**Solar Electric Technician Training**

**Module 6: Testing and commissioning**

**Section 1**

**Testing and commissioning of three-phase solar photovoltaic systems**

**Introduction:** This section provides vocational trainees with essential steps and considerations for testing and commissioning three-phase on-grid solar photovoltaic (PV) systems. The goal is to ensure the system operates safely and efficiently.

**What is testing and commissioning?**

Testing and commissioning is a methodical procedure for documenting and testing the performance of technical systems to verify that the system operates in conformity with the design intent [1].

**Steps for testing and commissioning (T&C)**

1. **Preparation**

* **Review installation documentation*:*** Ensure all installation manuals, single line diagrams (SLD) and wiring diagrams are thoroughly reviewed and understood.
* **Gather Tools***:* Collect all the necessary tools (multimeter, measuring tape, inclinometer, Global positioning system, earth tester, handheld pyranometer etc.) and ensure they are in good working conditions.
* **Team coordination:** Confirm that all the team members are on-site and aware of their roles and responsibilities.

1. **Pre-commissioning checks and visual inspection**

Before any testing or commissioning, perform the following checks:

* 1. **Safety measures**
* Always wear Personal Protective Equipment (PPE): gloves, goggles, helmet, and safety boots.
* Ensure all DC and AC isolators are turned off before beginning work.
* Verify isolation from the grid to prevent electrical shock or back feed from the inverter.

1. **Visual inspection**

Inspect all the components for physical damage, proper alignment and secure connection as:

* **Solar Panels:** Inspect the modules for physical damage (cracks, dirt, shading, etc.).
* **Cables:** Check for wear, damage, or loose connections on DC and AC cables.
* **Inverter:** Ensure it is securely mounted with adequate ventilation.
* **Grounding:** Confirm all metal components and the inverter are grounded correctly.
* **Combiner box:** Check that the wiring is secure and properly labelled.

1. **Wiring integrity tests**

* **Continuity tests:**Use a multimeter to check for continuity in all wiring.
* Polarity Check Confirm correct DC polarity (positive and negative connections) using a multimeter for voltage and current checks: Measure voltage at various points in the system to ensure proper functionality. This includes checks on both DC and AC side.

1. **Testing the DC side**
   * 1. **Open circuit voltage (Voc)**

* Measure the open-circuit voltage of each string using a multimeter.
* Compare the measured voltage with the manufacturer’s specifications. Note: Voc increases in cold weather and decreases in hot weather.
  + 1. **Short circuit current (Isc)**
* Using a clamp meter, measure the short-circuit current of each string.
* Compare the measured Isc with the panel’s datasheet.
* Safety note: Avoid prolonged contact when measuring Isc as it involves high currents.

1. **Insulation resistance test**

* Perform insulation resistance tests on DC cables (positive to ground and negative to ground) using an insulation resistance tester.
* The resistance should be above 1 MΩ to ensure the system is safely insulated.

1. **Testing the AC side**
   * 1. **AC voltage and frequency**

* Measure the grid voltage and frequency between phases (L1, L2, L3) and neutral using a multimeter.
* Confirm that grid voltage is within allowable range (typically 400V ±10%).
* Ensure the grid frequency matches the inverter's operational limits (50Hz).
  + 1. **Check AC connections**
* Inspect the inverter’s AC connections, ensuring proper cable sizing and that all terminals are tight.

1. **Components functionality checks**

* **PV modules:** Verify voltage and current output.
* **Inverters:** Check input and output voltages, and ensure they are functioning as specified.
* **Charge controllers:** Confirm settings and operational status.
* **Batteries:** Measure voltage and state of charge, and check connections.
* **Water pumps and controllers**: Conduct operational tests.

1. **Inverter start-up and testing**
   * 1. **Power up the system**

* Turn on the DC isolator and AC breakers.
* Observe the inverter start-up sequence. It should display grid voltage, DC input voltage, and begin synchronization.
  + 1. **Monitor system performance**
* Check the inverters display or use commissioning software to monitor DC input voltage, current, and power.
* Monitor AC output voltage, current, and power, ensuring values align with expected outputs.

1. **Connections inspections of earthing/grounding and protection devices**

* Earthing connections: Ensure all grounding connections are secure and comply with safety standards. Ensure the systems earthing is correct, with proper bonding of all metal components to avoid electric shock.
* Protection devices: Check that all fuses and circuit breakers are properly installed and functioning.

1. **Metering and grid integration test**

* Net metering functionality: Test to confirm accurate measurement of energy exported to the grid.
* Anti-islanding tests: Verify that the system disconnects from the grid during outages.

