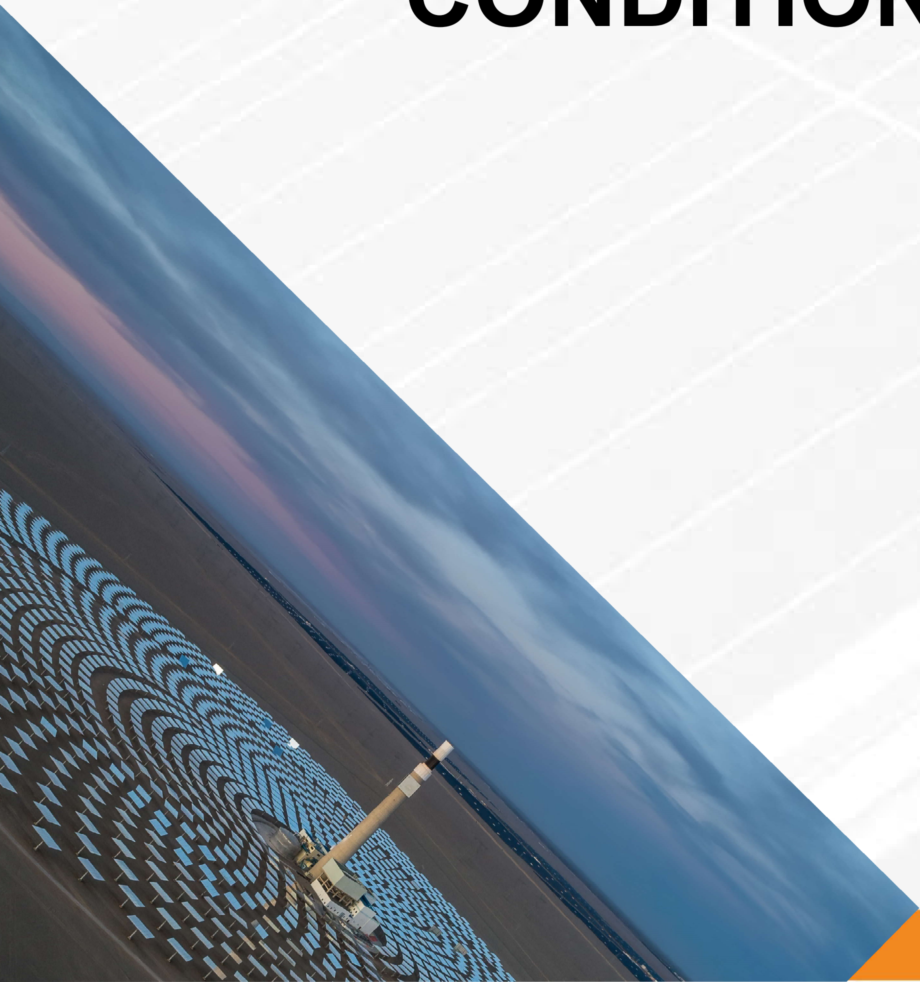
Module Outline

INVERTERS AND POWER CONDITIONING UNITS



Disclaimer

Relevance and Background

Inverters are a critical component of solar PV systems. Many a times they are called the brain of the system. Therefore, understanding their operation and proper selection is crucial for system efficiency and performance.

This module aims to address the importance of inverters and their role in solar PV system operation.

Theme – Technical
Competency – Electronics
Code of the Module – T02C02M05

Learning Outcomes

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

- Explain the functions and importance of inverters in solar PV systems.
- Identify and describe different types of inverters.
- Understand the selection criteria for inverters based on system requirements.
- Design and configure appropriate inverter setups for specific applications.
- Demonstrate knowledge of safety practices and regulations related to inverters.

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M05 L01	Lecture on Inverters and Power Conditioning Units

M05 L01: Lecture Presentation

The MS PowerPoint presentation will provide a comprehensive overview of inverters and their significance in solar PV systems, with a focus on the different types of inverters.

Hybrid inverters will be discussed in detail with different applications of new-generation solar plants with solar-battery-grid hybridization, and a high level of energy storage.

It will also incorporate real-world examples, case studies, and practical demonstrations where applicable to enhance understanding and engagement.

