Module Outline

STANDARDS, PERFORMANCE INDICATORS AND CERTIFICATION

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Relevance and Background

Good and continued system performance is paramount in getting the desired economic results from the PV system. Complying with national and international standards at the component and system level, and even in the operation phase of the system, is crucial for designers, installers and O&M engineers.

Once a high-quality system is ensured by adhering to these standards, it is equally important to conduct periodical tests on the systems to ensure that the performance is up to the expectations of the designers, investors and consumers.

Reliable testing and commissioning practices are pivotal to ensure the efficiency, safety, and compliance of solar PV systems.

Theme – Technical
Competency – Others
Code of the Module – T02C05M16

Learning Outcomes

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

- Understand important international standards of PV system components
- Identify and understand key factors influencing solar PV system performance
- Evaluate performance indicators to assess system efficiency
- Grasp the significance of thorough testing and commissioning in solar PV systems
- Acquire proficiency in diverse testing techniques for different system components
- Interpret and analyse performance metrics for optimal system functionality

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M16 L01	Lecture on Standards, Performance Indicators and Certification

M16 L01: Lecture Presentation

- The presentation in the first part lists all the international standards for system components, grid connectivity, and also during the operation and maintenance (O&M) period.

- The presentation then introduces the concepts of Capacity Utilization Factor (CUF) and Performance Ratio (PR) to validate predicted energy output against actual performance. These performance indicators (CUF and PR) and the probability values (P50/P75/P90) are introduced as metrics for evaluating system efficiency and energy production certainty. The influence of module selection, degradation considerations, and warranties on system performance is discussed. Also, the importance of simulation software is explained.
- The presentation also equips participants with the expertise needed to ensure the optimal performance and safety of solar PV installations. They will learn diverse testing techniques for components like solar modules, inverters, and cables. Safety protocols, performance metrics interpretation, and compliance with technical standards are emphasized.
- The presentation covers solar module tests, string testing, inverter evaluations, technical standards for grid connectivity, and the Unintentional Islanding Functionality Test. By the end of the presentation, participants will possess the skills to effectively validate, optimize, and secure the operation of solar PV systems in an evolving energy landscape.

Key Topics to be Covered

1. Standards
2. System Performance - Indicators
3. System Performance - Factors that Affect Performance
4. System Performance - Importance of Software
5. System Testing and Commissioning
6. Certification of Components

Table of Contents

1 Introduction

International standards have been developed by agencies after a series of consultations with various stakeholders like academicians, designers, engineers, researchers, and technical experts in the field of PV products and components. These standards must be complied with in the PV systems deployed anywhere in the world so that the consumers, grid engineers, the power grid itself, and investors get optimum output from the systems.

At the time of commissioning of these systems it is important to test these thoroughly before synchronizing with the grid. For off-grid systems, the component testing and connections, and operational testing are important so that the charging/discharging cycles and system performance are optimized throughout their lifetime.

Performance indicators play a pivotal role in evaluating the effectiveness of these systems. System performance monitoring is a continuous process that involves the collection and analysis of various data points related to the solar PV system's operation. This includes tracking energy generation, inverter efficiency, and performance metrices such as CUF and PR.

By monitoring these parameters in real-time, any deviations from the expected performance can be quickly identified, allowing for timely corrective actions. Performance monitoring systems can be equipped with advanced analytics and reporting tools to provide insights into the system's health and efficiency.

2 Standards

An International Standard is a technical standard developed by one or more International Standard Organizations. These are available for consideration or direct use worldwide.

The need for standardization grew with global trade and commerce to overcome any technical barrier due to independent standards by different countries or national agencies, or industrial bodies. However, international standards can be directly used or processed further to suit the local conditions, keeping the core technical content the same.

Standards by IEC (International Electrotechnical Commission) and IEEE (Institute of Electrical and Electronics Engineers) are among the most referred standards in the PV industry. PV systems incorporate various aspects from different fields like electronics, electrical, mechanical, civil, etc. The DC side electrical and electronic aspects are especially related to PV technology, and therefore the DC side component standards are specially developed for PV industry whereas others like electrical, civil or mechanical are accepted from already existing standards.

