Module Outline

PV CELLS AND MODULES

Disclaimer

Relevance and Background

PV modules, or panels as these are often called, are the most important component of any solar PV system, on-grid or off-grid. These not only are the costliest component, but also affect the system performance in the most substantial way. Presently, in the common on-grid systems the solar module has a cost share of about 55% to 65%; whereas in off-grid systems, where the battery also comes in, the cost share is about 45% to 55%. Also, the system's life is normally defined based on the life of the solar module. Therefore, it essential for an officer, planner, designer, engineer or technician to understand this component fully and completely.

Many a times the term PV technology actually means the technology of the solar module. The latter are the end usable product of a long production process from silica to polysilicon to wafer to cell to module. There have been tremendous developments in the materials used in solar cells and modules, their design, and chemistry in making cells from wafers or construction of modules from cells. Cost trends of modules and their raw material have substantial impact on the solar system costs and therefore also on the levelized cost of generation or the tariff at which the systems can generate electrical units.

Well-thought of procurement of a good module and its proper care in the field promises the success of the solar system over its lifetime. Therefore, it is imperative that this topic be given utmost importance in any training program, with one or more sessions devoted to it.

Theme – Technical
Competency – Electronics
Code of the Module – T02C02M04

Learning Outcomes

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

- Understand the basic principles of solar module operation,
- Identify different types of solar module technologies,
- Evaluate factors influencing solar module performance, and
- Apply better understanding in selecting, installing, and maintaining solar modules.

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M04 L01	Lecture on PV Cells and Modules

M04 L01: Lecture Presentation

The MS PowerPoint presentation will begin by introducing the PV effect, types of solar cells/modules and their construction. The main emphasis will be on crystalline technology and the others will be described in brief.

The presentation then explores the various PV technologies available in the market and emphasizes the IV curve, solar panel construction, and interconnection of solar cells. It highlights the importance of efficiency, fill factor, and discusses the advantages of half-cut Monocrystalline Passivated Emitter Rear Cells (MONO PERC) solar modules.

Participants will learn about Standard Test Conditions (STC) and Nominal Operating Cell Temperature (NOCT) conditions for solar modules, including both mono and bi-facial modules. The module datasheets will be discussed in detail, along with topics such as radiation variation, the impact of partial shadow, bypass diode importance, and temperature effects.

Lastly, the presentation briefly summarizes warranty and standards/quality measures related to solar modules.

By the end of the presentation, participants will gain a comprehensive understanding of solar PV modules, emerging technologies, and key considerations for their selection and performance evaluation.

Key Topics to be Covered

1. Common Component of PV Systems
2. Solar Cell Technologies
3. Solar Modules
4. Warranty, Standards and Quality Measures
5. Installation and Maintenance

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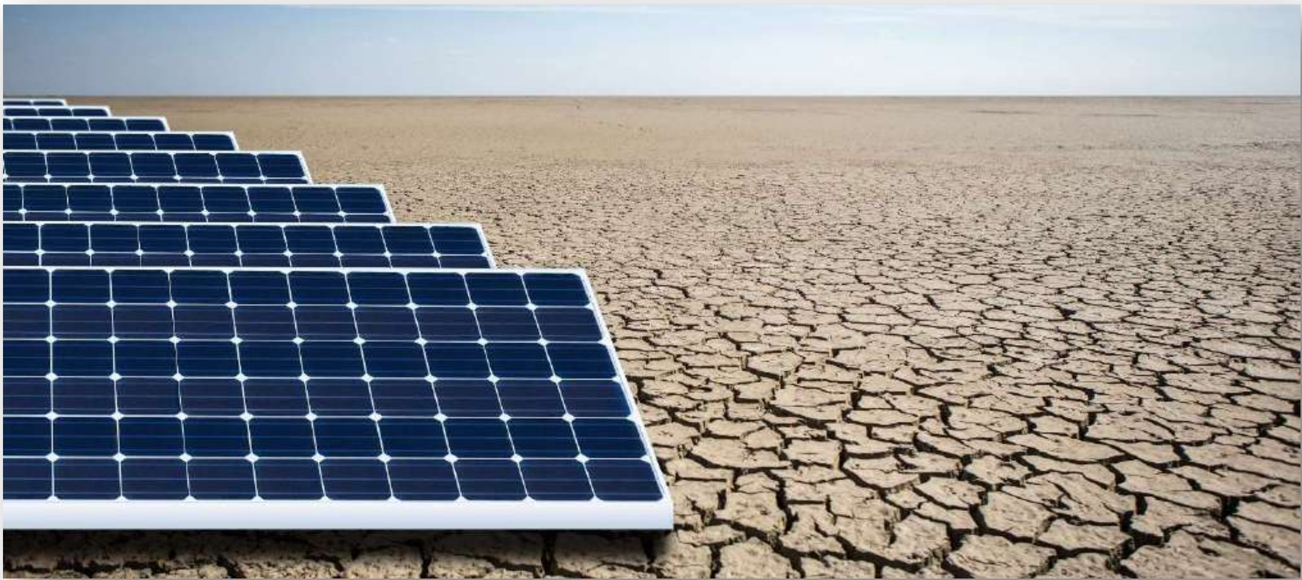
1 Common Component of PV Systems