By the end of the presentation, participants will have a comprehensive understanding of the various types of Inverters and their applications. They will be equipped with the knowledge necessary to make informed decisions when selecting and implementing Inverters in solar PV systems, thus ensuring optimal performance and durability.

Key Topics to be Covered

1. Introduction
2. Types of Inverters
3. Off-grid inverters
4. On-grid inverters
5. Inverter Efficiency
6. Standards in Solar Inverters

Table of Contents

1 Introduction

Inverters play a crucial role in renewable energy systems. They are electronic devices that convert direct current (DC) power from sources like solar panels or batteries into alternating current (AC) power, which is suitable for powering household appliances and electrical equipment.

Inverters come in various types, including grid-tied inverters, off-grid inverters, and hybrid inverters. Grid-tied inverters are designed to work in synchronization with the utility grid, feeding excess power back into the grid. Off-grid inverters are used in standalone systems where there is no grid connection, providing power solely from renewable energy sources and batteries. Hybrid inverters combine the features of grid-tied and off-grid inverters, allowing for both grid connectivity and energy storage.

2 Types of Inverters

- Off-Grid Inverters:
    - Used in standalone systems, not connected to the grid.
    - Requires battery storage to supply power during nighttime or when solar production is insufficient.
- Hybrid Inverters:
    - Combines grid-tied and off-grid functionalities.
    - Within this type there are two types: off-grid hybrid and on-grid hybrid.
    - On-grid hybrids can operate with or without a grid connection, utilizing battery backup and selling excess energy to the grid.
    - Off-grid hybrid inverters use the grid as an additional source to charge batteries.
- On-Grid (Grid-Tied) Inverters:
    - Most common type for residential and commercial applications.
    - Connected to the utility grid, allowing excess energy to be sold back to the grid (net metering).
    - No battery backup for storage
    - Stops functioning if the grid shuts off. Resumes automatically once grid returns within the permittable electrical parameters.
    - Can be designed to work on diesel generators (or any internal) grid during utility grid outage.

3 Off-Grid Inverters

Off-Grid Inverters are designed for standalone systems. These inverters have a single main function of using battery stored energy by converting it to AC and supporting loads in the circuit. The PV system known as stand-alone off-grid system also requires solar charge controller to use solar energy to charge the battery. Sometimes the charge controller is in-built in the inverter and in such cases the unit is known as 'power conditioning unit' as it combines charger and inverter functions. Sometimes the SCR can be a separate unit fitted between solar modules and batteries and inverter between batteries and loads.

Off-Grid Hybrid Inverters are also designed for standalone systems. These inverters integrate multiple power sources, such as solar panels, batteries, and sometimes a backup generator like diesel or biomass generator. They provide greater flexibility in managing energy and ensuring a reliable power supply.

Off-grid hybrid inverters can operate in various modes:

- **Standalone Mode:** In this mode, the inverter utilizes solar power from the panels and stored energy from the batteries to meet the electrical demand. It functions independently of the grid and can power loads without grid connection.
- **Grid-Assisted Mode:** This mode allows the inverter to use solar power and energy from the batteries while remaining connected to the grid. It enables users to draw power from the grid during times of high demand or low solar generation, supplementing the system's energy supply.

- **Grid-Charging Mode:** Off-grid hybrid inverters can also facilitate grid charging of batteries. When excess energy is available from the grid, the inverter can charge the batteries, providing backup power during grid outages or periods of high demand.

4 On-Grid Inverters

These are much smarter than the off-grid ones because they must synchronize with the grid in addition to the other normal functions of off-grid inverters. Other important features of on-grid inverters include providing priority to solar while injecting into the grid, controlling harmonics and maintaining grid stability, operating maximum power point tracking (MPPT) to maximize use of available solar energy, and providing anti-islanding protection. It is important to note that the on-grid inverter can synchronize with a diesel generator grid as well as utility grid, provided the grid parameters like voltage and frequency, match the inverter pre-decided values.

This inverter also has a local display where the system performance parameters can be read on the site. This data can also be communicated to the remote monitoring system through a modem or similar network.

All the mandatory grid integration standards of any state or country are completely handled by the inverter, which must comply with the locally applicable standards. It also provides safety to the system, the operator as well as to the electricity grid.

