

Module Outline

# PROTECTION AND MAINTENANCE OF PV SYSTEMS





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## Relevance and Background

As solar energy continues to gain prominence in the global energy landscape, proper O&M practices are essential to maximize the return on investment and sustain reliable energy generation from solar PV plants. This module also addresses the growing need for skilled professionals in the field of solar plant O&M, emphasizing cost-effective strategies.

The importance of O&M is underscored by its impact on various aspects of solar plants. By consistently implementing maintenance routines, operators can enhance energy output, prolong the lifespan of components, and safeguard the profitability of the plant. On the other hand, neglecting O&M can lead to decreased efficiency, increased downtime, and potential safety hazards.

Safety is paramount in O&M activities, as emphasized by the document's focus on HEALTH & SAFETY during O&M. Adhering to safety protocols, providing comprehensive training, and maintaining emergency response plans ensures the well-being of O&M personnel and minimizes operational risks.

Theme – Technical

Competency – Electrical

Code of the Module – To2Co3M11

## Learning Outcomes

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

- Understand the importance of O&M in solar PV plants and its impact on cost efficiency.
- Identify common defects and issues in solar PV systems (after commissioning) and assess their cost implications.
- Implement preventive and corrective maintenance strategies while considering downtime and repair costs.
- Conduct performance monitoring, data analysis, and cost-effective decision-making.
- Apply safety protocols, industry best practices, and relevant standards in O&M.
- Identify different devices and facilities in the circuitry and plant for its effective lifetime protection.

## Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M11 LO1	Lecture on Protection and Maintenance of PV Systems

## M11 L01: Lecture Presentation

The lecture will include an "Operation and Maintenance (O&M) of Solar PV Plants" document, which provides a comprehensive overview of key considerations for ensuring the efficient and sustainable performance of solar plant installations. The document emphasizes the significance of O&M practices throughout the lifecycle of solar plants, highlighting the critical role for maximizing energy generation, mitigating risks, and optimizing returns on investment.

Proposed indicators and performance metrics, such as capacity utilization factor (CUF), performance ratio (PR), and inverter efficiency, guide effective decision-making and performance evaluation. These indicators enable operators to monitor plant health, identify deviations, and proactively address potential issues.

The document delves into the different levels of O&M, including preventive, corrective, and predictive maintenance. It emphasizes the significance of Failure Mode and Effect Analysis (FMEA) and Root Cause Analysis in identifying potential failure modes, evaluating their impact, and addressing underlying causes to prevent recurrence.

Cost Priority Number (CPN) and Risk Priority Number (RPN) calculations prioritize maintenance efforts based on potential risks, contributing to effective resource allocation. The document also outlines various activities within O&M, such as visual inspections, cleaning, inverter maintenance, and cable inspections. Major tests, including I-V curve analysis and thermography, are highlighted as crucial steps to ensure optimal plant performance.

Component-wise O&M, including module maintenance, inverter testing, and cable inspections, is explained in detail. The importance of Remote Monitoring System (RMS) maintenance is stressed, underscoring the role of accurate data in effective decision-making.

In conclusion, the document provides a comprehensive understanding of the multidimensional nature of O&M for solar PV plants. By adhering to safety protocols, utilizing performance indicators, and implementing effective maintenance strategies, operators can ensure consistent energy generation, extend component lifespans, and maximize the financial benefits of solar power installations.