Any type of PV system has three main components: modules, inverter, and module mounting structures. In case of off-grid systems, another major component is added - a battery. All other components are civil or electrical components that are commonly known, even in non-solar sectors. The number and/or capacity of these components change according to the Capacity and type of solar power system.

2 Solar Cell Technologies

The solar market is continually evolving, offering a range of technologies to meet diverse energy demands. In addition to traditional silicon-based modules, emerging technologies such as tandem solar cells, perovskite-silicon tandem modules, and bifacial modules are gaining attention. Tandem solar cells combine multiple materials to achieve higher efficiency, perovskite-silicon tandem modules harness the complementary absorption of sunlight, and bifacial modules capture light from both sides, increasing energy yield. The aim is always to accommodate more power in the same surface area by increasing efficiency and to make higher yielding solar modules, so that they become more cost-effective and acceptable all over the world.



Solar modules utilize different solar cell technologies, made up of different material and chemistry, each with its own characteristics and performance. The most widely used technology is crystalline silicon, which can be further categorized into monocrystalline and multi-crystalline silicon. Crystalline silicon cells offer high efficiency and long-term stability. Other technologies include thin-film, which are lightweight and can be flexible, perovskite solar cells known for their high efficiency potential, and organic solar cells, which use organic materials for cost-effective production. As on date these have limited use in the field as they are yet to be commercially viable.

3 Solar Modules

Solar modules, also known as solar panels, are devices that convert sunlight into electricity using the PV effect. They consist of interconnected solar cells, which are the building blocks responsible for this conversion, being the semiconductor junction where electrons are released and start flowing thereby inducing electrical current. Solar modules are designed to withstand various environmental conditions and provide a reliable source of renewable energy.

3.1 IV Curve, Solar Panel Construction, and Interconnection

The IV curve, or current-voltage curve, characterizes the electrical behaviour of a solar cell or module. It demonstrates the relationship between the output current and voltage under different illumination conditions. Solar panels are constructed by encapsulating solar cells in a protective layer and placing them in a frame structure. The interconnection of solar cells within a module can be achieved through series or parallel connections to achieve the desired voltage and current levels.

A proper and careful module construction ensures lifelong durability of the module and sustained performance over life without early degradation. The solar modules thus manufactured are subjected to various tests to comply with the relevant standards and also each module carries its unique IV curve that is also shared with the purchaser.

