Module Outline

GRID INTEGRATION - DRE

Disclaimer

Relevance and Background

DRE sources of energy like solar and wind are crucial components for transition to clean and sustainable energy systems, helping to reduce greenhouse gas emissions and enhance energy security.

DRE technologies have emerged as viable alternatives, generating electricity locally from renewable resources. However, integrating intermittent DRE sources into existing grids poses technical, regulatory, and safety challenges. This module aims to equip learners and end users with the knowledge and skills to effectively address these challenges, contributing to a more sustainable and resilient energy future.

Theme – Technical
Competency – Electrical
Code of the Module – T02C03M09

Learning Outcomes

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

- Understand the significance of integrating DRE sources into existing electrical grids.
- Explain the key concepts and principles of grid connectivity standards for DRE systems.
- Describe the process of system testing and synchronization necessary for DRE grid integration.
- Identify and analyse the common challenges associated with DRE grid integration.
- Propose remedial actions and solutions to overcome challenges in DRE grid integration.
- Evaluate the environmental and economic benefits of integrating DRE into the grid.
- Demonstrate knowledge of safety protocols and regulations related to DRE grid integration.
- Apply best practices for efficient and reliable DRE grid integration.
- Interpret case studies and real-world examples of successful DRE grid integration projects.
- Engage in informed discussions on the future of solar energy integration into existing grids.

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M09 L01	Lecture on Grid Integration - DRE

M09 L01: Lecture Presentation

- The MS PowerPoint presentation will cover comprehensive knowledge about integrating DRE systems into existing electrical grids, along with the environmental and economic benefits accruing from the same.

Key Topics to be Covered

1. Process for Grid Interconnection of DRE
2. Grid Connectivity Standards
3. System Testing and Synchronization
4. Challenges of DRE Grid Integration
5. Suggested Remedial Actions for DRE Integration Challenges

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1 Introduction

Grid integration is essential for optimizing the utilization of solar energy resources and ensuring reliable power supply. Understanding the intricacies of this integration process is crucial for energy professionals, policymakers, and stakeholders in the renewable energy sector. This module aims to provide a comprehensive understanding of the key concepts, standards, best practices, and challenges involved in grid integration.

2 Process for Grid Interconnection of DRE

Stakeholders: The successful grid integration of DRE involves various stakeholders, each playing a crucial role in the process:

- **Consumer:** The primary beneficiary - consumers can own and operate these systems on their premises. Alternatively, third party-owned systems provide energy to consumers through leasing or power purchase agreements (PPAs).
- **Discom (Power Distribution Company):** These are entities responsible for supplying electrical power to consumers. Discoms can be either government-owned or private companies. In some cases, they also serve as grid operators, managing the distribution infrastructure.
- **EPC Company/Installer:** Engineering, procurement, and construction (EPC) companies or installers are responsible for designing, procuring components for, and installing DRE systems. These are responsible for seamless integration of solar energy with the grid.

- **Component Manufacturers and Suppliers:** Manufacturers and suppliers of DRE components such as solar panels, inverters, and batteries are essential stakeholders. They ensure the availability of reliable and efficient equipment for DRE projects.

Implementation Steps for Rooftop PV Plants

Grid integration of rooftop photovoltaic (PV) plants must follow a systematic and standardized process to ensure the safe and efficient connection of solar energy to the grid. Two major stakeholders-consumer and utility-in any grid-connected PV project must understand and execute their roles and responsibilities accurately and in a time bound manner.

The consumer needs to understand the mandatory requirements for a PV system and must adhere to these while designing and implementing the project. This includes formats for application, standards and specifications of components in the system, and all other procedures to be followed, along with critical protection features for grid integrity.

The utility must follow its role of technical facilitator as well as watchdog over the quality of the proposed and installed system by the consumer. This fits well into its major role of grid operator and manager.