## Key Topics to be Covered

1. Protection Systems in PV Plants
2. Lifecycle of Solar Plants
3. Importance of Maintenance for Solar Power Plants
4. Proposed Indicators in O&M
5. O&M Contractor KPIs
6. Uptime Calculation
7. Types of Maintenance
8. Different O&M Activities
9. Component-wise O&M
10. Health & Safety during O&M
11. Troubleshooting
12. Calculation of Cost Priority Number (CPN) and Risk Priority Number (RPN)



### 13. Challenges in O&M

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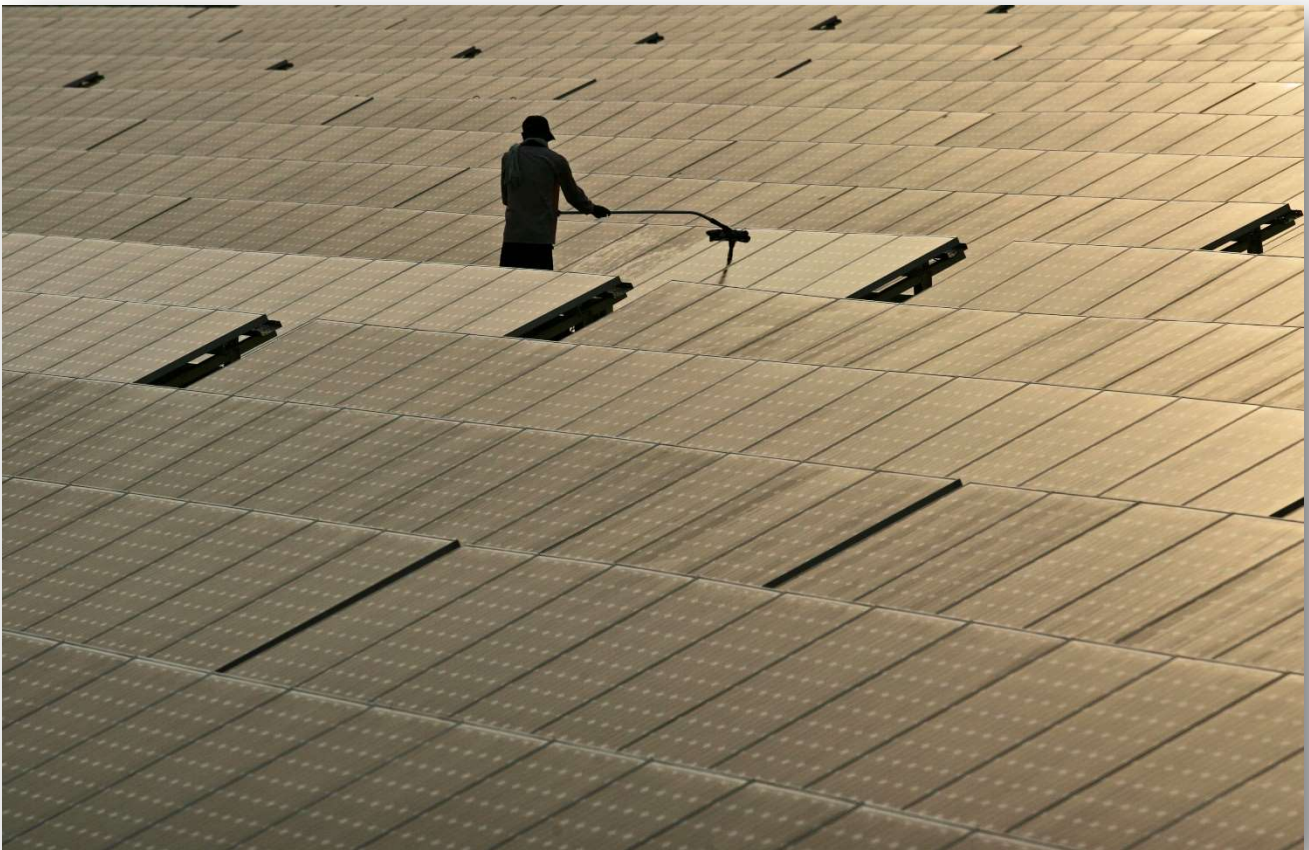
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## 1 Introduction

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Operation and Maintenance (O&M) is a critical aspect for ensuring the long-term efficient performance and profitability of solar PV plants. O&M practices involve regular inspections, monitoring, cleaning, and repairs to maximize energy generation, mitigate risks, and optimize return on investment. Neglecting O&M can result in decreased energy output, increased downtime, and



potential safety hazards.

