

Module Outline

PV INSTALLATION AND OPERATIONS





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Relevance and Background

Understanding the details of solar photovoltaic (PV) system installation becomes imperative to ensure the successful implementation of the system. This module addresses the growing demand for skilled professionals who can design and install solar PV systems effectively. With a focus on key components, design principles, safety measures, and installation best practices, this module empowers participants to contribute to the global transition towards cleaner energy sources and harness the potential of solar power.

Theme – Technical

Competency – Mechanical

Code of the Module – To2Co4M13

Learning Outcomes

By the end of this module, participants will be able to:

- Comprehend key PV system components
- Grasp PV system design philosophy
- Make informed component decisions
- Calculate cable sizing
- Implement safety features
- Follow installation best practices

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M13 L01	Lecture on PV Installation and Operations

M13 L01: Lecture Presentation

The MS PowerPoint presentation will cover comprehensive details on solar PV system components, design principles, installation practices, and safety measures.

Key Topics to be Covered

1. DRE Systems
2. Common Components of Solar PV systems
3. Design Philosophy for Stand-alone PV Systems
4. Designing and Sizing a Solar Mini-grid
5. Major Component Selection


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6. Cable Sizing in Solar PV systems
 7. Safety Features and Provisions in PV Systems
 8. Installation Best Practices



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1 DRE Systems

A certain level of knowledge and skills is necessary to successfully plan, implement, and manage grid-connected solar PV systems. Stakeholders should be aware of all the aspects required to build a high-quality solar PV system, from exploring the components that constitute these systems to understanding best practices, safety measures, and key areas of improvement from earlier experiences of system installation.

2 Common Components of Solar PV systems

The basic components of a grid-connected solar PV system are common to other types of systems as well, and newer components are added based on the type of system. These components are essential for the efficient generation, conversion, and integration of solar energy into the grid.

- **Solar Module:** The solar module, often referred to as a PV module or panel, is the heart of the system, comprising interconnected solar cells that convert sunlight directly into electricity through the PV effect.
- **Inverter:** The inverter plays a crucial role in transforming the DC (direct current) electricity generated by the solar panels into AC (alternating current) electricity, which is compatible with the grid and most electrical appliances.
- **Mounting Structure:** The mounting structure provides support and stability for the solar panels, ensuring optimal orientation and tilt to maximize energy capture from sunlight.
- **Meters:** Meters, such as energy meters and net meters, are installed to measure the electricity generated by the solar system and the energy consumed from the grid. Net meters enable tracking the difference between exported and imported energy, affecting billing.
- **Earthing Infrastructure:** Proper earthing is essential to prevent electrical hazards and ensure the safety of the system and personnel. It provides a safe pathway for the dissipation of electrical faults.



- **Lightning Protection System:** As solar installations are exposed to weather conditions, including lightning, a lightning protection system safeguards the system from damage caused by lightning strikes.
- **Cables:** Cables, both DC and AC, are routed in conduits and/or trenches to connect various components of the system. Proper cable laying ensures efficient energy transfer and reduces the risk of damage.
- **Connectors:** Connectors facilitate the secure and efficient connection of cables, ensuring minimal energy losses and maintaining system integrity.
- **DCDB (Direct Current Distribution Box):** The DCDB acts as a hub for managing the connections and protection of the DC side of the system, including combiner boxes and over-current and surge protection devices.
- **ACDB (Alternating Current Distribution Box):** Similar to the DCDB, the ACDB serves as a distribution point for the AC side of the system, connecting to the grid and managing circuit protection.
- **Interconnection:** The interconnection components ensure seamless integration of the solar system with the grid infrastructure, allowing the bidirectional flow of electricity.
- **Data Monitoring:** Advanced solar systems incorporate data monitoring systems that allow real-time tracking of system performance, energy generation, and consumption. This data aids in system maintenance and optimization.



