

SOLAR PHOTOVOLTAIC SYSTEM

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BONAFIDE CERTIFICATE

This is to certify that this Professional Training Report is the Bonafide work of **P.SRIDHAR (39140055)** who underwent the professional training in “**ENERGY MANAGEMENT AND CONSERVATION**” from 27 OCT 2020 to 1 DEC 2020.

Internal Guide

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PHOTOVOLTAIC SYSTEM

A photovoltaic (PV) system is composed of one or more solar panels combined with an inverter and other electrical and mechanical hardware that use energy from the Sun to generate electricity. PV systems can vary greatly in size from small rooftop or portable systems to massive utility-scale generation plants. Although PV systems can operate by themselves as off-grid PV systems, this article focuses on systems connected to the utility grid, or grid-tied PV systems.

PV materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. In order to withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics.

To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays is then connected to the electrical grid as part of a complete PV system. Because of this modular structure, PV systems can be built to meet almost any electric power need, small or large.

PV modules and arrays are just one part of a PV system. Systems also include mounting structures that point panels toward the sun, along with the components that take the direct-current (DC) electricity

produced by modules and convert it to the alternating-current (AC) electricity used to power all of the appliances in your home.

How Do The Systems Work?

The light from the Sun, made up of packets of energy called photons, falls onto a solar panel and creates an electric current through a process called the photovoltaic effect. Each panel produces a relatively small amount of energy, but can be linked together with other panels to produce higher amounts of energy as a solar array. The electricity produced from a solar panel (or array) is in the form of direct current (DC). Although many electronic devices use DC electricity, including your phone or laptop, they are designed to operate using the electrical utility grid which provides (and requires) alternating current (AC). Therefore, in order for the solar electricity to be useful it must first be converted from DC to AC using an inverter. This AC electricity from the inverter can then be used to power electronics locally, or be sent on to the electrical grid for use elsewhere.

PHOTOVOLTAIC EFFECT

The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. It is this effect that makes solar panels useful, as it is how the cells within the panel convert sunlight to electrical energy. The photovoltaic effect was first discovered in 1839 by Edmond Becquerel. When doing

experiments involving wet cells, he noted that the voltage of the cell increased when its silver plates were exposed to the sunlight.

Process

The photovoltaic effect occurs in solar cells. These solar cells are composed of two different types of semiconductors - a p-type and an n-type - that are joined together to create a p-n junction. To read the background on what these semiconductors are and what the junction is, [click here](#). By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side. This field causes negatively charged particles to move in one direction and positively charged particles in the other direction.

Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy. These photons can be absorbed by a photovoltaic cell - the type of cell that composes solar panels. When light of a suitable wavelength is incident on these cells, energy from the photon is transferred to an atom of the semiconducting material in the p-n junction. Specifically, the energy is transferred to the electrons in the material. This causes the electrons to jump to a higher energy state known as the conduction band. This leaves behind a "hole" in the valence band that the electron jumped up from. This

movement of the electron as a result of added energy creates two charge carriers, an electron-hole pair.

When unexcited, electrons hold the semiconducting material together by forming bonds with surrounding atoms, and thus they cannot move. However in their excited conduction band, these electrons are free to move through the material. Because of the electric field that exists as a result of the p-n junction, electrons and holes move in the opposite direction as expected. Instead of being attracted to the p-side, the freed electron tends to move to the n-side. This motion of the electron creates an electric current in the cell. Once the electron moves, there's a "hole" that is left. This hole can also move, but in the opposite direction to the p-side. It is this process which creates a current in the cell.

SYSTEM COMPONENTS

In addition to the solar panels, there are other important components of a photovoltaic system which are commonly referred to as the "balance of system" or BOS.[3] These components (which typically account for over half of the system cost and most of the maintenance) can include inverters, racking, wiring, combiners, disconnects, circuit breakers and electric meters.

SOLAR PANEL

A solar panel consists of many solar cells with semiconductor properties encapsulated within a material to protect it from the environment. These properties enable the cell to capture light, or more specifically, the photons from the sun and convert their energy into useful electricity through a process called the photovoltaic effect. On either side of the semiconductor is a layer of conducting material which "collects" the electricity produced. The illuminated side of the panel also contains an anti-reflection coating to minimize the losses due to reflection. The majority of solar panels produced worldwide are made from crystalline silicon, which has an efficiency limit of 33% for converting the Sun's energy into electricity. Many other semiconductor materials and solar cell technologies have been developed that operate at higher efficiencies, but these come with a higher cost to manufacture.