## 2 Protection Systems in PV Plants

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There are five types of electrical protection systems in the PV plant that include over-current, over-voltage (surge), earthing against fault current, lightning protection system, and anti-islanding. All these are mandatory under different international standards.

This is a repetition overview of these systems in the plant to reiterate their importance over the life of the plant. Also, these are to be maintained throughout, a point that has been detailed in other modules elsewhere.

Ground-based projects are more preferred for remote locations where there may not be any residential population, and therefore the safety and security of the plant needs special attention. These involve physical protection systems like fencing, security personnel, and also cameras, sensors, warnings and night vision cameras and so on.

### 3 Lifecycle of Solar Plants

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The lifecycle of a solar plant encompasses several phases, including development, construction, operation, and decommissioning. While O&M activities are primarily focused on the operational phase, they significantly impact the overall lifecycle. Effective O&M practices during the operational phase contribute to prolonged plant lifespan and consistent energy production.



### 4 Importance of Maintenance for Solar Power Plants

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#### 4.1 Maximizing ROI and Energy Generation

Thorough and consistent O&M practices ensure that solar modules operate at their highest efficiency, maximizing energy production and revenue generation. The investment made in a solar plant can yield substantial returns through proper maintenance, making it imperative to optimize energy output.

## 4.2 Ensuring Longevity and Efficiency

Regular cleaning, inspections, and timely repairs contribute to the longevity and efficiency of solar PV systems. Removing dirt, debris, and identifying defects prevent performance degradation, ensuring that the plant continues to operate at its peak potential.

## 4.3 Mitigating Risks and Failures

Neglected maintenance can lead to unexpected failures, system malfunctions, and safety hazards. Proactive O&M practices help identify and address potential issues before they escalate, reducing downtime and minimizing the financial impact of repairs.

# 5 Proposed Indicators in O&M

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Effective O&M involves continuous monitoring of critical parameters such as module temperature, energy production, and system performance. Regular reporting and data analysis provide insights into trends, deviations, and potential issues.

Key Performance Indicators (KPIs) like Capacity Utilization Factor (CUF), Performance Ratio (PR), and Inverter Efficiency offer quantitative assessments of plant performance. Tracking these indicators enables data-driven decision-making for maintenance and optimization efforts.

## 5.1 Capacity Utilization Factor (CUF)

CUF measures the actual energy generated compared to the energy that could be generated under ideal conditions. Monitoring CUF helps evaluate how effectively the plant operates throughout the year.

## 5.2 Performance Ratio (PR)

PR assesses the efficiency of energy conversion from sunlight to electricity. By comparing actual energy production to expected production, PR indicates how well the system is performing.

## 5.3 Inverter Efficiency

Inverter efficiency reflects the conversion efficiency of DC to AC power. Monitoring inverter efficiency ensures optimal power conversion and contributes to overall system efficiency.

# 6 O&M Contractor KPIs

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## 6.1 Role of O&M Technicians and Engineers

O&M professionals play a crucial role in executing maintenance tasks, ensuring system reliability, and promptly addressing issues. Their expertise contributes to effective O&M practices.

## 6.2 Reliability and Responsiveness

O&M contractors must exhibit proactiveness in promptly responding to issues and scheduling maintenance activities. Their ability to address concerns efficiently minimizes downtime and ensures consistent performance.



## 6.3 Adherence to Schedule and Quality Standards

Contractors are responsible for adhering to scheduled maintenance tasks and upholding industry standards. Thorough documentation, quality checks, and adherence to guidelines ensure the effectiveness of maintenance efforts.

## 7 Uptime Calculation

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### 7.1 Determining Availability and Downtime

Uptime refers to the portion of time that the solar plant is operational. Downtime includes scheduled maintenance and unscheduled interruptions due to failures or repairs.

### 7.2 Calculating System Uptime

System uptime is calculated by dividing the total operating time by the total possible operating time and multiplying by 100%. High uptime percentages reflect efficient O&M practices and minimal interruptions.