Additional Components of Grid-Connected Solar PV Ground-Based Systems: These components contribute to the effective operation and management of larger ground-based solar installations:

- **Evacuation Switchgear:** Evacuation switchgear ensures safe and controlled transfer of generated solar power from the solar system voltage to the higher grid level voltages. It enables efficient coordination between the solar system and grid infrastructure.
- **Main Control Room:** The main control room serves as the nerve center of the solar installation. It houses the monitoring and control systems that oversee the performance, data collection, and maintenance of the solar PV system.
- **Compound Wall:** A boundary wall encloses the solar installation area, providing security and protection from unauthorized access, as well as protection against external elements.
- **Access and Internal Roads:** Well-designed access and internal roads facilitate easy movement within the solar installation site, enabling maintenance activities, equipment transportation, and overall site management.
- **Module Washing System:** To maintain optimal efficiency, solar panels require periodic cleaning. A module washing system automates this process, ensuring the removal of dust and debris to enhance energy generation.
- **Water Harvesting and Drainage:** Water harvesting systems collect rainwater for various site uses, including cleaning and maintenance. Proper drainage systems prevent waterlogging and soil erosion, ensuring site integrity.

Additional Components of Off-Grid Solar PV Systems and Solar Mini-grids:

- **Battery Energy Storage:** Battery energy storage systems store excess energy generated during peak sunlight hours for later use, enhancing energy reliability and enabling power supply during low sunlight periods or grid outages.
- **Solar Charge Regulator:** In off-grid or hybrid systems, a solar charge regulator manages the charging and discharging of batteries, preventing overcharging and enhancing battery lifespan.
- **Off-Grid Inverter/Power Conditioning Unit:** In off-grid systems, an off-grid inverter converts DC energy from battery storage into AC energy for use within the system, providing energy independence in remote areas.
- **Power Distribution Network:** The power distribution network, forming a localized grid, ensures efficient distribution of electrical energy to the connected consumers. Proper network design minimizes losses and ensures energy reliability.

Understanding these key components is essential for designing, installing, and operating a successful grid-connected solar PV plant.

3 Design Philosophy for Stand-alone PV Systems

Planning and sizing stand-alone PV systems is a critical process that involves multiple considerations to ensure reliable and efficient operation. This section outlines the key steps involved in planning and sizing a stand-alone PV system, from determining power requirements to selecting appropriate batteries and charge regulators.



- **Sizing the PV Array:** To ensure the optimal performance of a stand-alone PV system, it's essential to accurately size the PV array. This involves a series of calculations and assessments to:
 - Identify the precise power needs of the system, accounting for all connected loads.
 - Understand when the loads will be operational to calculate the energy demand during those periods.
 - Calculate the daily total energy required based on the load and its operational hours.
 - Gather data on solar irradiation at the system's location to estimate the available sunlight.
 - Account for losses due to factors like shading, temperature, and inefficiencies.
 - Calculate the PV array's expected output by considering location-specific irradiation, energy requirement, and system losses.

- **System Design:** The design of a stand-alone PV system involves decisions related to the system's configuration and components:
 - Choose between DC and AC operation based on loads to be supported on the system. Inverters (off-grid) are necessary only for AC loads. For DC operation, determine the system voltage that ensures efficient battery charging by PV arrays. For AC operation, select an inverter based on the power requirement of loads, i.e., total load wattage.
 - Calculate the appropriate cable conductor size on the DC and AC sides, considering cable lengths, current to be carried, and targeted system losses limits.
- **Battery Sizing:** Batteries are a crucial component of stand-alone PV systems, and their sizing directly impacts system autonomy and reliability:
 - Select batteries suitable for the intended application and environmental conditions.
 - Determine the battery capacity based on the energy requirement for a typical day.
 - Define the desired period of autonomous operation (days of autonomy) during which the system can operate without solar input.
 - Select a charge regulator based on the battery charging requirements and PV array configuration.

4 Designing and Sizing a Solar Mini-grid

This involves the following considerations to ensure reliable and efficient energy distribution to multiple consumers.