Over the years, standards for PV systems have been developed for -

- **PV System Components**
- **Integration of PV Systems with the Grid**
- **Testing and Commissioning of Installed Systems**
- **O&M of Systems**

Each country agency develops its own standards based on the electrical infrastructure and other relevant standards in place. These normally are either full adoptions or some modifications of the international ones.

It is mandated that everyone follows the national or locally applicable standards. In case these are different than the international standards and the components are to be imported into the country, they are required to be type-tested and certified under the locally applicable standards in order to be used in the systems.

2.1 Component Standards

PV system component standards are set mainly by IEC or Underwriters Laboratory (UL), which are globally accepted or adopted. IEC standards are followed widely in Europe and some other countries, while UL standards are followed mainly in USA and a few other countries.

The component standards include the production, testing and operation protocols. Each component is type-tested at a recognized laboratory anywhere in the world. These certificates are acceptable in any country once the national agency has made that standard mandatory.

2.2 Grid Connectivity Standards

These are mainly developed by IEC, UL, and Institute of Electrical and Electronics Engineers (IEEE). Only two IEEE standards, IEEE 519 and IEEE 1547, completely define the technical requirements for connecting distributed generators (including PV systems) to the electricity grid. Therefore, mostly all countries have adopted these two standards and made them mandatory for grid connectivity.

2.3 O&M Standards

Standards during the O&M period cover the periodical checks of all the components and connections to confirm that these are still within the operating limits as designed by the standards.

Another major set of O&M standards deal with the PV system performance testing and results analysis, so that there is uniformity in the results globally and these could be compared with each other during the analysis. All prerequisites and testing methods are defined in these standards.

3 System Performance - Indicators

Rooftop PV systems offer advantages like reduced transmission losses as the energy is generated close to the point of consumption. Optimizing rooftop systems involves considering factors such as roof orientation, tilt angles, shading from nearby structures, and available space. An efficiently designed rooftop system maximizes energy yield while utilizing existing infrastructure.

3.1 Performance Indicators and Acceptable Range

Performance indicators like CUF and PR provide quantitative measures of the solar PV system's performance. The acceptable range for these indicators depends on factors such as system design, location and technology. Deviations from the acceptable range may indicate the need for adjustments or improvements in the system.

3.2 Detailed Calculation of PR & CUF

PR is calculated as the ratio of the actual energy output of the system to the expected energy output based on theoretical calculations. CUF is calculated as the ratio of the actual energy output to the maximum possible energy output, if the system operates continuously at its peak capacity. These calculations offer insights into the efficiency and effectiveness of the system's energy conversion.

Performance Ratio (PR) testing and calculations are carried out after considering environmental factors used as corrections in formula. There are different forms of calculating PR, wherein either only irradiance correction factor is considered or additionally temperature correctional factor is also considered or only temperature correctional factor is considered. Considering both the factors is ideal but requires ongoing recording of irradiance and cell temperature at the site of the plant on which PR test is to be performed.

- Solar energy meter reading is taken as actual energy generated from the plant.
- Following factors shall be excluded for calculation:
    - Generation loss due to grid outage or abnormal grid parameters.

- Irradiance below 250 W/m2
- The measured global solar radiation of the period of the outage of the power evacuation system shall be excluded to calculate average global solar radiation for the period of PR test.

Irradiance corrected PR formula is:

PR = Actual energy output in the period / (Average Irradiance (kW/m2) on the panel x Hrs x Active area of PV module x PV module efficiency)

Temperature and Irradiance corrected PR formula is:

PR = Actual energy output in the period / (Average Irradiance (kW/m2) on the panel x Hrs x Active area of PV module x PV module efficiency x TCF)

Where TCF is temperature corrected factor = (actual cell temp in 0C - 25 0C x module temp coefficient) - this coefficient is provided by the module manufacturer in the datasheet of the specific model.