## 8 Types of Maintenance

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There are generally three types of maintenance – preventive, corrective and predictive. Preventive maintenance involves scheduled inspections, cleaning, and minor repairs to prevent potential failures. Regular maintenance reduces the likelihood of unexpected issues. Corrective maintenance focuses on addressing failures as they occur, promptly restoring normal operation and minimizing downtime. Swift intervention prevents revenue losses. Finally, predictive maintenance utilizes data analytics to predict potential failures before they happen. This proactive approach enables timely intervention and minimizes unexpected disruptions.

## 9 Different O&M Activities

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### 9.1 Major Tests before Action

I-V curve analysis helps to detect module defects, shading issues, or performance deviations. Analyzing these curves enables targeted maintenance efforts.

Thermography identifies hotspots in panels, indicating potential issues. String testing evaluates individual string performance, identifying underperforming strings.

Ensuring compliance with power quality standards and grid requirements is vital for grid stability. Regular power quality tests maintain grid connectivity and reliability.

### 9.2 Visual Inspections and Monitoring

Regular visual inspections identify visible defects and anomalies. Monitoring system performance through visual assessments contributes to early issue identification.

### 9.3 Cleaning and Panel Maintenance

Cleaning solar panels from dirt and debris optimizes energy generation. Regular cleaning prevents shading and maximizes energy yield.

### 9.4 Inverter and Electrical System Checks

Monitoring and testing inverters and electrical systems ensures proper functioning and early detection of anomalies. Prompt intervention prevents system-wide failures.

### 9.5 Recommended Schedule for O&M

The table below outlines the regular activities for O&M of the plant with their recommended periodicity, which may vary slightly due to actual site conditions.

Component	Activity	Description	Interval	By
PV Module	Cleaning	Clean any bird droppings/dark spots on modules.	Immediately	User/Technician
	Cleaning	Clean PV modules with plain water or mild dishwashing detergent. Do not use brushes, any types of solvents, abrasives, or harsh detergents.	Fortnightly or as per the site conditions	User/Technician
	Inspection (for plants >100 kWp)	Use infrared cameras to inspect for hot spots; bypass diode failure.	Annual	Technician
PV Array	Inspection	Check the PV modules and rack for any damage. Note down location and serial number of damaged modules.	Annual	User/Technician
	Inspection	Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible.	Annual	User/Technician
	Vermin Removal	Remove bird nests or vermin from array and rack area.	Annual	User/Technician
Junction Boxes	Inspection	Inspect electrical boxes for corrosion or intrusion of water or insects. Seal boxes if required. Check position of switches and breakers. Check operation of all protection devices.	Annual	Electrician
Wiring	Inspection	Inspect cabling for signs of cracks, defects, loose connections, overheating, arcing, short or open circuits, and ground faults.	Annual	Electrician
Inverter	Inspection	Observe instantaneous operational indicators on the faceplate of the inverter	Monthly	Electrician

		to ensure that the amount of power being generated is typical of the conditions. Inspect inverter housing or shelter for physical maintenance, if required.		
Inverter	Service	Clean or replace any air filters.	As needed	Electrician
Instruments	Validation	Spot-check monitoring instruments (pyranometer, etc.) with standard instruments to ensure that they are operational and within specifications.	Annual	PV Specialist
Transformer	Inspection	Inspect transformer oil level, temperature gauges, breather, silica gel, meter, connections, etc.	Annual	Electrician
Tracker (if present)	Inspection	Inspect gears, gear boxes, bearings, etc. as required.	Annual	Technician
	Service	Lubricate tracker mounting bearings, gear boxes, etc. as required.	Bi-annual	Technician
Plant	Monitoring	Daily operation and performance monitoring.	Daily	Site In-charge
Spare Parts	Management	Manage inventory of spare parts.	As needed	Site In-charge
Logbook	Documentation	Document all O&M activities in a workbook available to all service personnel.	Continuous	Site In-charge



## 10 Component-Wise O&M

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### 10.1 Module Maintenance and Cleaning

Regular module cleaning enhances energy generation by eliminating dirt and debris. Cleaning schedules should be aligned with local environmental conditions.