- **Sizing Components Similar to Off-Grid Systems:** Sizing the components of a solar mini-grid follows a similar process to off-grid systems:
 - Determine the power requirements of the mini-grid by assessing the total load from all connected users.
 - Calculate the energy demand by understanding the daily operational hours and usage patterns of all users together.
 - Utilize solar irradiation data to estimate the available sunlight for energy generation.
 - Calculate system losses to ensure accurate component sizing.
 - Select appropriate solar modules, batteries, inverters, and charge regulators based on the calculated requirements.
- **Incorporating Secondary Energy Sources:** Decide whether solar energy will be the sole energy source for the mini grid. If not, design the capacity of the secondary energy source, such as a backup generator or wind turbine, as per the energy requirements.
- **User Point Analysis and Cable Routing:** Perform a thorough study of user points to understand their energy consumption patterns. Design appropriate cable routing and determine the conductor sizing to minimize power losses during energy distribution.

- **External Electrical Protection Devices:** Ensure external electrical protection devices are integrated into the mini-grid design:
 - Decide on protective devices like Miniature Circuit Breakers (MCB), Molded Case Circuit Breakers (MCCB), fuses, and isolators.
 - Integrate a lightning protection system to safeguard the mini grid from lightning strikes.
- **Metering and Billing Mechanism:** Plan for proper meters at all user points to monitor energy consumption accurately. Establish a pre-decided billing mechanism to ensure fair and transparent billing for each user.

5 Major Component Selection

Solar PV module selection: The selection and utilization of PV modules play a crucial role in the efficiency and performance of a solar power system. Key considerations for PV modules cover:

- **Varying Power Generation:** PV modules generate varying power throughout the day and across different seasons due to the changing position of the Sun.



- **Ideal Sun Orientation:** Ideally, PV modules should be positioned to face the Sun's travel path, although they are often practically fixed in specific orientations. Facing the equator and employing a tilt angle close to the location's latitude can optimize energy capture. 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.
- **Degradation Over Time:** PV modules experience degradation over time, resulting in a gradual reduction in their energy output from the time of installation.
- **Impact of Shadows:** Shadows cast on PV modules can have a twofold impact. They not only reduce power generation directly by shading a portion of the module but can also cause permanent damage.
- **Regular Cleaning:** Regular cleaning of PV modules is essential to maintain their efficiency. Accumulation of dirt, dust, and debris can significantly impact energy generation.

The successful utilization of PV modules requires careful consideration of their positioning, orientation, maintenance, and the impact of shading. By aligning the modules to optimize Sun exposure, monitoring degradation, preventing shadows, and ensuring consistent cleaning, the overall performance and lifespan of a solar power system can be effectively managed.

Inverter selection: Choosing the right inverter is a critical decision in designing a solar power system. This section explores the factors to consider when selecting an appropriate inverter. Key factors for inverter selection are as follows:

- **IEC Certifications:** Ensure that the chosen inverter has relevant International Electrotechnical Commission (IEC) certifications for the proposed model and confirm the validity of these certificates.
- **Manufacturer's Track Record:** Evaluate the manufacturer's reputation and track record in producing inverters for specific applications. Consider their years of experience in the industry.
- **Management System Certifications:** Verify if the manufacturer holds ISO certifications for their management systems, indicating their commitment to quality and processes.
- **Warranties:** Check the warranties offered for the inverter. Look for both product warranties (typically a minimum of 5 years, with the option to extend to 10 years) and service warranties (e.g., response time for complaint resolution).
- **Service Centers and Spares:** The presence of accessible service centers and readily available spare parts is crucial for prompt maintenance.

- **Monitoring Capabilities:** Determine whether the inverter offers on-site, remote, or mobile monitoring options for effective system performance tracking.

Selecting the right inverter, solar power system operators can ensure the reliability, efficiency, and longevity of their systems.

PV Array and Inverter Matching: Efficiently matching the PV array with the inverter is a crucial step to ensure optimal system performance, and requires the following key considerations:

- **Matching to Voltage (MPPT) Specification:** The PV strings should be matched to the voltage specification of the inverter's Maximum Power Point Tracking (MPPT) technology. This ensures that the inverter can extract the maximum power from the PV modules, even under varying conditions.
- **Matching to Inverter's Current Rating:** The current output of the PV array should be compatible with the inverter's current rating. This prevents overloading of the inverter and ensures safe operation.
- **Matching to Inverter's Power Rating:** The total power output of the PV array should be within the inverter's power rating. This prevents any power loss and inefficiencies due to underutilization or overloading of the inverter.

