Module Outline

SOLAR TECHNOLOGIES, OPERATIONS AND APPLICATIONS

Disclaimer

Relevance and Background

Out of all the renewable energy (RE) sources, solar energy has been harnessed by mankind for many centuries in various forms. Due to the technology and application range, customers are still unsure of what technology is best for a particular application and how they should choose the product depending on their requirement. For example, there are many potential customers who wonder if the solar photovoltaic (PV) system also generates hot water or if the old solar water heating system on their roof can be used for lighting.

Solar thermal applications such as cooking, drying and heating were more well-known, but the advent of PV technology and its applications have changed the solar energy sector.

Thus, it is important that participants are made aware of different solar technologies, their applications and operations, and their costs.

Theme – Foundation
Competency 1 – General
Code of the Module – T01C01M02

Learning Outcomes

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

- Gain information on the important features and components of some prominent solar technologies.
- Learn the functioning, advantages, and limitations of some of the most common solar technologies and applications.
- Get an overview of global costing and economics of major solar technologies and products.

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M02 L01	Lecture on Solar Technologies, Operations and Applications

M02 L1: Lecture Presentation

The MS PowerPoint presentation begins by introducing solar energy basics and distinguishing between PV and thermal forms. Being the first technical training module on solar energy it provides an overview of all the products and systems in both these forms by explaining in brief the definitions of the terms, product features, common applications and some basic discussion on project costs and economics.

It begins by introducing the PV technology principle, possible PV system configurations, and explains the difference between on-grid and off-grid systems and their variants. It details some module and inverter types and mounting structure variants. The presentation also talks about the newly popular floating solar concept.

In thermal applications the low, medium and high temperature applications are discussed giving examples of cooking, heating and power generation technologies using solar heat.

Further, the presentation talks about some standard PV products – the available models and their uses. These include some common industrial applications as well.

Lastly it touches upon the major components on the project economics and costing aspects, discussing different parameters on which these are dependent.

Key Topics to be Covered

1 Introduction to Solar Energy
2 Solar Thermal Operating Principle
3 Solar PV Operating Principle
4 Standard Components of PV Systems
5 PV System Configurations
6 PV Technologies in Market
7 Solar Thermal Applications
8 PV Applications and Products
9 Costing and Economics of PV Applications

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SOLAR TECHNOLOGIES, OPERATIONS AND APPLICATIONS

1 Introduction to Solar Energy

The Sun is a massive source of energy in the form of light and heat. Harvesting solar energy takes place in both these forms through the use of photovoltaics (PV) and thermal. There is an energy form conversion in PV from light to electricity, whereas in thermal there is only the capture and transfer of heat to any medium. Therefore, thermal is a simple technique where a black body or surface is used to absorb and capture maximum heat from the Sun. However, in PV we need a higher technology where a special semiconductor junction is prepared, which captures light from the Sun and converts it to electrical current flowing through the cells and captured at the junction box for further use.

Common solar thermal uses are cooking, heating, and drying. Newly developed techniques enable us to use heat to produce steam and then to generate electrical power using turbines. Solar PV uses are to generate electricity for various applications.

2 Solar Thermal Operating Principle

Solar thermal devices normally work on three principles, absorption or collection of heat from the Sun, transfer or conduction of this heat to another medium, and storage of heat for further use. As the black colour absorbs more heat from the atmosphere, all the heat collection surfaces of these devices are in black. Similarly, as some metals like copper are good conductors of heat with much higher transfer capacity than many other metals, this is used in many devices. Solar water heaters work on this principle and the collectors are available in two types - flat plate and vacuum tube.

3 Solar PV Operating Principle

When solar irradiance, or radiation or rays in common language, falls on a semiconductor junction the photons impart the energy to the electrons, making them free to move. Thus, photon-induced voltage is called PV. The P and N semiconductor junction is prepared by different chemical depositions on a substrate, most common among these being Silicon. More the radiation falling on the surface, more the current flow. So, power generation from a solar cell is directly proportional to radiation. An individual solar cell is a unit to convert light to electricity and a number of these cells can be assembled to form a solar module. Because the solar cells need to be kept in the open, these are encapsulated in different plastic material and covered with glass from above. This provides the modules with the desired longer life. Any load like a battery or lamp can be connected to the output from the module, to use the generated electricity.