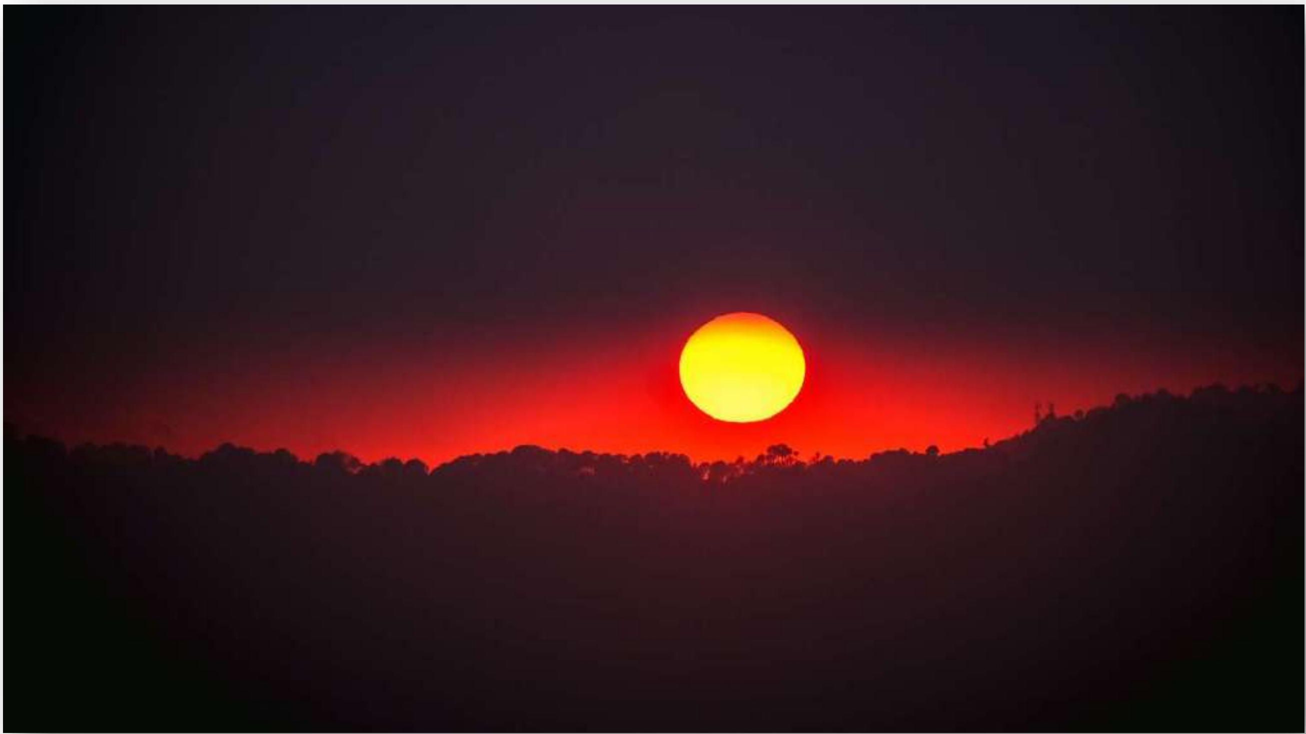
3.2 Efficiency and Fill Factor:

Efficiency is a critical parameter that measures the ability of a solar cell or module to convert sunlight into electrical energy. It represents the ratio of the electrical power output to the incident solar power. Fill factor quantifies how effectively a solar cell utilizes the available area to generate power. Higher efficiency and fill factor values indicate better performance and optimized energy conversion. Component selection, design of the particular model, and its construction in the factory have huge impact on the efficiency and the fill factor.

The efficiency of a module is lower than that of a cell because the cells are connected in series and parallel, and there are losses in these connections. Also, the encapsulant and the glass offer some resistance to the sunlight imparting on the surface. Though the efficiency of a module is defined when manufactured, the real power output keeps on varying in field conditions due ever-changing irradiance and temperature. Other factors like unclean surface of a module also impacts the output unfavourably.

3.3 Variation in Radiation, Impact of Partial Shadow, and Temperature Effects

Solar module performance is influenced by variations in solar radiation levels caused by factors like weather conditions and geographic location. Partial shading on modules, even from minor obstructions, can lead to significant power losses due to the mismatch of current and voltage. Temperature variations also affect module performance, with higher temperatures leading to decreased efficiency due to increased resistive losses.



3.4 STC & NOCT Conditions

STC and NOCT are the defined parameters used to characterize solar module performance. STC represents standard laboratory testing conditions and has three components:

- **Solar irradiance = 1,000 Watts per sq m**
- **Cell temperature = 25 degrees Celsius**
- **Air mass = 1.5**

However, in real field conditions the solar modules may never get such conditions to operate in. During the solar generation hours in a day the ambient temperature itself can be much higher and the cell temperature is always higher than the ambient by about 25 to 30 degrees. Similarly, the irradiance continues to vary; and at very few locations on the Earth, and that too only for a limited period, the modules may get much higher irradiance. Therefore, each module datasheet also presents the NOCT values of the module. The NOCT simulates nearly these real-world operating conditions. These normally are:

- **Solar Irradiance = 800 Watts per sq m**
- **Ambient Temperature = 20 Degrees Celsius**
- **Air Mass = 1.5**
- **Wind Speed = 1 m/s**

3.5 MONO PERC, Bifacial and Half-Cut Cell Modules and Advantages

MONO PERC solar modules are a technological advancement over monocrystalline, in module design. These capture part of the escaped solar rays through the regular cell surface, and within the cell structure provide a passivated surface wherein some more electrons are captured, and more power can be generated as compared to the regular monocrystalline module.