Array Mounting Structure - Design & Materials


The design and materials used for the array mounting structure play a pivotal role in the durability and efficiency of solar PV systems.



- **Thermal Aspects:** The array mounting structure should account for the expansion and contraction of both the modules and the structure itself due to temperature changes. This prevents structural stress and potential damage.
- **Corrosion Resistance:** Utilizing corrosion-resistant materials is essential for the longevity of the mounting structure. Corrosion can significantly weaken the structure and affect the overall system integrity.
- **Wind Load Rating:** The mounting structure should be engineered to withstand the maximum expected wind speeds in the installation area. Adequate wind load rating ensures the system's stability during adverse weather conditions.
- **Material Accumulation:** Consideration should be given to potential material accumulation on the PV array, such as snow and ice. Designing the structure to shed accumulated materials prevents excessive load and ensures continuous energy generation.
- **Mechanical Loads:** The array mounting structure must comply with relevant standards to withstand various mechanical loads, including wind, snow, and dynamic forces. Adhering to these standards ensures safety and reliability.
- **Compliance with Codes and Standards:** The support structures and module mounting arrangements should align with applicable building codes, regulations, and industry standards. Additionally, they should meet the specific mounting requirements provided by the module manufacturer.

Key Balance of System (BoS) Components: A successful PV system relies on a well-designed BoS components as follows:

Key BoS Components	Description
DC and AC Cables	Transmit power within the system and to the grid, requiring proper sizing for efficiency.
Array Junction Box/DC Combiner Box	Central point for connecting DC strings, equipped with safety features for efficient management.
Over Current Protection Device	Circuit breakers safeguard against overloads and short circuits, enhancing system safety.
Disconnection Devices	Enable safe isolation of components for maintenance without disrupting the entire system.
Plugs, Sockets, and Connectors	Facilitate maintenance by allowing the isolation of specific components when necessary.
Lightning Protection Device	Protects against lightning strikes, minimizing potential downtime and damage.



Key BoS Components	Description
Earthing and Bonding Arrangement	Ensures safety by preventing electrical shock hazards and maintaining consistent component potential.
Energy Meters	Measure generated energy for performance monitoring and accurate billing.
System Monitoring	Real-time tracking of performance enables timely issue detection and energy generation optimization.
Marking and Signage	Clear labelling and signage provide vital information for technicians and enhance safety.

6 Cable Sizing in Solar PV systems

Efficient cable sizing is a cornerstone of designing solar PV systems for optimal performance and minimal energy loss. Determining the following are key considerations:

- Cable lengths between system components, like panels, inverters, and batteries, play a crucial role in sizing cables.
- For 12V and 24V systems, cable sizes are selected based on current capacity and distance to minimize voltage drop.

- Tools are available to simplify cable sizing, considering cable material resistance, current load, and cable length.



7 Safety Features and Provisions in PV Systems

The role of safety considerations in the design and operation of solar PV systems is described in the table below:

Particular	Functions
Safety Issues – Personnel & System Safety	Protection Against Electric Shock: Maximum installation voltage on buildings is typically 1000V DC to mitigate electric shock risks.
	Protection Against Overcurrent: Systems with multiple parallel strings or external sources like batteries can lead to overcurrent issues. Appropriate protection devices must be incorporated.
	Lightning & Overvoltage Protection: Evaluation of lightning arrestors and surge protection devices is vital to prevent damage from lightning-induced surges.
Minimum Three Earthing's Necessary for	Bonding: Ensures even potentials across an installation.
	Protective Earthing: Establishes a fault current path.


Each Rooftop PV System	Functional Earthing: Enables proper operation of electronic equipment.
	Lightning Protection: Provides lightning pathways.
	Ensuring Safety: Prevents voltage above 50V on metalwork.
Lightning Protection System (LPS)	External Lightning Protection: Involves air-termination, down-conductor, and earth-termination systems for lightning dissipation.
	Internal Lightning Protection: Includes equipotential bonding and surge protection to safeguard against internal surges.
	Separation Distance: Observing safe separation distances to prevent hazardous spark formation.