There are two types of classification of on-grid inverters.

- Based on presence of In-built transformer for galvanic separation between DC and AC
  - Transformer-less, use electronic switches to step up the DC voltage step by step rather than using regular transformers. These are more common in string inverters mainly used in small capacity rooftop plants and may pass on some DC component, but detects and also controls it as per international standards.
  - Isolated, meaning with a built-in isolation transformer, step up the DC voltage using conventional transformer technology, before inverting it to AC. This provides separation between DC and AC voltages. These are more common in large MW-scale projects as central inverters and provide complete isolation as the name suggests.
- Based on how inverters are connected to the solar modules
  - Micro inverter, which is attached to each individual inverter
  - String inverter, which is connected to one or more strings of modules and may have more than one MPPT
  - Central inverter, which is connected to large arrays and subarrays as a single point even in multi-MW capacity.

As the solar industry develops further, and the requirements of different standards are understood by the developers and inverter manufacturers, newer models of inverters are produced that make the installation and operation much easier and safer. For example, many inverters are now equipped with in-built protections against overcurrent and voltage surge, so separate boxes are not required to accommodate these safety devices. On-grid hybrid inverters are other examples where the consumer gets the benefits of grid-connected and off-grid systems when there is an outage.

5 Inverter Efficiency

Temperature has a significant impact on the performance and efficiency of inverters. High operating temperatures can lead to increased internal resistance, reduced component conductivity, and accelerated aging, affecting the overall performance and lifespan of the inverter.

To mitigate the effects of temperature, inverters are often derated. Temperature derating involves reducing the inverter's capacity or power output at elevated temperatures to maintain safe and reliable operation within specified temperature limits. Derating curves provided by manufacturers indicate the reduction in performance as the temperature increases.

To address temperature issues, proper thermal management is essential. This may involve adequate ventilation, heat sinks, cooling fans, or installation in environments with suitable ambient temperatures. Effective thermal management helps dissipate heat, maintain optimal operating temperatures, and extend the lifespan of inverters.

Anti-islanding is a safety feature in on-grid hybrid inverters. It prevents the inverter from supplying power to the grid during outages. This protects utility workers and prevents damage to the grid. By monitoring grid parameters, the inverter disconnects from the grid if abnormal conditions are detected, ensuring compliance with safety standards and regulations.

6 Standards in Solar Inverters

Inverters plays a vital role in the solar energy industry. These standards are developed to ensure the safety, performance and compatibility of solar hybrid inverter systems. Let's explore their importance:

Safety: Standards establish guidelines and requirements to ensure the safe operation of solar hybrid inverters. They address various aspects of electrical safety, fire protection, and protection against electrical hazards. Compliance with safety standards helps mitigate risks and ensures the protection of system users, installers, and grid operators.

Performance and Reliability: Standards define performance requirements, testing methods, and efficiency benchmarks for solar hybrid inverters. They ensure that inverters meet minimum performance criteria, including conversion efficiency, voltage regulation, power quality, and response to varying environmental conditions. Compliance with performance standards ensures that inverters deliver the expected performance levels and contribute to the overall system efficiency.

Grid Interconnection: Standards establish technical requirements for the grid interconnection of solar hybrid inverters. They define parameters for voltage and frequency control, power quality, and anti-islanding functionality. Compliance with grid interconnection standards ensures that solar hybrid inverters operate safely and seamlessly when connected to the utility grid, preventing disruptions or damage to the grid, and ensuring grid stability.

Regulatory Compliance: Standards are often referenced in regulations and codes that govern the design, installation, and operation of solar hybrid inverter systems. Compliance with these standards ensures adherence to legal requirements, and facilitates regulatory approvals and certifications. Meeting regulatory compliance ensures that solar hybrid inverters meet the necessary quality and safety standards set by regulatory authorities.

By adhering to standards, manufacturers, installers, and system owners can have confidence in the safety, performance, and reliability of solar hybrid inverters. Standards also foster a level playing field in the industry, promote uniformity, and facilitate the growth of a robust and sustainable solar energy market.

A typical datasheet of on-grid inverter is presented here, just to explain some important features of inverters that are shown in the datasheet.