Capacity Utilization Factor (CUF) comparatively is a simple formula without actual measurements except of output energy taken from solar energy meter reading.

CUF = Actual energy output in the period / (Installed plant capacity in kWp x 24 x 365)

4 System Performance - Factors that Affect Performance

4.1 Optimum Tilt Angle & Azimuth

The optimum tilt angle and azimuth angle of solar panels are critical for capturing the most sunlight throughout the year. The tilt angle is the inclination of the panels relative to the ground, and the azimuth angle determines the orientation of the panels with respect to the north. These angles vary based on the geographical location of the PV system. Adjusting these angles optimally ensures that the panels receive the maximum amount of solar radiation, resulting in higher energy generation.

4.2 Component Selection and Technology

Choosing the right components is crucial for system efficiency. The selection of solar modules, inverters, and mounting structures should consider factors like technology efficiency, reliability, and compatibility. Solar module technology, size and efficiency should be aligned with the available space and energy requirements to ensure optimal energy generation.

4.3 NS and EW Oriented Plants

Plants oriented towards the north-south (NS) direction have a more consistent energy output throughout the day, as the panels receive relatively uniform sunlight exposure. On the other hand, east-west (EW) oriented plants emphasize higher energy production during peak sunlight hours. The choice between NS and EW orientation depends on the energy consumption pattern and the desired energy output profile.

4.4 Module Degradation and Warranty

Over time, solar modules experience a gradual reduction in their efficiency due to various factors, including exposure to environmental conditions. This degradation is factored into design optimization to ensure that the system can still meet energy requirements even as modules age. Warranty terms, including degradation rates, play a role in estimating the longevity and performance of the PV system. Of course, the maintenance plays a major role in keeping module performance within the designed range over the time.

5 System Performance - Importance of Software

Software tools are essential for accurately simulating the performance of solar PV systems. PV system simulation software and shading analysis tools help in assessing how different design parameters affect energy generation. These tools provide insights into the expected performance under varying conditions, enabling better decision-making during design optimization.

5.1 P50/75/90 and Performance Indicators

P50, P75 and P90 values represent different levels of confidence in achieving certain energy production targets. For instance, P50 represents the aggressive expected energy output, while P90 represents the conservative energy output that will be exceeded 90% of the time.

6 System Testing and Commissioning

6.1 Technical Standards for Connectivity

Technical standards for connectivity ensure that the solar plant is seamlessly integrated into the electrical grid. These standards define the requirements for grid synchronization, voltage levels, frequency response, and protection mechanisms. Adhering to these standards is essential to avoid grid disturbances and ensure stable operation.

6.2 Explanation of Unintentional Islanding Functionality Test

The unintentional islanding functionality test assesses the system's ability to detect and disconnect from the grid during power outages. This prevents the unintended creation of an "island," where the solar system continues to generate power while the grid is down. Unintentional islanding can pose safety risks to utility workers and affect grid stability.

6.3 Anti-Islanding Test

The anti-islanding test is a critical assessment to ensure that the solar PV system can detect and disconnect from the grid in the event of a power outage. This test confirms that the system's anti-islanding protection functions effectively, preventing the unintentional operation of the solar plant as an isolated power source during grid failure. By conducting this test, the system's compliance with safety standards and grid interconnection requirements is verified, enhancing grid stability and the safety of utility workers.

System Testing During O&M Periods

6.4 Measurement Parameters (as per IEC 61724)

IEC 61724 is an international standard that outlines the measurement parameters for monitoring PV system performance. These parameters include global horizontal irradiance, plane of array irradiance, module temperature, AC power output, and more. Adhering to these measurement standards ensures accurate and consistent assessment of the system's performance. Proper measurement parameters enable effective comparison of data across different systems and locations, aiding in performance analysis and optimization.

