

Module Outline

SOLAR RADIATION AND SOLAR PATH





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Relevance and Background

Solar radiation, a term that encompasses sunlight and its associated energy, forms the bedrock of solar energy production. The quantity and quality of solar radiation hitting the Earth's surface, significantly influences the performance of PV arrays. Therefore, understanding the concepts of solar radiation is vital for designing and operating effective solar PV projects.

This training module is designed to enable participants to understand the impact of solar radiation on PV systems. It will help participants to navigate the complexities of solar radiation to maximize energy output and optimize system design.

Theme – Technical

Competency – Others

Code of the Module – To2Co5M14

Learning Outcomes

Upon completing this training module, participants will gain a comprehensive understanding of various aspects related to solar radiation and its profound impact on the performance and design of solar PV systems, such as:

- Solar Radiation Concepts
- Interpretation of Solar Data
- Analysis of Solar Geometry
- Optimization of System Design
- Shading Analysis
- Solar Panel Orientation
- Solar Measurement Instruments
- Sun Path Diagrams
- Tracking Mechanisms
- Enhancing PV System Performance
- Solar Resource Databases

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M14 Lo1	Lecture on Solar Radiation and Solar Path



M14 L1: Lecture Presentation

The MS Power Point presentation will cover concepts ranging from solar geometry and collector angle optimization to shading analysis and measurement instruments, to provide a holistic understanding of how solar radiation shapes the design, efficiency, and overall effectiveness of PV installations.

Key Topics to be Covered

1. Solar Intensity
2. The Solar Spectrum
3. Air Mass and Solar Time
4. Sun Path Diagrams
5. Application of Information for PV Design
6. Seasonal Optimization of Tilt Angle



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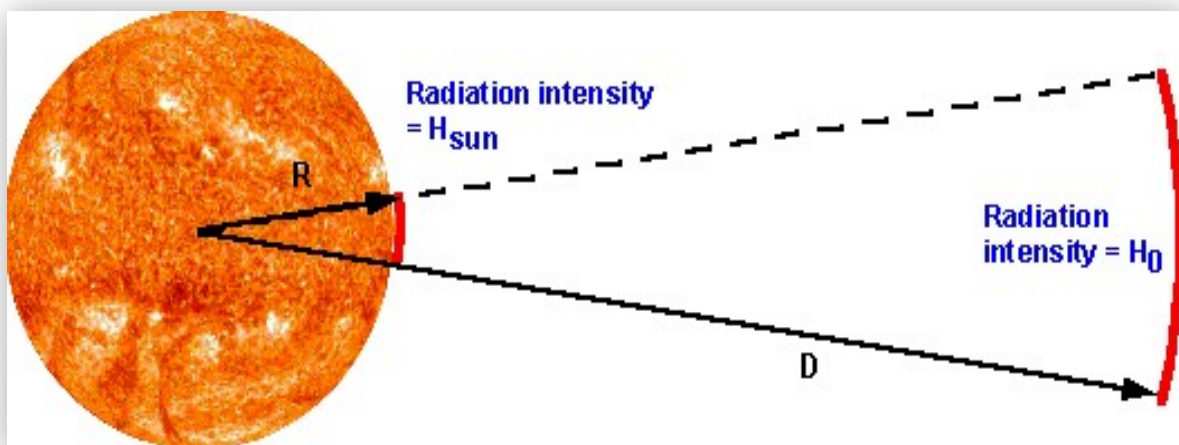
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1 Introduction

At the core of solar energy conversion lies the interplay between the Sun and Earth's atmosphere. This dynamic interaction gives birth to solar radiation, the energy currency of PV systems. Solar radiation intensity, measured in watts per square meter, dictates the energy output of PV arrays. Grasping this foundational concept empowers designers and engineers to harness the full potential of solar energy.

