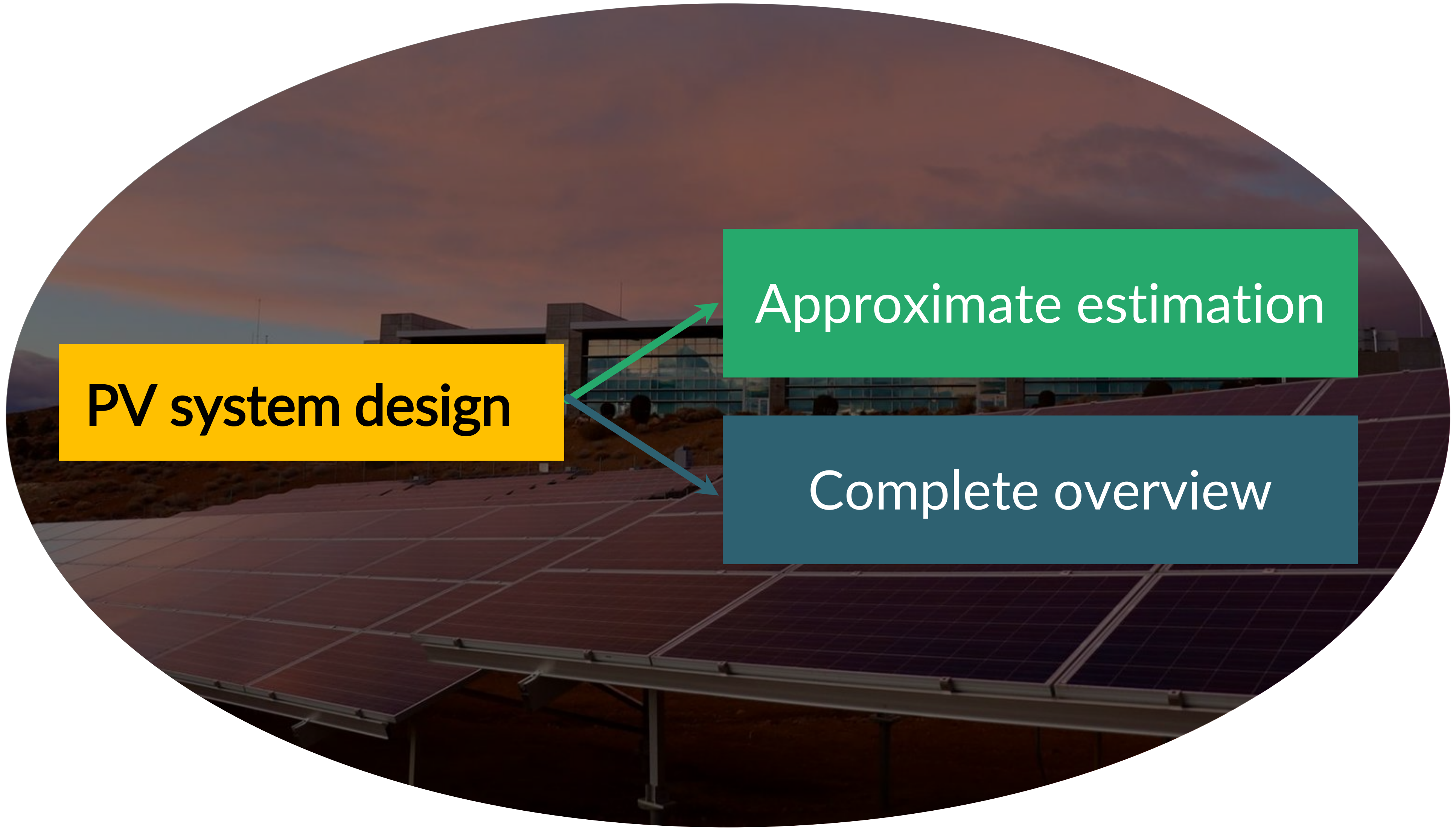
Type	PICO	Solar Home Systems	Mini-Grids	National Grids
Capacity	1–11 Wp	10–250 Wp	< 15 Wp	> 15 MW
Scale	Small home appliances and devices such as calculators, toys, cameras, cell phones and tablets	Standalone systems for residences	Decentralized systems for a localized group of customers isolated from the grid, involving one or more small-scale electricity generation units (solar PV, fuel cells, micro hydro, wind, storage devices such as flywheels and batteries)	Interconnected network that provides electricity to multiple customers over large distances
Market	Remote communities	Isolated users/ institutions, remote communities	Isolated users/ institutions, remote Communities, rural towns	Regional and urban areas

Source: https://renewablesroadmap.iclei.org/resourcescategories/fact-she

OVERVIEW OF SOLAR PV SYSTEM DESIGN

Approximate system design

- Determine the connected load in Watts *W) and Watt hours (Wh)
- Determine size and choice of electronic components
- Determine battery size (number, capacity voltage, Ampere hour (Ah) rating, etc.)
- Determine PV module size (number, capacity, rating, etc.)
- Determine size of wires in mm, fuse (A), junction box (Volts & Amps), etc.