3 Grid Connectivity Standards

The grid integration of DRE sources such as PV systems relies on a set of established standards and regulations to ensure safe and efficient interconnection with the electric power system. Some of the key international standards and regulations include:

- **IEEE 1547** - Standard for Interconnecting Distributed Resources with Electric Power Systems (2003): This standard provides guidelines for the interconnection of DRE sources, including PV systems, with the electric power system. It outlines technical requirements, safety provisions, and operational protocols to ensure the seamless integration of solar energy into the grid.
- **IEEE 519**: Recommended Practice and Requirements for Harmonic Control in Electric Power Systems (2014): This standard addresses the control of harmonics, which are undesirable disturbances in the electrical waveform. Ensuring that DRE sources, like PV systems, meet harmonic control requirements, helps maintain the quality and reliability of power on the grid.
- **Interconnection Technical Specifications & Requirements**: These specifications and requirements, often based on IEEE 1547, provide detailed guidance on grid interconnection. They cover aspects such as voltage regulations, synchronization procedures, and the use of isolation devices. Adherence to these specifications is crucial to prevent grid instability and ensure safe operations.

The interconnection of DRE sources, such as PV systems, with the grid must adhere to specific parameters outlined in IEEE 519 to ensure the stability and quality of electrical power. These parameters include:

Parameters	Requirement as per IEEE 519
Grid Compliance	Align with overall grid standards.
Equipment Standards	All equipment must meet relevant compliance standards.
Metering	Use compliant meters for accurate measurement.
Safety	Ensure safety measures and power supply reliability.
Harmonic Current	Limit harmonic current to prevent waveform distortions.
Synchronization	Synchronize PV systems to keep voltage fluctuations within ± 5%.
Voltage Range	Operate within a voltage range of 80% to 110%.
Flicker Control	Prevent excessive voltage flicker per IEC 61000.
Frequency Management	Handle frequency deviations promptly.
DC Injection	Limit injected DC power to 0.5% of the rated output.
Power Factor	Maintain a lagging power factor above 0.9 when output exceeds 50%.
Islanding/Disconnection	Island or disconnect within specified timeframes during faults or deviations.
Overload Protection	Automatically switch off during overload or overheating.
Paralleling Device	Withstand up to 220% of normal voltage at the interconnection point.

These parameters ensure safe, compliant, and reliable integration of PV systems into the grid.

These international standards are adopted by many countries. However, only locally applicable standards are to be complied with for off-grid systems as well as for grid integration, for which the local regulations need to be studied, identified and then applied accordingly.

4 System Testing and Synchronization

Key activities involved in testing and commissioning for grid integration of DRE systems are:

Activity	Description
Testing of Components Prior to Installation	Inspect and test individual components before installation. Ensure components are meeting quality and performance standards. Identify and address any defects or issues before installation.
Testing of Components During Installation	Continuously monitor and verify component integrity during installation. Check electrical connections, cable routing, and mounting for proper installation. Promptly address installation issues to prevent future problems.
Testing of Components and Performance after Installation	Conduct comprehensive testing of the entire DRE system after installation. Verify correct and designed functionality of all components. Assess system performance under various conditions for optimal operation.
Commissioning of Plant by EPC Company in the Presence of Utility Officer	Perform the commissioning process in the presence of a utility company representative. Ensure compliance with grid connectivity standards. Confirm readiness for integration with the utility grid.
Pre-Commissioning Inspection	Visually inspect all system components. Check for compliance with safety standards. Inspect electrical connections and wiring for integrity.
Electrical System Testing	Test electrical systems for proper functionality. Verify integrity of electrical connections. Ensure safe operation under various conditions.
Inverter and Transformer Testing	Conduct specific tests on inverters and transformers. Verify voltage and frequency parameters. Ensure synchronization with the grid.
SCADA and Monitoring System Testing	Test the SCADA system and monitoring equipment. Ensure accurate and reliable data monitoring. Verify effective control and management of the DRE system.
Performance Testing	Evaluate overall system performance. Measure energy generation and efficiency.

Activity	Description
	Assess performance under different load conditions.
Safety Systems Testing	Verify functionality of all safety mechanisms. Test emergency shutdown procedures. Ensure appropriate responses to safety threats.
Grid Connection Testing	Test the DRE system's connection to the utility grid. Verify synchronization of voltage and frequency with grid parameters. Ensure seamless integration with the grid.
Emergency Shutdown Testing	Simulate emergency scenarios and test system response. Ensure safe disconnection from the grid during faults or emergencies.
Operational Testing	Test system operation under normal conditions. Verify operational requirements are met. Ensure all components work together smoothly.

- **Pre-commissioning Test** – The table below provides a structured overview of the pre-commissioning tests and their respective item types and remarks for grid integration of DRE systems.