Bifacial solar modules, capable of capturing light from both front and back surfaces, offer increased energy generation potential by utilizing reflected and diffuse sunlight. The quantum of additional power depends on the back (terrace or ground) surface reflectivity, tilt angle of the module installation, and the distance of the rear cells of the module from the back surface.

Half-cut cell modules feature solar cells that are physically halved as the name suggests, thereby reducing electrical losses and increasing module efficiency. The advantages of a combination of half cut MONO PERC modules include improved shading tolerance, enhanced performance in low-light conditions, and reduced module degradation over time.

Over the years these types have become more popular due to their advantages as stated above.

3.6 Interconnection of Modules

Currently the individual module wattage is increasing day by day and has gone beyond 500 watt peak (Wp). However, to install larger power plants by using these modules requires interconnecting them in series and parallel. The modules in series are called a 'String'. Connecting a number of modules in series increases the voltage and the resultant string voltage must match the inverter Maximum power point tracking (MPPT) range. Therefore, the designer decides the number of modules in each string based on the inverter models selected for the particular power plant. Many such strings can be connected in parallel to make an array of required capacity.

It is important to connect electrically similar modules in series, as a string will operate at the lowest available individual module power in series. Dissimilar modules in one string will unnecessarily waste the potential of the higher capacity modules.

While planning the rooftop installation it is necessary to understand the possibility of shadows on the individual module in a string, because here again the full string will operate at the lowest power module, which will be the one in the shadow.

3.7 Effects of Environmental Factors

The solar modules in the field are subjected to all open environmental variations and these affect the module performance as well as life. The most common factor affecting day-to-day performance is dust or any other material accumulated on the glass surface. Dust accumulation, which is called soiling of the module, can have varying losses depending on the location, season, and frequency and method of module cleaning.

The temperature normally has a negative effect on the performance because normally the temperatures are higher than the STC; and higher the temperature, higher the losses in the module.

Probably the most important effect on the module performance and its life is from shadows. Not only does the power output reduce due to the shading of a cell or module, but cell life can drastically reduce because of sustained shadows. Hence, it is very critical to ensure that the modules, or even a part of a single module, is never in shade during the peak generation hours, normally between 9 AM and 4 PM on any day.

3.8 Datasheet Interpretation

Interpreting solar module datasheets is essential for understanding the specifications and performance characteristics of the modules. Datasheets provide information on parameters such as maximum power output, efficiency, temperature coefficients, voltage-temperature characteristics, and warranty details. Thorough interpretation of datasheets enables informed decision-making during module selection and system design.

4 Warranty, Standards and Quality Measures

Solar modules come with two different warranties - a product warranty against manufacturing defects and a performance warranty covering power output degradation over its lifetime. The product warranty is normally shorter, at about 10 to 12 years, whereas performance warranty is for a lifetime of over 25 or 30 years.

The replacement performance warranty terms and conditions need to be understood and all the manufacturer's guidelines on usage of modules must be followed so that the warranty doesn't become void.

Proper fixing, handling, installation, and interconnection of solar modules ensure optimal system performance, safety as well as continuation of warranty. Compliance with industry standards and quality measures, such as certifications like IEC 61215 and UL 1703, assures reliability, durability, and adherence to safety standards in solar modules.

5 Installation and Maintenance

It is important to note that solar modules do not generate constant power during the day as well as over the year. It is continuously changing.

Ideally the module should be installed at a proper tilt angle, normally equal to the latitude of the location for lower latitude region and 300 for higher latitude region, and with proper orientation, True South in the Northern hemisphere, and True North in the Southern hemisphere, i.e., facing the Equator.

Similarly, the module ideally must always be facing the Sun and so biaxial trackers are ideal for installation. These can provide East-West tracking of the Sun during the day and North-South tracking during the year. However, these add cost to the system and hence fixed tilt and orientation are practically used in many installations across the world.

Modules degrade over the years and each manufacturer provides the warranty of maximum degradation over their lifetime. The degradation warranty can be either linear where each year's highest degradation is warrantied, or stepped - where it is warrantied for the first 10 years and then for the next 25 years.

Modules need to be cleaned regularly and the frequency depends on the local conditions. The cleaning must be done with clean and soft water, with a soft cloth. Normally cleaning is carried out in the mornings or evenings when the module temperature is low. In rare conditions mild soap can be used to remove hard dust and other impurities. One should never use detergents as these will affect the glass surface, thereby reducing the solar radiation reaching the cell surface.

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)*