QUESTION: ESTIMATING SOLAR PV SYSTEM DESIGN

QUESTION

A house has the following electrical appliance usage. Determine its power consumption demands and design the system using this approximate estimation.

Appliances	Lamp	Fan	Refrigerator
Consumption (in Watts)	18	60	75
Hours of operation (h)	4	2	12

Assumptions:

The system will be powered by 12 V_{dc}, 110 W_p PV module. The system will be powered by 12 Vdc, 110 Wp PV module. The average peak sunshine hours is 3.4 h. Required autonomy for backup is 3 days. Overall system loss is 1.3, battery loss is 0.85. Depth of discharge is 0.6. Nominal battery voltage is 12 V. Short circuit current is x1.3.

ANSWER: ESTIMATING SOLAR PV SYSTEM DESIGN

Total appliance energy use:

(18W × 4 h) + (60W × 2 h) + (75 W × 24 x 0.5 h)

= 1,092 Wh/day

> Total energy need from PV panels:

1,092 × 1.3 = 1,419.6 Wh/day

1. Size of PV Panel:

- Total W_p of PV capacity needed = 1,419.6 / 3.4 = 413.9 Wp
- Number of PV panels needed = 413.9 / 110 = **3.76 modules**.

Actual requirement = 4 modules

∴ This system should be powered by at least four 110 Wp modules.

2. Inverter sizing:

- Total wattage of all appliances = 18 + 60 + 75 = **153 W**.
- For safety, the inverter should allow for 25–30% more wattage i.e., the inverter size should be >190 W.

3. Battery sizing:

- Total appliance use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 12 hours); Nominal battery voltage = **12 V**
- Days of autonomy = **3 days**
- Battery capacity:

$$\frac{[(18\text{ W} \times 4\text{ h}) + (60\text{ W} \times 2\text{ h}) + (75\text{ W} \times 12\text{ h})] \times 3\text{ days}}{(0.85 \times 0.6 \times 12)}$$

- Total Ampere-hours required = **535.29 Ah**

∴ The battery should be rated 12 V 600 Ah for 3 day-autonomy.

4. Solar charge controller sizing:

- PV module specification:

P_m = 110 W_p; V_m = 16.7 V_{dc}; I_m = 6.6 A; V_{oc} = 20.7 A; I_{sc} = 7.5 A

Solar charge controller rating = (4 strings x 7.5 A) x 1.3 = 39 A.

∴ The solar charge controller should be rated 40 A at 12 V or more.

Assumptions:

The system will be powered by 12 V_{dc}, 110 W_p PV module. The system will be powered by 12 Vdc, 110 Wp PV module. The average peak sunshine hours is 3.4 h. Required autonomy for backup is 3 days. Overall system loss is 1.3, battery loss is 0.85. Depth of discharge is 0.6. Nominal battery voltage is 12 V. Short circuit current is x1.3.