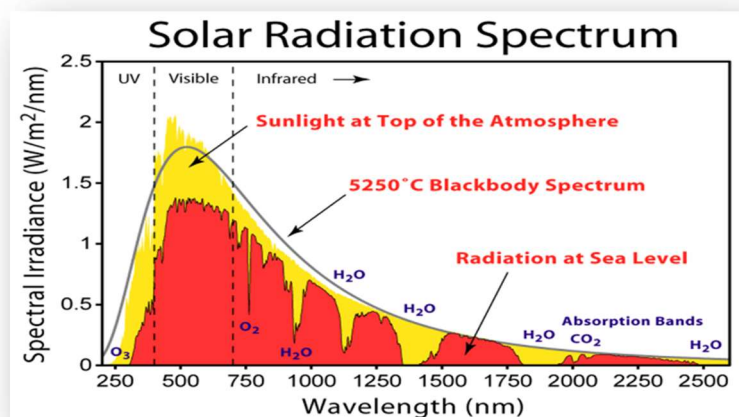
2 Solar Intensity

The diverse solar radiation experienced by different planets within our solar system highlights the intricate dance between distance and intensity. Earth's position relative to the Sun influences the amount of solar radiation it receives. This realization underscores the significance of geographic location when designing PV systems, emphasizing the need for strategic placement for optimal energy yield.



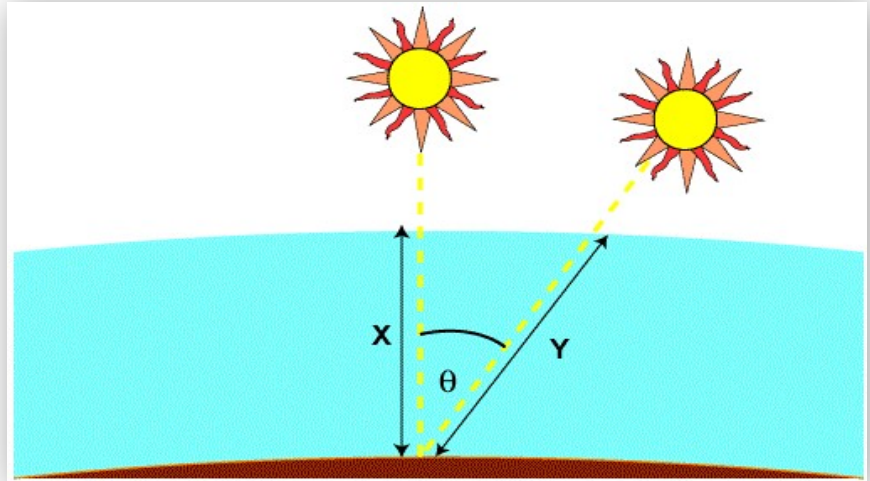
3 The Solar Spectrum

The Sun's radiance encompasses a spectrum of wavelengths, including visible light, ultraviolet, and infrared rays. This spectrum plays a pivotal role in energy conversion through PV systems. Different solar cell technologies respond uniquely to these wavelengths, necessitating tailored system configurations to capture the full breadth of solar energy.