1. **System Performance testing and validation**
   1. **Output power measurement**

* Measure the inverter’s AC output current using a clamp meter and compare it to the power displayed on the inverter.
  1. **Solar irradiance comparison**
* Use a solar irradiance meter to measure sunlight at the time of commissioning.
* Compare the system’s output to the expected performance based on the irradiance, panel specifications, and temperature.
  1. **Optional**
* I-V Curve Tracing: Use an I-V curve tracer to analyse the performance characteristics of the solar panels. This provides detailed diagnostics of the panel’s output.

1. **Troubleshooting common issues occurred during T&C**
   1. **Low voltage on DC side**

* Check for shading, loose connections, or damaged PV modules.
  1. **Inverter not syncing with grid**
* Ensure the grid voltage and frequency are within acceptable ranges.
* Check that the AC wiring is connected correctly and phase sequence is correct.
  1. **Low power output**
* Inspect for any shading, dirt, or module damage affecting the solar panels.
* Measure and compare the solar irradiance and panel efficiency to expected performance.

1. **Final commissioning steps**
   1. **Check for errors**

* Review the inverter display for any error codes or warnings.
* Resolve any issues before proceeding to the final step.

## Grid connection

* Once the system passes all tests, connect the inverter to the grid.
* Verify the inverter is exporting power to the grid.

## Labelling

* Ensure all components, cables, and isolation points are clearly labelled according to local standards.

## Documentation

* Record results: Document all test results, findings, and any corrective actions taken.
* Complete checklists: Ensure all T&C checklists are filled out accurately.
* Submit the commissioning report to the supervising authority.

1. **Final review & handover**

* Team debriefing: Conduct a final review with the installation team to discuss findings and ensure all tasks are completed.
* Client handover: Prepare for the handover to the client, including providing documentation and performance metrics.

1. **Post-commissioning follow-up**

* Schedule maintenance: Discuss future maintenance requirements and schedule follow-up visits if necessary. Schedule regular system checks (annually or bi-annually) to inspect panel conditions, wiring, and inverter performance.
* Feedback collection: Gather feedback from the team and stakeholders for continuous improvement.

1. **Monitoring system performance**

* Monitor system performance via remote monitoring tools (if available) to detect any issues early.

By following these steps, you will ensure a thorough and effective testing and commissioning process, leading to a well-functioning solar PV system. Always adhere to local electrical codes and safety protocols when working with PV systems.

**For further reading:**

1. Solar PV installation manuals (provided by the inverter and panel manufacturers).

2. Local grid connection and safety regulations.

# **References**

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| [1] |  | The Engineering Toolbox, “Commissioning,” The Engineering Toolbox, 2005. [Online]. Available: https://www.engineeringtoolbox.com/commissioning-d\_870.html. [Accessed 21 September 2024]. |

**Required tools for T&C**

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| Global Positioning System  (GPS)  *To gather location data* | Graphical user interface  Description automatically generated  Earth tester  *To verify the quality of earthing* |
| Handheld Clamp Meter, Measuring Tool Handheld Ammeter Electronic ...  Clampmeter (Ammeter and Voltameter)  *To measure voltage and current* | Handheld pyranometer  *To evaluate the performance of a system at a given time* |
| Inclinometer  *To measure tilt of solar panels and verify inclination of other structures in the system* | Vinex Open Reel Measuring Tape 30mStanley (STHT36125-812) 3Meter Measuring Tape  Measuring tape  *To measure the dimensions such as solar array area, panel height, ground clearance etc.* |

**Section 2  
Common wiring faults and hazards in three-phase solar photovoltaic (PV) systems**

**Introduction:** In three-phase solar photovoltaic (PV) systems, proper wiring is crucial for the system's efficiency, safety, and longevity. Common wiring faults can arise during installation or operation and may lead to serious hazards. Understanding these issues is essential for safe and effective system performance. This section outlines typical wiring faults and their associated hazards.