- The first part Input (DC) mentions various parameters on the DC side of the inverter, i.e., the solar array.
  - Maximum DC capacity that can be connected to this inverter in kWp
  - MPP voltage range of the inverter meaning a voltage range where the Maximum Power Point Tracking will come in force thereby extracting maximum possible solar energy from the array
  - Numbers of MPPT inputs in the inverter and numbers of inputs per MPPT - this provides the designer inputs on designing the strings of modules including modules in a string, strings in an MPPT, maximum strings that can be fitted to the inverter
- The second part Output (AC) mentions how this inverter will interact with the grid.
  - AC capacity of the inverter with figures of current and voltage at maximum and rated
  - Grid frequency range so that the inverter can synchronize with the grid with these parameters
  - Maximum harmonics created by the inverter thereby maintaining the grid health
  - Power factor showing the feeding capability of inverter and also how the reactive power in the grid will be treated within a range
- Third part on Efficiency mentions maximum and European efficiency. There will also be a table where efficiency at different voltage levels will be presented thereby providing the designer inputs on where to optimize the string voltage.
- Fourth part mentions Protections, and most of these are mandatory in many countries as per regulations and so will be present in the datasheets of all the inverters.
  - What may be different is whether this inverter has in-built DC / AC side protections like fuses (over current protection) or SPDs (surge protection devices). With such inclusions in the inverter itself, the system may not have external protection provided in the junction boxes.
- In the last part of General Data there will be mentioned other information useful for the designer and installer of the PV system.

- IP protection can inform whether this inverter can be installed outdoor
- If this transformer-less or with transformer
- Locally available displays

Type Designation	SG30CX
Input (DC)	
Recommended max. PV input power	45kW
Max. PV input voltage	1100 V **
Min. PV input voltage / Start-up input voltage	220 V / 250 V
Rated PV input voltage	585V
MPP voltage range	200 – 1000 V
No. of independent MPP inputs	3
No. of PV strings per MPPT	2
Max. PV input current	78 A (26 A / 26 A / 26 A)
Max. DC short-circuit current	120 A (40 A / 40 A / 40 A)
Output	
Max. AC Output power	29.9 kVA
Rated AC output apparent power	29.9 kVA
Max. AC output current	48.15 A
Rated AC voltage	3 / N / PE, 230 / 400 V
AC voltage range	312 – 528 V
Rated grid frequency / Grid frequency range	50 Hz / 45 – 55 Hz, 60 Hz / 55 – 65 Hz
Harmonic (THD)	< 3 % (at rated power)
Power factor at rated power / Adjustable power factor	> 0.99 / 0.8 leading – 0.8 lagging
Feed-in phases / connection phases	3 / 3-PE
Efficiency	
Max. efficiency / European efficiency	98.6 % / 98.3 %
Protection	
DC reverse polarity protection	Yes
AC short circuit protection	Yes
Leakage current protection	Yes
Grid monitoring	Yes
Ground fault monitoring	Yes
DC switch	Yes
AC switch	Yes
PV string monitoring	Yes
Q at night function	Yes
PID recovery function	Yes
DC Terminal Protective Cover	Yes
Communication dongle (EyeM4)	Yes
Surge Protection	DC Type II / AC Type II
General Data	

Type Designation	SG30CX
Dimensions (W*H*D)	702 * 595 * 310 mm
Weight	50 kg
Topology	Transformer less
Degree of protection	IP66
Night power consumption	≤2 W
Operating ambient temperature range	-30 to 60 °C (. 45 °C derating)
Allowable relative humidity range	0 – 100 %
Cooling method	Smart forced air cooling
Max. operating altitude	4000 m (> 3000 m derating)
Display	RS485 / WLAN / Operational: Ethernet
Communication	RS485 / WLAN / Optional: Ethernet
DC connection type	MC4 (Max. $6mm^2$)
AC connection type	OT or DT terminal (Max.70 mm^2)
Compliance	IEC 62109, IEC 61727, IEC 62216, IEC 60068, IEC 61683, IEC 61000-6-3, AS/NZS 4777.2:2020
Grid Support	Q at night function, LVRT, HVRT, active & reactive power control and power ramp rate control
Country of manufacture	China

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)*