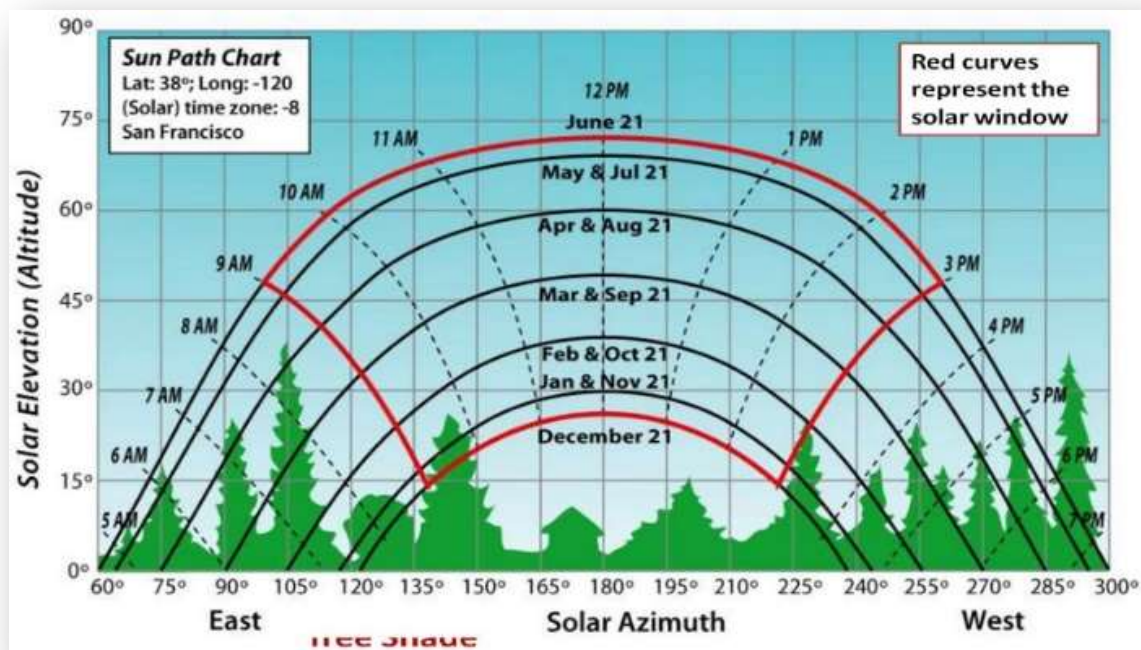
4 Air Mass and Solar Time

Understanding air mass is pivotal for comprehending solar radiation's journey through the Earth's atmosphere. Equally important is the distinction between solar time and sidereal time, as the former dictates the availability of sunlight during the day. Mastering these concepts empowers PV system designers to align system orientation for optimal energy generation.



5 Sun Path Diagrams

The Sun's trajectory across the sky transforms with the changing seasons, affecting light and shadow. Sun path diagrams visually encapsulate this celestial composition, serving as indispensable tools for designing PV arrays.



- Such diagrams for a location are used by simulation software and shadow analysis tools such as Pathfinder to understand the effect of shadow objects on the system installation.
- It is ensured normally that in the solar window (between 9 am and 4 pm) throughout the year there will not be any shadow on the PV array.

The design of a solar PV system is heavily influenced by location-specific factors, including solar geometry, radiation intensity, and shading patterns. The ideal scenario is to ensure that each solar module consistently faces the sun at a right angle throughout the year, maximizing solar radiation absorption for efficient energy conversion. This concept is known as "Tracking the Sun," where systems are designed to follow the Sun's path.

However, practicality often comes into play. Through years of experimentation and research, designers have discovered that fixed-type mounting structures are often more viable and cost-effective. These structures optimize solar energy, considering the complex interplay of factors such as Sun path, shading, and module orientation. While tracking arrays, which meticulously follow the Sun's movement, are suitable for large-scale projects like MW installations, fixed structures are commonly adopted due to their practicality and reliability.

6 Application of Information for PV Design: Understanding Features of Tracking

Solar tracking systems rely on two pivotal factors: tilt and orientation of solar modules. Tilt denotes the angle of the module plane concerning the horizontal, while orientation refers to its deviation from True South or North.

Tilt variance optimizes energy absorption year-round. Adjusting from North to South ensures modules receive direct solar rays perpendicularly as the Sun's angle changes across seasons. Similarly, altering orientation impacts sunlight exposure throughout a day, from East to West. This adaptability maximizes perpendicular Sun rays' reception across the sky. Fixed installations offer efficient radiation capture too. Aligning modules to True South/North and applying a tilt equal to latitude ensures robust energy absorption. While tracking mechanisms bolster energy yield by tracing the Sun's path, simpler fixed setups remain reliable and practical.

When considering solar tracking for PV design, multiple options cater to various project requirements:

- **Fixed Structure:** Involves static installation with a fixed tilt and orientation, primarily aiming for simplicity and reliability.
- **Seasonal Tracking:** Adapts to seasonal Sun position changes by adjusting tilt angles at specific intervals, normally about three in a year. This optimizes energy capture during varying solar altitudes.
- **Dual-Axis Tracking:** A two-axis tracking system follows both the Sun's daily path and seasonal altitude changes, ensuring the panels are perpendicular to sunlight at all times.
- **Plane Orientation:** Selecting the orientation of panels matters:

- **Tilted or Fixed, N-S Axis:** Modules are aligned to face the North-South direction, ideal for consistent energy generation throughout the day.
- **Tracking Horizontal Axis, E-W:** The panels track the sun along the East-West axis, maximizing morning-to-evening energy capture.
- **Tracking Vertical Axis:** Rotates panels vertically, beneficial for capturing sunlight at different angles throughout the day.
- **Tracking Sun-Shields:** Implementing sunshades in tracking systems prevents direct sunlight from causing overheating and damage.
- **Double Orientation (Heterogeneous):** Combines fixed and tracking systems on the same site, accommodating varying energy needs and optimizing production.
- **Unlimited Shed Tracking:** Intelligently incorporates structures like sunshades, integrating shading solutions with tracking mechanisms for enhanced energy capture.