8 Installation Best Practices

To ensure the smooth and efficient installation of solar PV systems, engineering, procurement and construction (EPC) contractors must be equipped with proper planning and training to avoid common pitfalls. The following table details best practices across different aspects of installation:

Installation Best Practices	Suggestions to Avoid Common Mistakes Solutions
PV Module Installation	<ul style="list-style-type: none"> • Provide adequate clamps and correct positioning to prevent reduced module load-bearing capacity. • Provide sufficient spacing to maintain fixing integrity and warranty. • Tighten the clamp bolts with proper torque tools and avoid any deformity in and damage to the modules. • Tightening module clamp bolts shortly after assembly avoids risks of wind damage.
Mounting Structure	<ul style="list-style-type: none"> • Isolate dissimilar metals to prevent galvanic corrosion. • Prevent deformation during piling to maintain structure integrity. • Ensure accurate pile installation to prevent misalignment.
Civil Works	<ul style="list-style-type: none"> • Suppress dust to prevent dirt accumulation. • Install perimeter fencing to prevent intrusion. • Prevent drains from getting blocked during earthworks. • Manage surface water run-off to avoid flooding. • Don't exceed public track load-bearing capacity.

Installation Best Practices	Suggestions to Avoid Common Mistakes Solutions
	<ul style="list-style-type: none"> • Perform levelling works after installations.
Equipment Enclosures	<ul style="list-style-type: none"> • Seal unused glands and cable conduits. • Maintain gaskets on entrance doors. • Seal cable trenches into inverter housings. • Prevent water ingress to avoid corrosion damage.
Environmental Monitoring	<ul style="list-style-type: none"> • Position pyranometers correctly for accurate performance assessment. • Prevent pyranometer shading to avoid PR calculation inaccuracies.
Cable Management	<ul style="list-style-type: none"> • Pad cables crossing sharp edges. • Ensure proper cable labelling. • Use sufficient cable ties to support spans. • Maintain appropriate cable bending radius. • Adequately bury cables and protect conduit.
Signage	<ul style="list-style-type: none"> • Include health and safety info and emergency contacts. • Label electrical components and perimeter fence. • Identify support structures.
Spare Parts	<ul style="list-style-type: none"> • Provide proper storage for spare components to avoid damage.
Electrical Safety	<ul style="list-style-type: none"> • Ensure compliance with regulations. • Qualify PV modules to latest IEC standards. • Follow available standards for earthing. • Separate lightning arrestor earthing from PV system. • Employ DC overcurrent protection. • Use appropriate DC surge protection. - Class 2 SPD as per IEC 60364-5-53.
Lightning Protection	<ul style="list-style-type: none"> • Comply with lightning protection standards. • Install dedicated system for larger PV systems.
Ingress Protection	<ul style="list-style-type: none"> • Maintain IP65 rating for outdoor-installed PV equipment.



In conclusion, the successful installation of solar PV systems requires a comprehensive understanding of key components, design principles, safety measures, and best practices. By carefully considering factors such as module selection, inverter matching, cable sizing, and adherence to safety standards, practitioners can ensure the optimal performance and reliability of the system. Attention to detail during installation, from module positioning to cable management, can prevent common mistakes and potential system failures. By implementing these guidelines, solar energy projects can achieve their intended goals of sustainability, energy efficiency, and a positive environmental impact.

Reading Material

1. *Utility Scale Solar Power Plants – A Guide for Project Developers and Investors* by International Finance Corporation
<https://documents1.worldbank.org/curated/en/868031468161086726/pdf/667620WP00PUBL005BoSOLARoGUIDEoBOOK.pdf>
2. *Handbook for Rooftop Solar Development in Asia* by Asian Development Bank
<https://www.adb.org/sites/default/files/publication/153201/rooftop-solar-development-handbook.pdf>
3. *Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition* by National Renewable Energy Laboratory
<https://www.nrel.gov/docs/fy18osti/68469.pdf>