1. **Common wiring faults**

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| **Common wiring faults** | **Explanation** | **Causes** | **Impacts** |
| **Loose connections** | Loose connections between wires, terminals, and components can occur during installation or due to vibration and environmental wear over time. | * Poor initial tightening. * Expansion and contraction of metal parts due to temperature changes. * Vibration or mechanical stress on cables. | Loose connections can cause increased resistance, leading to:   * Overheating of cables or terminals. * Reduced power efficiency. * Potential arcing or sparking. |
| **Incorrect polarity** | In DC circuits, polarity (positive and negative) must be correctly wired. Reversed polarity is one of the most common faults in PV systems. | * Incorrect wiring during installation. * Inadequate labelling of positive and negative terminals. | * Damage to system components such as inverters, charge controllers, and batteries. * Possible failure of the system to generate power. * Risk of electrical shock. |
| **Inadequate or incorrect grounding** | Grounding ensures safety by providing a path for electrical faults to discharge safely into the earth. Improper grounding can lead to dangerous faults. | * Incomplete or poor grounding connections. * Using improper materials (wrong gauge wire, corrosion-prone materials). | * Higher risk of electric shock to personnel. * Potential for damage to equipment during a lightning strike or power surge |
| **Crossed or incorrectly wired phases** | In three-phase systems, it is critical that each phase is correctly connected to prevent imbalance and ensure proper functioning. | * Mislabelling or misunderstanding of phase connections (R, Y, B or L1, L2, L3). * Incorrect connection to inverters or AC distribution panels. | * Imbalanced load on the inverter and electrical system. * Reduced power quality or system efficiency. * Overheating or damage to the inverter. |
| **Short circuits** | A short circuit occurs when live wires (positive and negative) come into contact directly or through a conducting material, creating a direct path for the current. | * Faulty insulation or damaged cables. * Loose or exposed conductors touching metal surfaces. | * Potential fire hazard. * Damage to PV panels, inverters, and other components. * Sudden system shutdown or tripping of circuit breakers. |

1. **Potential hazards**

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| **Potential hazards** | **Causes** | **Risks** |
| **Electrical shock** | Incorrect wiring, ungrounded systems, or exposed conductors | * High voltages in PV systems can cause severe injury or death. * Even low DC voltage from PV arrays can cause serious shock if not properly insulated or handled. |
| **Fire hazard** | Loose connections, short circuits, or overheated wires | * Arcing from loose connections can lead to fires. * Overheated cables from high resistance can ignite nearby materials |
| **Damage to equipment** | Reversed polarity, incorrect phase wiring, or short circuits. | * Inverters, batteries, and other components can be permanently damaged. * Warranty voids if improper wiring is determined as the cause. |
| **Reduced system efficiency** | Incorrect phase connections or loose wiring. | * System will not operate at full capacity. * Increased operational costs due to inefficiency. |
| **Ground faults** | Damaged insulation or conductive material contact with metal surfaces | * Can lead to dangerous electrical conditions. * If undetected, may cause slow damage to the PV system. |

1. **Preventive measures**

* Ensure tight connections: Regularly check all electrical connections for tightness.
* Proper labelling: Always label cables and terminals clearly to avoid confusion during installation and maintenance.
* Use correct polarity: Double-check the polarity of the DC side of the system to prevent reversed connections.
* Verify grounding: Ensure that the grounding system is robust and the desired earth resistance value is met.
* Regular inspections: Conduct routine inspections of wiring, insulation, and connections to detect and fix any potential problems early.

**Conclusion**

Proper wiring and regular maintenance of three-phase solar PV systems are essential for safety, efficiency, and reliability. By understanding common wiring faults and potential hazards, installers and operators can ensure the safe and effective operation of these systems.

**Section 3**

**Key functions and metering systems in three-phase solar photovoltaic (PV) systems**

Introduction: This section provides an overview of essential functions and metering systems in three-phase solar PV installations, particularly focusing on net metering, the anti-islanding function, and the installed metering systems required to comply with regulatory and technical standards. Understanding these aspects is crucial for safe, efficient, and legally compliant installation and operation of solar PV systems.

1. **Net metering function**

**What is net metering?**

Net metering is a billing mechanism that allows solar PV system owners to send excess electricity generated by their system back to the grid. When the system generates more energy than the home or business uses, the surplus is exported to the grid, and the owner receives credit for it. During periods when the system generates less energy than needed, electricity is drawn from the grid, and the credits can offset the cost.

**How net metering works?**

* Energy export to the grid: When your solar system generates more electricity than is consumed on-site, the excess electricity flows into the grid.
* Energy import from the grid: When solar production is insufficient (e.g., during the night or cloudy days), electricity is imported from the grid.
* Billing and credits: The utility company installs a bidirectional meter to record the energy imported from and exported to the grid. Customers are billed based on the net energy use, i.e., the difference between energy imported and exported.

**Benefits of net metering**

* Cost savings: Solar PV owners reduce their electricity bills by earning credits for excess energy sent to the grid.
* Incentives for renewable energy: Net metering encourages more widespread adoption of renewable energy systems by providing financial incentives.
* Efficient energy use: It helps reduce the load on the power grid, especially during peak solar generation times.