4 Standard Components of PV Systems

Common major components of PV systems are, solar modules to collect radiation and convert it to electricity, battery to store the generated energy, charger to charge the battery, inverter to convert DC into AC, and module mounting structures to fix and retain the modules in the open area for more than 25 years. Other components are regular electrical and civil parts like cables, connectors, circuit breakers, foundations for the structure and so on. For ground-mounted systems there are also other work items such as fencing the area, roads for easy access, and so on.

5 PV System Configurations

PV systems are broadly classified into on-grid and off-grid, depending on whether these interact with the utility electrical grid or not. There are different metering methods within the on-grid configuration and the most common are net metering and gross metering. Similarly the off-grid systems can be either stand-alone, having only solar as the sole energy source, or hybrid with more energy sources available to charge the battery.

5.1 On-Grid Systems

These systems are connected to the grid and can operate only when the grid in ON. Such systems are normally used for fully grid feeding (export) as in large capacity multi-megawatt projects (and gross metered rooftop projects), or for self-consumption as in net metered rooftop projects, but also being grid-interactive. These systems are not designed for particular loads and so the capacity decisions are not based on load wattage or operation hours like in off-grid. Any small or large capacity system can be built and energy exported to the grid.

In case the net metered rooftop system generates more energy than necessary, it is exported to the grid and stored or 'banked' there for future use. Banking of energy is in a sense energy accounting method wherein exported energy is measured so that credit can be given to the consumer. It should be noted that actual energy is not stored anywhere, either locally or in the grid. Such systems are connected to the consumer side of the grid. Gross metered systems are connected to the utility side of the grid because these are meant for exporting all generated energy to the grid.

The large capacity projects also export generated energy to the grid but may require first to step up voltage to the high-tension level so as to limit the current carried through the cables. Therefore, such systems have step-up transformers and other relevant switchgear for energy export.

5.2 Off-Grid Systems

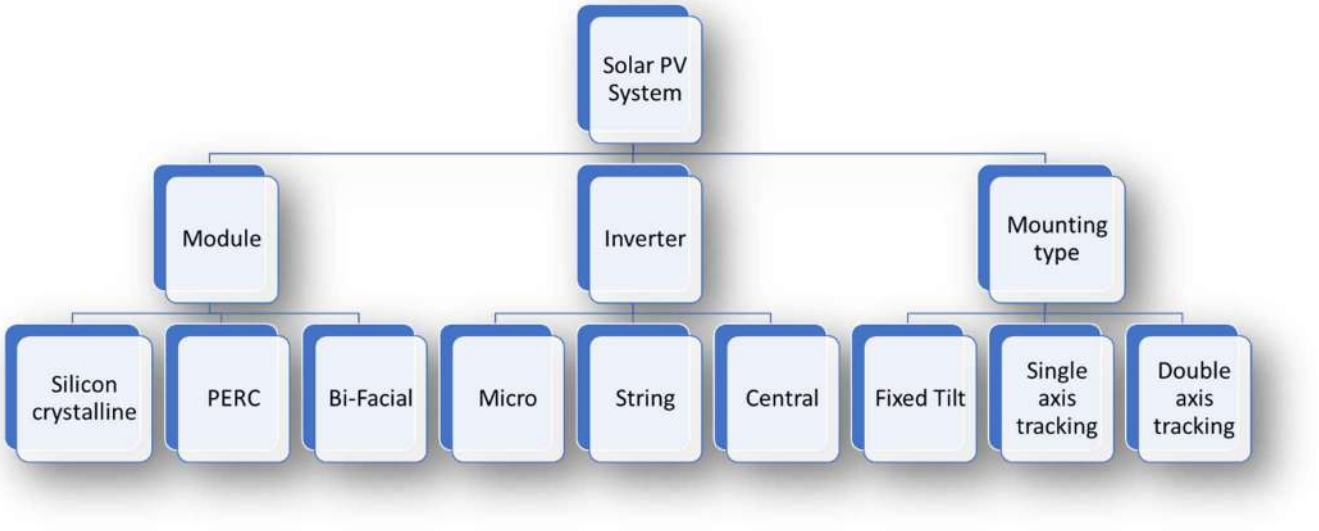
These systems are designed for powering or supporting particular loads for particular hours in a day. The modules and battery capacity depend on the energy requirement, whereas the inverter capacity depends on the power requirement. In case of stand-alone systems the battery capacity can be designed for higher than a daily requirement to take care of the "no-sun" days. If it is a hybrid system