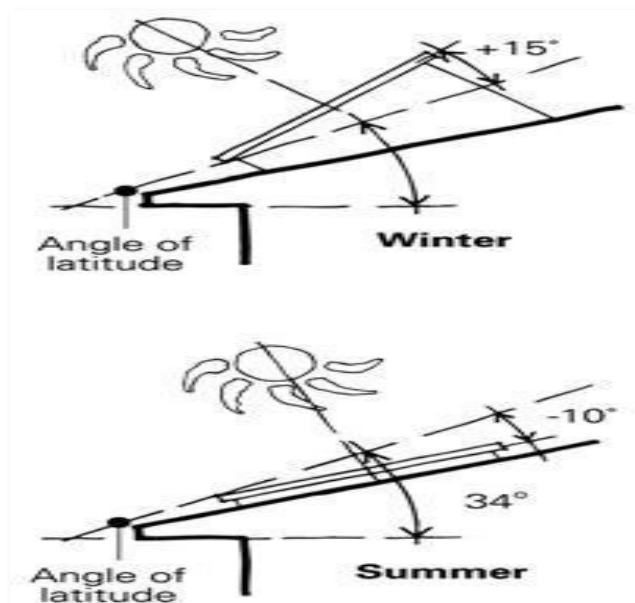
7 Seasonal Optimization of Tilt Angle

Solar PV installations can optimize energy yield through seasonal adjustment of tilt angles. The annual optimum tilt angle generally corresponds to the location's latitude. For winter, the tilt angle is optimized by adding 15 degrees to the latitude, ensuring better solar radiation capture during lower Sun altitudes. In contrast, for summer, the tilt angle is optimized by subtracting 10 degrees from the latitude, maximizing energy absorption during higher Sun altitudes. This calculated approach aligns the solar panels optimally for the changing Sun path throughout the year.

○ Optimum Tilt Angle Module Power:

Determining the optimum tilt angle for a solar module involves utilizing calculators that provide insights specific to a location. Key parameters include:

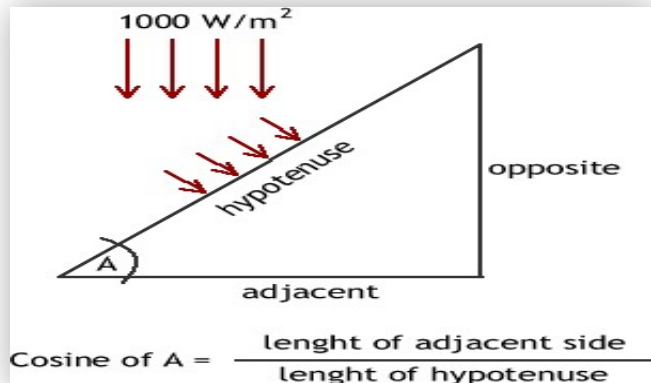
- The radiation captured by a module with a fixed orientation and tilt angle.
- Solar radiation collected by a collector that continually tracks the Sun's movement.
- Radiation captured by a fixed module lying horizontally.



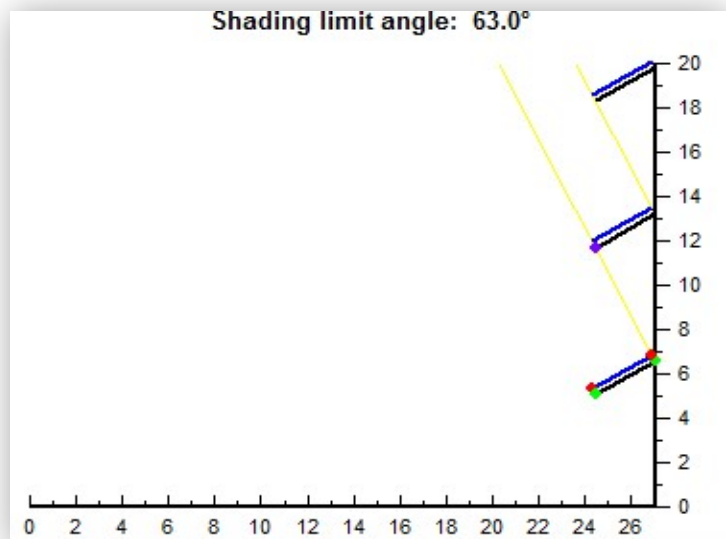
These calculations aid in optimizing the tilt angle, resulting in efficient energy capture and utilization.