**Regulatory requirements for net metering**

* Eligibility: Not all locations allow net metering. Regulatory bodies determine which customers are eligible based on the system size and energy production.
* Limitations: There may be a cap on the amount of electricity that can be credited to a solar owner’s account.
* Bidirectional metering: A utility-grade bidirectional meter is required to measure energy flow in both directions accurately.

1. **Anti-islanding function**

**What is Islanding?**

Islanding occurs when a solar PV system continues to power a local circuit or area even though the grid power has been shut down. This can pose significant risks to utility workers, damage equipment, and create hazardous conditions.

**Anti-Islanding function**

To prevent islanding, grid-connected solar inverters are equipped with an anti-islanding function. This feature automatically detects when the grid power is lost and immediately disconnects the PV system from the grid.

**How Anti-Islanding works?**

* Grid Monitoring: The inverter continuously monitors the grid’s voltage and frequency.
* Disconnection on Grid Failure: If the inverter detects a significant deviation from normal grid conditions (e.g., voltage drop or loss of frequency), it will automatically disconnect the solar system from the grid.
* Reconnection: The system will reconnect once the grid power is restored and stable, ensuring that electricity flows safely.

**Importance of Anti-Islanding**

* Safety: Prevents solar-generated power from feeding back into a de-energized grid, protecting utility workers and the public from electric shock during maintenance or repairs.
* Compliance with Regulations: Most national electrical codes and grid standards (like IEEE 1547 or IEC 62116) require solar systems to have anti-islanding protection to operate safely within the utility network.
* Equipment Protection: Protects both the solar PV system and grid infrastructure from damage that could occur if the system continues operating during an outage.

**Testing and Regulatory Compliance**

* Compliance Testing: Solar inverters must be tested and certified to meet the anti-islanding requirements of relevant standards (e.g., UL 1741 for the U.S.).
* Verification: During installation, the anti-islanding functionality is often verified as part of the commissioning process.

1. **Installed metering systems to meet regulatory and technical requirements**

**Types of meters in solar PV systems**

There are typically two types of meters installed in grid-tied solar PV systems:

* 1. **Bidirectional meter (net meter)**
* Function: Measures the electricity flowing in two directions: from the grid to the customer (imported energy) and from the solar PV system to the grid (exported energy).
* Requirement: This is the main meter used for net metering purposes, recording both consumption and export for billing.

**2. Generation meter**

* Function: Measures the total amount of electricity generated by the solar PV system.
* Requirement: Often required for system monitoring and reporting, especially for regulatory bodies or incentive programs (e.g., Feed-in Tariff or Renewable Energy Credits).

**Metering system design and setup**

* Installation location: Meters must be installed at points where the grid interfaces with the consumer’s electrical system, ensuring accurate measurement of energy flows.
* Accuracy: Installed meters must meet the accuracy requirements specified by regulatory bodies (typically Class 1 or Class 2 accuracy for revenue meters).
* Tamper-proofing: Meters should be tamper-resistant and sealed to prevent unauthorized access and manipulation of readings.

**Regulatory and technical compliance**

* Grid code compliance: The installed metering systems must comply with local utility grid codes and standards, which dictate the specific type of metering, accuracy, and data reporting protocols.
* Data monitoring: In some cases, advanced meters (smart meters) that can transmit real-time data to the utility for monitoring energy production, consumption, and system performance are required.
* Certification: Meters and solar systems must be certified by relevant authorities to ensure compliance with regulatory requirements (e.g., local energy commissions, ISO standards, etc.).

**Data reporting**

* Remote monitoring: Modern smart meters often come with remote monitoring capabilities, allowing both the system owner and utility companies to track energy usage and production in real time.

**4. Summary of key requirements**

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| **Function** | **Key features** | **Regulatory compliance** |
| Net metering | Measures energy exported to and imported from the grid. Customers receive credits for excess energy sent to the grid. | Utility grid codes, and bidirectional meters |
| Anti-Islanding | Automatically disconnects the solar PV system from the grid when grid power is lost to prevent dangerous conditions. | Inverter standards like IEEE 1547, UL 1741, IEC 62116 |
| Installed metering | Includes bidirectional meters for net metering and generation meters for measuring solar production. Must be accurate, tamper-proof, and certified. | Grid code compliance, smart meter requirements, data reporting protocols |

**Conclusion**

A clear understanding of the net metering function, anti-islanding safety features, and proper installation of compliant metering systems is essential for the safe and efficient operation of three-phase solar PV systems. These systems must meet all regulatory and technical requirements to ensure safety, performance, and legal compliance.