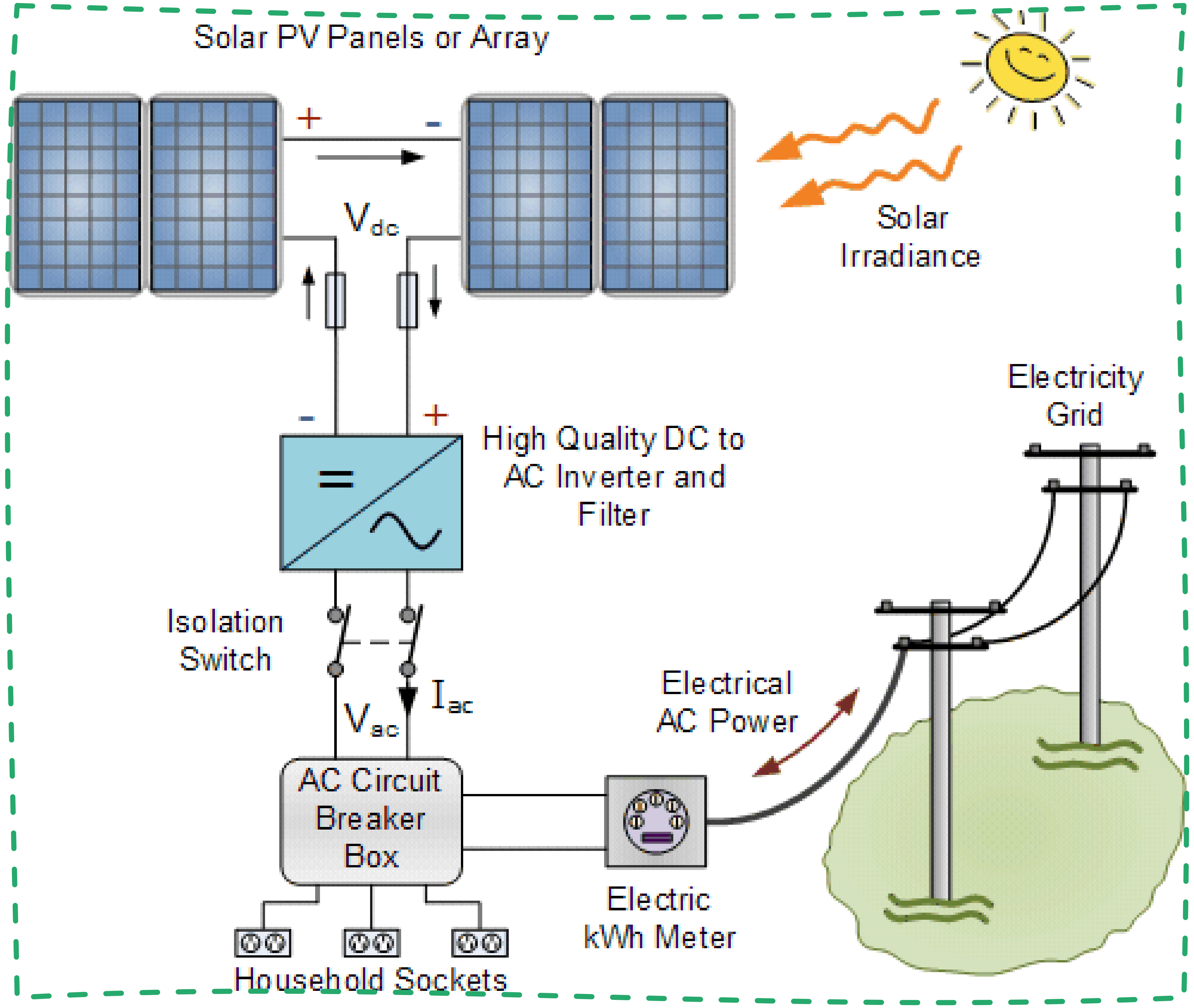
2. SOLAR PV SYSTEM DESIGN CRITERIA– COMPLETE OVERVIEW

Project monitoring & optimization

Finance & regulatory compliance

Operation & maintenance

Testing & commissioning



Feasibility and site selection

Permitting and approvals

Design & engineering

Procurement & construction

Source: https://www.alternative-energy-tutorials.com/solar-power/grid-connected-pv-system.html

PV SYSTEM LOSSES & ENERGY YIELD

- Solar PV modules utilize solar radiation to generate electricity
- **The total generated energy depends on various factors such as:**
  Temperature, soiling, shading, electrical components and system limitations (module efficiency)
- **Hence, the system features some losses i.e. energy losses.**

Ratio of actual and theoretically possible energy outputs = Performance ratio (PR)

$$\text{Performance Ratio} = \frac{\text{Actual reading of plant output in kWh per annum}}{\text{Calculated nominal plant output in kWh per annum}}$$

The performance ratio of a PV plant is a valuable metric that helps to fulfil financial, environmental, and accountability responsibilities. It supports effective resource management, contributes to sustainability goals, and enhances the overall well-being of the community they serve.

ECONOMICAL EVALUATION

Levelized Cost of Electricity (LCOE):

- *Definition*: Average cost of generating electricity over the plant's lifetime
- *Purpose*: Compares solar power costs with other sources of energy

Calculation → Levelized cost of electricity LCOE = CAPEX + OPEX / Total energy yield

$$\text{Levelized cost of electricity LCOE} = \frac{\text{CAPEX + OPEX}}{\text{Total energy yield}}$$

Simple Payback Period:

- *Definition*: Time to recover initial investment through savings or revenue.
- *Purpose*: Assess financial viability.

Calculation → Simple payback period = CAPEX / Yearly savings

$$\text{Simple payback period} = \frac{\text{CAPEX}}{\text{Yearly savings}}$$

Factors influencing economic evaluation:

- Installation costs
- Operating & maintenance costs
- Energy generation
- Energy prices
- Incentives & subsidies
- Discount rate
- Expected lifetime

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IKI INTERNATIONAL CLIMATE INITIATIVE
on the basis of a decision by the German Bundestag

END OF CHAPTER 2 OF 3

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