with another source like AC grid or wind or DG set, the battery and module capacity can be reduced, thereby reducing the capital cost, and even then, supporting the daily load for the required hours.

Here the maintenance requirement increases because of the battery that needs to be topped up regularly, or alternatively a sealed maintenance-free battery can be used with additional higher capital cost.

6 PV Technologies in Market

There are different technologies available for PV systems, based on modules, inverters and module mounting structures.



Solar modules have developed over the years and increased in efficiency and other field operating conditions such as PID (potential induced degradation) effect, and life of the module. Similarly, individual module capacity is also increasing and has reached over 600 Wp.

This allows fewer modules for the same generation and leads to speedier installation in the field. After years of using Silicon crystalline modules with increasing efficiencies the current trend is to apply technology of Passive Emittance Rear Contact (or Cell) known as PERC wherein a rear surface also can convert the Sun rays escaped through the front cell surface and can add to the energy generation. Similarly, another type has evolved and is being used on a larger scale which has semiconductor surface on both sides of the module thereby increasing generation than a single surface cells.

The types of inverters, based on their relationship with the module, range from micro where each module can have an inverter, to central where more than 2 or 3 MW modules can have one single inverter. Most commonly used models currently are string inverters, which are of the mid capacity range from 1 kW to 100 kW.

The use of module-tracking structures is increasing in ground-based multi megawatt power projects because of their higher generation capability from the same module capacity. However, the fixed type still prevails in solar rooftop (SRT) installations.

With the advent of floating solar plants, the structure for floating the modules on water surfaces is also evolving with different designs being tried and tested.

7 Solar Thermal Applications

Solar thermal applications can be classified into three categories based on the temperatures they use: low, medium and high.

Low temperature applications include water heaters and cookers. These two products are very commonly used due to their portability, ease of use, and decades of experience. Box type or Dish type

cookers are used for making food during the sun-hours and have different models. Solar water heaters using any of the two collector types can be used for individual households or for a community. Larger heaters also find applications in industries where the processes require hot water or even steam, wherein solar heats water to about 80 to 90 degrees Celsius as pre-heating of boiler feed water.

Medium temperature applications include different concentrator designed dishes that concentrate solar heat onto a medium like water or oil, and heats it at temperatures in the range of 200 degrees Celsius. Common industrial sectors that can make use of this technology are textile, pharmaceuticals, food, dairy and so on. Such concentrators can also be used for cooking purposes for a larger requirement like industrial canteen or community kitchen, where generated steam is used in special utensils for cooking food.

High temperature applications use different types of concentrators to generate power by producing steam and running turbines on that steam to operate alternators to produce electricity. Tower or Fresnel or Parabolic designs are common in this application.

8 PV Applications and Products

Over the years many standard solar PV products have been developed and used all over the world. Some of these have been described below:

8.1 Solar Lanterns

Solar lanterns are very useful when the light source needs to be portable and quite handy. These lanterns have required capacity solar modules that charge the battery inbuilt in the lantern during daytime. Then in the evenings or in the night the LED powered light can be carried wherever required.