- **Incident Angles and IAM Losses:**

The angle at which sunlight strikes a solar panel significantly impacts its energy absorption. Incident Angle Modifier (IAM) losses account for reduced energy conversion due to non-optimal incident angles. As the angle increases from the panel's normal, IAM losses intensify. Tracking systems and careful design considerations help mitigate these losses, ensuring optimal energy production across various solar positions.



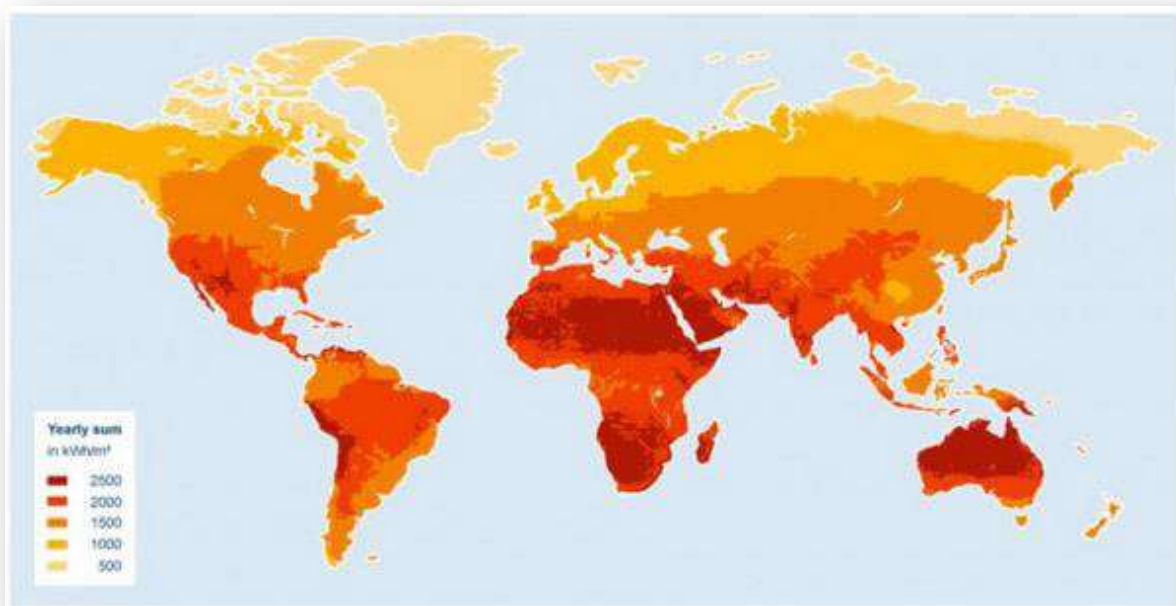
- **Plane Orientation** - Unlimited Sunshield: When it comes to plane orientation, the concept of an "unlimited sunshield" involves aligning the PV panels to always be perpendicular to sunlight. This theoretical setup allows maximum solar energy harvesting throughout the day. However, in practice, such an arrangement is not feasible due to cost and complexity. Thus, a balance is struck between optimal orientation and practicality, ensuring efficient energy generation. The presentation will provide a general comparison between these factors.



- **Insolation Maps:** Insolation maps provide valuable information about the solar energy potential of different regions. These maps depict the amount of solar radiation received on the Earth's surface over a specific period. By analyzing insolation maps, we can identify regions with higher solar energy potential, guiding site selection for solar PV installations. These maps are based on historical weather data, solar irradiance measurements, and atmospheric conditions. Insolation maps play a crucial role in determining the feasibility and expected energy output of solar PV projects in different geographical areas.

8 Shading Analysis


Shading analysis is essential for designing layouts that minimize shading-induced inefficiencies. Skill in this analysis guarantees that PV systems operate at peak energy-generating potential. Some shading examples to understand its impact are as below:



- **Shadow from Nearby Structures:** Objects like buildings, trees, or utility poles can cast shadows on solar panels, reducing their efficiency.
- **Time-Dependent Shadows:** Shadows change in length and direction as the Sun's position varies throughout the day and across seasons.
- **Inter-Row Shadows:** In arrays with multiple rows, shading from one row onto another can lead to energy losses.
- **Partial Shading:** Even partial shading on a small part of a solar panel can significantly impact the entire panel's output.
- **Bypass Diodes:** Solar panels often have bypass diodes to mitigate energy losses caused by shading.