6.5 Site Safety Features During Testing

During the testing and commissioning phase, safety measures are paramount. Clear signage indicating hazardous areas, restricted access zones, and the use of appropriate personal protective equipment (PPE) ensure the safety of personnel involved. Safety protocols should be communicated and enforced to prevent accidents or incidents. Safety features also include emergency response plans and proper training for personnel to handle unexpected situations.

6.6 Solar Modules On-Site Test

On-site testing of solar modules involves multiple steps to ensure their quality and performance. Visual inspections check for physical damage, cracks, or defects on the module surface. Electroluminescence (EL) testing involves capturing images of the module in the dark to identify internal defects not visible to the naked eye. Potential-Induced Degradation (PID) tests assess the module's performance under high-voltage stress conditions to ensure its durability over time.

6.7 String Testing (Voltage, Current & Insulation Testing)

String testing involves evaluating the electrical connections between multiple solar modules connected in series (a string). This includes voltage and current measurements to ensure that the string is functioning properly. Insulation testing checks for any leakage of electrical current due to inadequate insulation, which could lead to safety hazards or reduced system performance.

6.8 AC Cable Insulation Resistance Test with Megger

The insulation resistance test is performed on AC cables using a Megger instrument. This test measures the resistance of insulation between the conductors and the cable's outer sheath. Adequate insulation resistance ensures that electrical leakages are minimized, preventing potential safety risks and system malfunctions.

6.9 Earth Resistance Test with 3 Point & Clamp Resistance Tester

The earth resistance test assesses the effectiveness of the grounding system. Grounding is crucial to dissipate any potential fault currents into the ground, ensuring safety. Both 3-point and clamp resistance testers are used to measure the earth resistance, providing accurate and reliable results.

6.10 Inverter On-Site Tests & Power Quality Tests

On-site inverter tests are crucial to validate their proper functioning. Power quality tests, including DC injection, flicker analysis, and Total Harmonic Distortion (THD) tests ensure that the inverter's output adheres to strict standards such as IEEE 1547. DC injection tests simulate various grid conditions to verify that the inverter can safely disconnect during grid faults. Flicker analysis assesses the inverter's impact on grid stability, and THD tests ensure that the inverter output conforms to acceptable harmonic levels. These tests assess the inverter's impact on the grid and its ability to maintain power quality.

7 Certification of Components

All the components to be used in the PV plant must comply with the standards as mandated by the local authority and it is duty of the plant designer and installer to ensure that record is maintained of the certificates of all the components proving that only standards complying components are used in the plant. The component manufacturers provide the certificates and test reports for the item they are to supply, and these must be studied carefully to check and ensure their conformity to the standards.

Few important aspects of the certificates and test reports:

- It must be checked that these pertain to the exact model that is being used in the plant.
- For all components the "type test reports" are acceptable, meaning the model certificate is available but not for the particular serial number of the component being used.
- It must be checked that the certificate is valid as on the planned date of plant commissioning.
- Solar modules certificates are provided by the laboratories for a particular "Bill of Material" and any change in the material requires fresh certificate, as the original certificate becomes invalid.
- The certificates and test reports must be from the qualified recognized test laboratories.

Conclusion

In conclusion, regular monitoring of performance using KPIs can achieve optimal efficiency, maximize energy output, and ensure a reliable and sustainable source of electricity by the PV system. The comprehensive testing and commissioning activities outlined in this document collectively ensure the reliable and safe operation of solar PV systems. Each activity contributes to the overall performance, longevity, and adherence to industry standards. By meticulously conducting these activities, solar PV systems are positioned to contribute efficiently to clean energy generation while upholding safety and quality standards.