### 10.2 Maintenance of Mounting and Racking Systems (MMS)

Inspecting MMS for corrosion, structural integrity, and proper alignment is crucial. Well-maintained MMS ensures stable and optimal module orientation.

### 10.3 Inverter Maintenance and Testing

Inverter maintenance involves regular inspections, cleaning, and firmware updates. Inverter testing validates proper operation and optimal energy conversion.

### 10.4 Cable and Wiring Inspections

Inspecting cables and wiring for damage, wear, and proper connections prevents electrical issues and safety hazards. Prompt repairs maintain electrical integrity.

### 10.5 Earthing System Maintenance

Maintaining the integrity of the earthing system is essential for safety and system stability. Regular testing ensures effective grounding and minimizes electrical risks.

### 10.6 Remote Monitoring System (RMS) Maintenance

RMS monitoring provides real-time insights into system performance. Regular maintenance of the RMS ensures accurate data collection and reliable reporting.

Validating data from the RMS ensures that performance analysis and decisions are based on accurate information. Reliable data enhances the effectiveness of O&M efforts.

## 11 Health & Safety during O&M

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### 11.1 Safety Protocols and Guidelines

Safety is paramount in O&M activities. Following established safety protocols and guidelines, such as wearing appropriate personal protective equipment (PPE), practicing lockout/tagout procedures, and adhering to safe work practices, safeguards O&M personnel from potential hazards.

## 11.2 Training and Protective Measures

O&M personnel should receive comprehensive training in safety procedures and hazard identification. Implementing all protection measures, electrical safety protocols, and proper handling of equipment enhances the safety of all personnel involved.

## 11.3 Emergency Response Procedures

Well-defined emergency response plans, equipped with firefighting equipment, first aid kits, and evacuation routes, ensure that O&M personnel are prepared to address unforeseen emergencies promptly and effectively.



## 12 Troubleshooting

### 12.1 Failure Mode and Effect Analysis (FMEA)

FMEA involves analysing system components to identify potential failure modes. Each failure mode is evaluated for its effects on the overall system.

Potential failure modes are assessed based on their impact and likelihood. Prioritizing high-impact, high-likelihood failure modes ensure resources are allocated effectively.



## 12.2 Root Cause Analysis

Root cause analysis identifies the underlying factors contributing to failures. By addressing these factors, the likelihood of recurring failures is minimized.

## 13 Calculation of Cost Priority Number (CPN) and Risk Priority Number (RPN)

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### 13.1 Assessing Maintenance Priorities

CPN is calculated by combining factors such as severity, frequency, and detectability. RPN is calculated by multiplying CPN with the likelihood of failure. Higher values indicate higher priority.

### 13.2 Prioritizing Risks for Mitigation

High CPN and RPN values highlight critical issues that need immediate attention. Prioritizing these risks ensures that resources are allocated to mitigate the most significant threats.

## 14 Challenges in O&M

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The remote locations of ground-based plants and scattered nature of DRE plants may pose some challenges in planning and executing O&M activities.

Multi-megawatt projects are spread over thousands of acres and require security as well as civil, electrical and mechanical maintenance activities to be carried out frequently. Manpower for most of these activities are normally sourced locally to provide employment. Highly skilled manpower may not be easily available, but with newer techniques of online and remote monitoring, these issues are being addressed to an extent.

The DRE usually consists of small individual capacities of plant spread out over a city or region, and is normally maintained by a single team moving around these plants as per the planned schedule. Access to the site, working at heights, and improper spacing between rows may pose other challenges to the O&M activities.

The onus is therefore on the management to supervise the work and schedule, and provide technical backup support whenever necessary, so that optimum plant performance is maintained.



## 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>