When analysing shading in solar PV installations, it's important to consider two key effects:

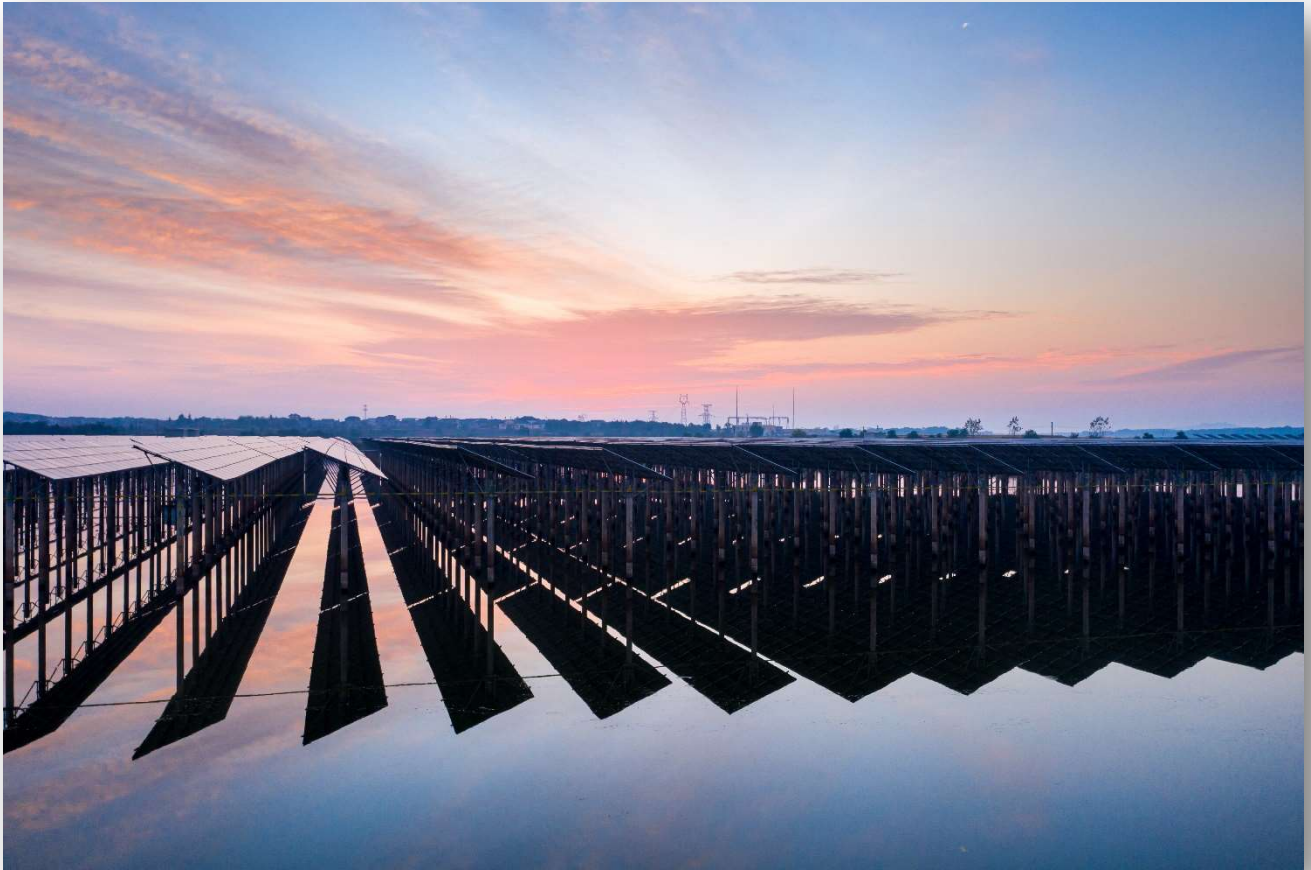
- **Primary Effect:** Direct shading occurs when parallel rays of direct sunlight cast shadows on the PV panels. This effect has an immediate and significant impact on energy production.

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- **Secondary Effect:** Shading refers to the fading darkness of a shadow as it falls on objects further away. Therefore, distant shadows have less impact on PV system performance.