8.2 Home Lighting Systems

Home lighting systems can be designed in different configurations and capacities and is commonly used in individual homes for lighting purpose as well as for operating fans in the rooms, with interchangeable loads. The capacity of the module and battery depends on these loads.

8.3 Solar Streetlights

Solar streetlights are independently standing solar lights normally on poles to illuminate the surrounding area during the whole or part of the night based on the battery charging that happens during daytime with the solar module.

8.4 Small and Medium Power Packs

Solar power packs are very versatile in their uses because once the AC electrical power is produced by this pack it can be stored and used to support any kind of load for whatever operational hours during periods of no sunshine. These power packs can be of different capacities like a few kilowatts to a few hundred kilowatts and can be used anywhere.

8.5 Solar Water Pumps

Another very important use of solar energy can be for pumping water. Such solar water pumps normally do not have any energy storage device like batteries and can operate only during sunshine hours. The pump supported by solar can be of submersible or surface type and from 1 HP up to 10 HP capacity. It is useful to design or decide on the solar pump capacity based on the total head and the total water quantity required to be delivered at that particular head. Similarly individual households can also use solar pumps to pump water from ground storage to rooftop tanks.

8.6 Solar-Based Mini-Grids

Solar-based mini-grids are decentralized electricity distribution systems that rely primarily on solar energy to provide power to small communities or remote areas. These mini-grids combine solar energy generation with energy storage and distribution technologies to create reliable and sustainable electricity solutions for communities that are not connected to the national grid.