Pre-commissioning Test	Description	Remarks
Capacity of Installed System	Check AC capacity that is equal to inverter capacity. The solar array capacity can be the same or higher.	Ensures system capacity aligns with inverter capacity and installation layout.
Installation Layout	Is it as per drawing?	Confirms the locations of all protective features and checks if the installed capacity matches the approved capacity.
DC Side Isolator Switch	Between solar array and inverter	Essential for safe maintenance of the inverter during the daytime, allowing for the disconnection of the DC side.

Pre-commissioning Test	Description	Remarks
AC Disconnect Manual Switch	Provided with locking arrangement	Ensures easy isolation of the entire system from the grid, crucial for grid maintenance or faults.
Meters Approved by Concerned Authority	Ensure certified and sealed meters	Mandatory for net metering; meters must be tested and certified by the discom meter testing laboratory.
Signage	Warning and specification signs	Essential for grid engineers and O&M staff, must follow net metering regulations or industry standards.
Earthing Protections	Separate for DC, AC, and lightning arrestors	Three separate earthing systems required; AC side can connect to building earthing if in good condition.
Lightning Protection System (LPS)	Consists of lightning arrestor and earthing	Should be installed on the northern side of the plant, away from the solar field to avoid casting shadows.
Initial Commissioning Tests	As per equipment manufacturer's/test procedures	Includes operability test on the isolation device, unintentional islanding functionality, cease to energize functionality, and more.
Anti-Islanding Conformity Test	Confirm bi-directional flow on net meter	Test whether the meter records power flow to the grid when the consumer load is lower than generation and vice versa.
Check Consumption (Import) Only Mode	Ensures meter operates in 'import only' mode when PV system is not generating	Tests the meter's recording of power flow during periods when the PV system is not generating.
Check Operation of Solar (Generation) Meter	Tests the recording of power flow by the solar 'generation' meter.	Ensures proper functioning and recording of power flow by the solar generation meter.

In addition to the above tests, it is necessary to maintain the records of electrical testing values for different currents and voltages and keep testing these throughout the life of the system.

A typical format is presented below, and some values are also shown as a sample, only for the ease of understanding.

Inverter and Junction Boxes					
Sr. No.	List of parameters	Checked ?	Desired Value	Obtained Value	Remark
		Yes / No			
1	DC System Voltage - Check point (DCDB)				
A	String 1 - Voltage	Yes	671.22	527.6	
B	String 2 - Voltage	Yes	596.64	531.7	
C	String 3 – Voltage	Yes	522.06	523.4	
2	DC System Current - Check point (DCDB)				
A	String 1 - Current	Yes	8.72	2.74	
B	String 2 - Current	Yes	8.72	2.74	
C	String 3 - Current	Yes	8.72	2.74	
3	AC System Voltage - Check point (ACDB)				
A	Phase to Phase				
	Red to Yellow	Yes	415	420.5	
	Yellow to Blue	Yes	415	413.9	
	Blue to Red	Yes	415	418.9	
B	Phase to Neutral				
	Red to Neutral	Yes	230	246.8	
	Yellow to Neutral	Yes	230	231.8	
	Blue to Neutral	Yes	230	243.3	
C	Phase to Earth				
	Red to Earth	Yes	230	246.8	
	Yellow to Earth	Yes	230	233.2	
	Blue to Earth	Yes	230	243.5	
4	AC System Current - Check point (ACDB)				
A	Phase				

Inverter and Junction Boxes						
		Red			14.8	
		Yellow			9.2	
		Blue			14.8	
5	Earthing					
A	Lightning Arrester		Yes			Yes
B	Inverter		Yes			Yes
C	Structure		Yes			Yes

Actual Nos. of strings, desired values will change according to the plant design.

- **Unintentional Islanding Functionality Tests** - These tests are essential to confirm the inverter's behavior during power interruptions from the mains and ensure safety measures against unintentional islanding.

Test	Objective	Steps	Recording
Unintentional Islanding Functionality Test	Ensure the inverter stops supplying power quickly upon mains power loss and resumes only after a sufficient mains presence.	Test 1: • Turn OFF the main switch connecting the inverter to the grid. • Measure the time taken for the inverter to stop exporting power (use a timing device). • Record the time taken.	Time taken for inverter to cease exporting power.
		Test 2: • Turn ON the main switch connecting the inverter to the grid. • Measure the time taken for the inverter to re-energize and start exporting power (use a timing device). • Record the time taken.	Time taken for inverter to re-energize and export power.