The impact of shading on a solar PV system can be identified by these key factors:

- **Number of Shaded Modules:** The more modules affected by shading, the greater the reduction in overall system performance.
- **Cell and Bypass Diode Interconnection:** Shading can cause hotspots in shaded cells, leading to potential module damage. Bypass diodes can mitigate these effects.
- **Degree of Shading:** Partial shading has less impact compared to full shading, where the entire module is affected.
- **Spatial Distribution and Shading Over Time:** Changing shadow patterns over the day and across seasons affects energy production.
- **Module Interconnection:** Series or parallel connection of modules impacts energy loss due to shading.
- **Type of Inverter:** Different inverters handle shading effects differently.
- **Module Technology:** Some technologies are more tolerant to shading due to bypass diodes.

- **Shadow Size:** The size of a shadow is determined by the object's dimensions, location, and the time of day.




9 Solar Radiation Data Availability

Accurate solar irradiance data is essential for designing efficient solar PV systems. Two sources of solar irradiance data include:

- **Measured Data:** Actual on-site measurements provide precise information but can be costly. Measured data remains unparalleled in accuracy.
- **Satellite Data:** Satellites collect vast weather data, including solar radiation, covering diverse locations. Although less precise, they offer widespread coverage and are more cost-effective.

Combining both types of data refines understanding, highlighting high solar potential regions. Balancing the advantages of measured and satellite data can lead to informed and effective solar PV system design.



Dedicated Solar Radiation Resource Assessment (SRRA) stations play a crucial role, as they collect ground-level solar radiation data and thus assist in quantifying solar potential across diverse locations.

Other sources of data availability include:

- **Local Meteorological Stations:** These stations offer highly accurate historical data, but are limited in number and often provide data for only a few years.
- **Data Modelling:** Multiple data points like clouds, air quality, wind and temperature are integrated to refine solar radiation estimation. Some private companies provide relevant real-time and historical data as below:
 - **Global Solar Atlas:** A World Bank initiative offering solar radiation data.
 - **Solargis.com:** Provides comprehensive solar energy data.
 - **Solcast.com:** A DNV company offering solar and weather data.

10 Instruments for Solar Radiation Data Collection and Record

Accurate measurement of solar radiation relies on specialized instruments such as pyranometers, **pyrheliometers**, and **solar trackers**. Meteorological instruments like wind sensors, rain gauges, and temperature sensors also contribute to understanding local conditions affecting solar energy. Accurate solar radiation data collection relies on a range of specialized instruments:

- **Solar Measuring Instruments:**
 - **Pyranometer:** Measures total solar radiation received.
 - **Shaded Pyranometer:** Shields from direct sunlight to assess diffuse radiation.
 - **Pyrheliometer:** Measures direct solar radiation.
 - **Solar Tracker:** Orientates to optimize panel exposure to the sun.
- **Meteorological Measuring Instruments:**
 - **Ultrasonic Wind Sensor:** Records wind speed and direction.
 - **Rain Gauge:** Measures rainfall intensity and accumulation.
 - **Pressure Sensor:** Monitors atmospheric pressure variations.
 - **Temperature & Relative Humidity Sensor:** Measures temperature and humidity levels.
- **General Instruments:**
 - **GPS:** Provides precise location coordinates.
 - **Data Logger & Modem:** Records and transmits data.
 - **GPRS:** Offers data transmission over cellular networks.
 - **Solar PV Panel:** Demonstrates panel output under given conditions.

- **External Battery:** Powers instruments in remote locations.



This array of instruments enables accurate solar radiation and meteorological data collection, contributing to effective solar PV plant performance monitoring and system optimization.

In conclusion, understanding the fundamental principles of solar radiation and its effects on PV arrays is crucial for effective solar energy utilization. This training module provides participants with a solid foundation to design, install, and maintain efficient solar PV systems, contributing to a sustainable and cleaner energy future.



Reading Material

1. *Solar Radiation Data for African Countries – SOLARGIS*
([Solar resource maps and GIS data for 200+ countries | Solargis](#))
2. *Explaining Solar Radiation Data and its uses – NREL*
([Shining On: A Primer on Solar Radiation Data \(nrel.gov\)](#))
3. *A. Ameer et al. – J. Clean. Prod. (2020)*
([Forecast modelling and performance assessment of solar PV systems](#))
4. *B. Amrouche et al. – Appl. Energy (2014)*
([Artificial neural network based daily local forecasting for global solar radiation](#))