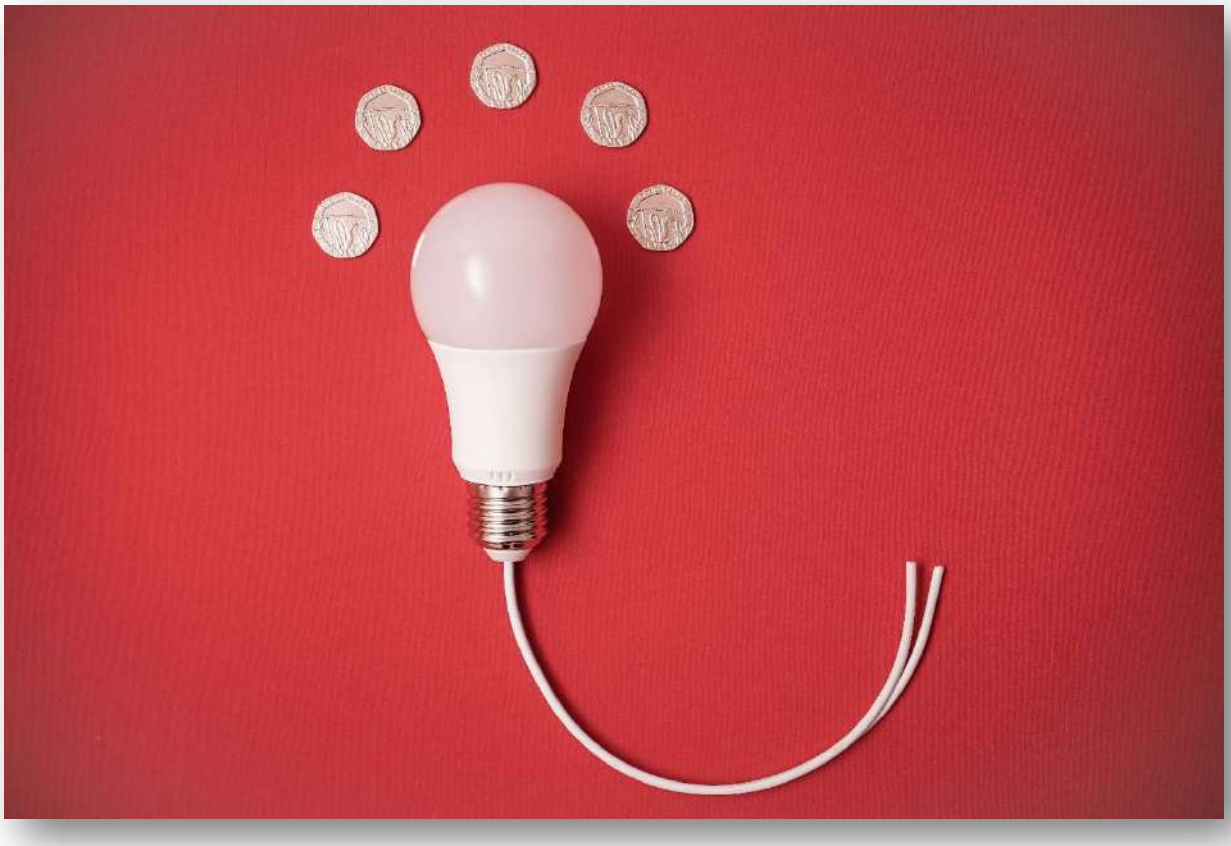
8.7 Off-Grid Industrial Applications

These include the solar products used as roadside "furniture" such as solar studs and traffic signals or warning lights. These are all stand-alone products with a module, charger, battery and the lights all integrated in a single product. So, they can be deployed without any external wiring, avoiding any road digging for installation or for maintenance.

Other standard solar products also used in many remote industrial applications are powering cathodic protection equipment along the pipelines carrying oil or gas, small telecom equipment powering needs, etc., and can be portable or stationary.

9 Costing and Economics of PV Applications

Overall, off-grid systems can be more expensive due to the presence of a battery in addition to other on-grid system components. However, such systems become economically viable and attractive when the users can increase their working hours or take up some productive activity, which otherwise was not possible due to the lack of reliable power. This is mainly true for remote areas where the main grid has not yet reached. Net metered systems in grid-connected systems are more attractive as these save the consumer energy purchase costs at higher tariffs and can pay back the system cost earlier than the gross metered system where the tariff paid for exported energy is normally much lower than the saved consumer retail tariff.



The solar power plant costs, a major component of the project economics, include costs from the planning stage to operating and maintaining the plant, along with all the charges and taxes levied on the project by different authorities.

The capital cost further has many variables dependent on the site, chosen equipment, term loan interest rates, permitting charges and O&M expenses. Similarly, the capital cost of the plant depends on types of modules, inverters and mounting structures used in the plant. The plant's per kilowatt

capital cost is adversely proportional to the plant capacity and reduces as the capacity increases. The cost for energy evacuation from the plant changes according to the voltage levels and distances of required transmission lines.

Depending on the business model, these expenses may be borne by the developer if the project is Opex type or by the consumer directly if it is Capex type. In an Opex model the cost has direct impact on the Power Purchase Agreement (PPA) tariff or rent charges or user charges for the user.

The revenue for the solar power plants depends on the implementation model. Revenue is from the saved tariff for net metered plants or from received tariff for gross metered plants.

Following is the discussion on economics of PV systems in some practical cases.

- Off-grid system for a household where grid has not reached or where grid is unreliable in the nighttime.
  - Here the comfort of having power is so much that rather than the economic attractiveness of the system the available budget decides the capacity that a consumer will go for.
  - This system can substantially improve the quality of life of the family and therefore the payback period is not as important.
  - Having power from the off-grid system can actually open up newer opportunities for the household for newer economic activities or increasing the hours of existing activity thereby earning more revenue because of this system, though not from the system itself.
- Net metered grid-connected system by an investor on roof of an industry
  - Investor wishes to get attractive returns on investment in a shortest possible period of time. This is possible when the roof is ideally sloping and is made up of metal, thereby reducing the structure cost.
  - The business of the consumer to whom the investor would supply power must be continuously expanding and must have long term continuity so that energy demands are growing and predictable. The business cycle of the consumer can have direct impact on the project economics for an investor.
  - The investment would be at risk in the scenario of reducing retail energy tariff for the consumer and therefore study of past and future trends is necessary.