Some Major International Standards

Solar Module	
IEC 61215	Design Qualification and Type Approval for Crystalline Silicon Terrestrial Photovoltaic (PV) Modules
IEC 61701	Salt Mist Corrosion Testing of Photovoltaic (PV) Modules
IEC 61853- Part 1	Photovoltaic (PV) module performance testing and energy rating –: Irradiance and temperature performance measurements, and power rating
IEC 62716	Photovoltaic (PV) Modules – Ammonia (NH_3) Corrosion Testing (As per the site condition like dairies, toilets)
IEC 61730-1,2	Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements for Construction, Part 2: Requirements for Testing
IEC 62804	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation. IEC TS 62804-1: Part 1: Crystalline silicon (mandatory for applications where the system voltage is > 600 VDC and advisory for installations where the system voltage is < 600 VDC)
IEC 62759-1	Photovoltaic (PV) modules – Transportation testing, Part 1: Transportation and shipping of module package units
Solar PV Inverters	
IEC 62109-1, IEC 62109-2	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements, and Safety of power converters for use in photovoltaic power systems Part 2: Particular requirements for inverters. Safety compliance (Protection degree IP 65 for outdoor mounting, IP 54 for indoor mounting)
IEC 61683	Overall efficiency of grid-connected photovoltaic inverters:

(as applicable)	This European Standard provides a procedure for the measurement of the accuracy of the maximum power point tracking (MPPT) of inverters, which are used in grid-connected photovoltaic systems. In that case the inverter energizes a low voltage grid of stable AC voltage and constant frequency. Both the static and dynamic MPPT efficiency is considered.
IEC 62116/ UL 1741/ IEEE 1547 (as applicable)	Utility-interconnected Photovoltaic Inverters - Test Procedure of Islanding Prevention Measures
IEC 60255-27	Measuring relays and protection equipment – Part 27: Product safety requirements
IEC 60068-2 (1, 2, 14, 27, 30 & 64)	Environmental Testing of PV System – Power Conditioners and Inverters a) IEC 60068-2-1: Environmental testing - Part 2-1: Tests - Test A: Cold b) IEC 60068-2-2: Environmental testing - Part 2-2: Tests - Test B: Dry heat c) IEC 60068-2-14: Environmental testing - Part 2-14: Tests - Test N: Change of temperature d) IEC 60068-2-27: Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock e) IEC 60068-2-30: Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle) f) IEC 60068-2-64: Environmental testing - Part 2-64: Tests - Test Fh: Vibration, broadband random and guidance
IEC 61000 – 2,3,5 (as applicabl	Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) testing of PV Inverters
Fuses	
IEC 60947 (Part 1, 2 & 3), EN 50521	General safety requirements for connectors, switches, circuit breakers (AC/DC): a) Low-voltage Switchgear and Control-gear, Part 1: General rules b) Low-Voltage Switchgear and Control-gear, Part 2: Circuit

	Breakers c) Low-voltage switchgear and Control-gear, Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units d) EN 50521: Connectors for photovoltaic systems – Safety requirements and tests
IEC 60269-6	Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
Surge Arrestors	
IEC 62305-4	Lightening Protection Standard
IEC 60364-5-53	IEC 60364-5-53 Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
IEC 61643-11:2011	Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods
Cables	
IEC 60227 IEC 60502/ (Part 1 & 2)/ IEC69947	General test and measuring method for PVC (Polyvinyl chloride) insulated cables (for working voltages up to and including 1100 V, and UV resistant for outdoor installation)
BS EN 50618	Electric cables for photovoltaic systems (BT(DE/NOT)258), mainly for DC Cables
Earthing /Lightning	

IEC 62561 Series (Chemical earthing)	IEC 62561-1 Lightning protection system components (LPSC) - Part 1: Requirements for connection components IEC 62561-2 Lightning protection system components (LPSC) - Part 2: Requirements for conductors and earth electrodes IEC 62561-7 Lightning protection system components (LPSC) - Part 7: Requirements for earthing enhancing compounds
Junction Boxes	
IEC 60529	Junction boxes and solar panel terminal boxes shall be of the Junction boxes and solar panel terminal boxes shall be of the IP 54 protection for indoor use

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/667620WP00PUBL005B0SOLAR0GUIDE0BOOK.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)*