5 Challenges of DRE Grid Integration

- **Utility Challenges:**
  - **Technical Quality of Power:** Maintaining control over parameters such as DC injection, flickers, frequency, and harmonics is crucial to avoid disturbances in the grid.
  - **Uniformity with Standards:** Adherence to standards for key equipment like inverters, modules, switches, and junction boxes is mandatory to ensure power quality, reduce discom's efforts in handling complaints, and restrict breakdowns.
  - **Issues due to Phase Imbalance:** Factors like different capacities on different single phases, demand variations across locations and times, and varying radiation can lead to phase imbalances, resulting in higher reverse flows and losses.
  - **Safety and Security:** Ensuring the safety and security of utility personnel during distribution network maintenance is essential, especially in the presence of distributed PV systems.
- **Possible Mitigations:**
  - **Scheduling and Dispatch of Demand Response:** Implementing demand response strategies and energy storage solutions for grid balancing.
  - **Even Distribution of Solar Power Plants (SPPs):** Distributing SPPs evenly across each phase to reduce imbalances.
  - **Micro Balancing Areas:** Creating balance zones or micro balancing areas at the phase, circuit, feeder, or substation level to facilitate better grid management and development of micro-grids, storage devices, and smart grids.
  - **Level of Local Capacity:** Deciding the capacity percentage at the distribution transformer (DTR) level should depend on peak-day demand rather than DTR capacity alone. Modifications may be needed to handle excess solar generation, introducing reverse feed.
- **Grid Integration Challenges:**

The effect of solar power generation and its effect on grid stability is a significant concern. Several key factors to be considered for successful grid integration:

  - **Grid Size:** The grid must be large enough to respond to variations in generation from solar energy. This requires significant expansion and modernization of the grid infrastructure.
  - **Communication:** The grid needs to react faster to accommodate fluctuations in solar generation. This necessitates faster and more efficient communication systems within the grid.
  - Energy Storage: Effective and low-cost grid-level energy storage solutions are crucial for balancing intermittent solar generation and ensuring a stable power supply.

- **Deemed Generation Clause:** Implementing policies like the "deemed generation clause" can help ensure fair compensation for renewable energy generators and promote grid stability.

- **DRE Feed to Discom Network:**
  - A limited DRE penetration is beneficial as it lowers feeder loading, enhancing grid stability.
  - **High DRE Penetration:** Challenges arise with high DRE adoption, affecting voltage levels and practical grid operations.
  - **Voltage Effects:** DRE impacts voltage levels, necessitating monitoring and control.
  - **Equipment Concerns:** Considerations include transformers, inverters, meters, testing, calibration, and grid parameter adaptability.

- **High Penetration of DRE in Distribution Systems:**
  - **Voltage Variations:** High DRE penetration can cause significant voltage fluctuations on the feeder.
  - **Reverse Feeding:** Issues may arise with reverse power flow from DRE systems.
  - **Protection Challenges:** Malfunctions and failures in protection systems can occur.
  - **Power Factor Impact:** DRE integration may affect the power factor, requiring monitoring and control measures.

These challenges highlight the need for careful planning and grid management when integrating DRE into the distribution system, as explained below.

6 Suggested Remedial Actions for DRE Integration Challenges

These actions aim to address the challenges associated with high penetration of DRE into the power distribution system and enhanced grid stability and management.

- **Multistage Inverters:** Implement multistage inverters with L/C circuitry and harmonic filter circuits to manage reactive power and harmonics.
- **Measurement and Monitoring:** Regularly measure harmonic content, DC injection, and flicker in the presence of concerned parties.
- **Proposed Amendments:** Introduce primary responses by solar power stations, Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) on solar power generators, ramp-up and ramp-down rate specifications, voltage regulation services, and improved reactive power control.
- **Compliance Monitoring:** Review limits of harmonics and establish compliance monitoring.
- **Requirements for Absorbing DRE Generation:** Implement LT-level monitoring, performance monitoring for all DRE, collect field-level climate data, consider storage facilities, adjust consumer load profiles, and enhance utility procedures, capacity development, and grid management.
- **During O&M on Grid Line:** Ensure safety during planned or forced maintenance on the distribution network, including proper line earthing and manual isolation of supply from solar rooftop PV plants, to prevent back-feeding.

These actions will effectively address the challenges posed by integrating DRE into the grid, contributing to a more sustainable and resilient energy future.

Reading Material

1. *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)