INVERTERS

An inverter is an electrical device which accepts electrical current in the form of direct current (DC) and converts it to alternating current (AC). For solar energy systems, this means the DC current from the solar array is fed through an inverter which converts it to AC. This conversion is necessary to operate most electric devices or interface with the electrical grid. Inverters are important for almost all solar energy systems and are typically the most expensive component after the solar panels themselves.

Most inverters have conversion efficiencies of 90% or higher and contain important safety features including ground fault circuit interruption and anti-islanding. These shut down the PV system when there is a loss of grid power. PV systems either have one inverter that converts the electricity generated by all of the modules, or microinverters that are attached to each individual module. A single inverter is generally less expensive and can be more easily cooled and serviced when needed. The microinverter allows for independent operation of each panel, which is useful if some modules might be shaded, for example. It is expected that inverters will need to be replaced at least once in the 25-year lifetime of a PV array.

Advanced inverters, or "smart inverters," allow for two-way communication between the inverter and the electrical utility. This can help balance supply and demand either automatically or via remote communication with utility operators. Allowing utilities to have this insight into (and possible control of) supply and demand allows them to reduce costs, ensure grid stability, and reduce the likelihood of power outages.



WIRE

Wires are pieces of metal that transport electricity. They are usually flexible which makes them easier to use. These electrical conductors are key to all electrical devices, from the electric circuit board in a computer to the transformer in a neighborhood, or even the electrical transmission system carrying electric power hundreds of kilometers. Without wires electricity would be unavailable for everyone, making

them a necessary component to modern life. Depending on their purpose, wires can have varying sizes and compositions.

Wire gauge (size)

Differing cross sectional sizes of wires are known as wire gauges, they are organized by the American Wire Gauge system (AWG). Knowing the gauge is important because each is rated for a different ampacity, meaning that each wire size has a maximum electric current it can handle before damage (possibly serious) might occur. To read more on the American Wire Gauge system and how differing gauge sizes are utilized visit the wire gauge page.

Composition

Most wires are coated in an insulating material in order to prevent electrocution when handling. Typically this insulating material is composed of plastic or rubber-like material. However, very large wires used for electrical power transmission aren't always insulated since they are far overhead and their danger is limited. Smaller wires are often made of ductile material so that they can bend and be bent easily.

Copper

Copper wire - the most commonly used conductive wire - is cost effective and offers a low resistivity (only silver has a lower resistivity

but is very expensive). It is used in many commercial applications and therefore is widely available and comes in a variety of different gauges. Copper is quite ductile as well as being a good conductor, which is an added advantage for many applications.

Aluminum

Although aluminum wire is more cost effective than copper, its properties are not as favorable, it has a higher resistivity and has a lower elasticity (it's more plastic) meaning that if heated enough it expands and is more susceptible to diverging from its original shape once the heat is reduced.

Solid wires have only one conductive strand and are much more difficult to move or bend. They are typically used when a lot of movement isn't necessary or when the wire is small .

Stranded wires contain a large number of thin solid wires that are wrapped around each other to make a single larger wire. They are much more flexible than solid wires and are often used when the wire undergoes frequent movement or manipulation..

Superconductors

Wires made from superconductors can carry much higher electric currents than what is normally seen. For example, at the European Organization for Nuclear Research (CERN) a world record was recently

set for maximum current transmission. Using two 20 meter cables of magnesium diboride (MgB_2) - a superconducting material - cooled to 24 K (that's -249°C), a team was able to run 20 000 amperes (A) of current. This number is huge when compared to the maximum seen in non-superconducting wires, which is around 380 - 400 A. The superconductor was able to carry approximately 50x more current! Superconductors are very advanced materials and are may be useful for future electrical transmission systems.

ELECTRIC METER

An electric meter is a device used to measure the electrical energy usage of a home, building, or other electrically powered device. They are used in order to provide accurate billing to customers.

Analog electric meters, like the one seen in figure 1, make use of various coils and gears, however its operation can be simplified to that of an electric motor. The electric current moving through the coils produces changing magnetic fields in which a metal disc responds to. With the help of a permanent magnet, the disc spins proportional to how much electricity is used. Its motion rotates gears which finally show the reading on a clock-like dial.

Digital meters simply state the number of kWh of electricity have been used. It's important to note that neither the digital nor the analog meters reset at the beginning of the month, the power company subtracts off the start from the end to figure out how much to bill the household. Digital meters are often able to communicate directly with the power company, reducing the need for people to walk around neighbourhoods looking at everyone's meters.

How to read

An electric meter seems complicated with all of those spinning dials each rotating in opposite directions, however it isn't too difficult once the secret is revealed. The following video provides an excellent guideline on how to read an electric meter, which is summarized below.

Steps

Start at the far right dial. Record the digit that the dial is on, or if it is between two digits record the smaller of the two.

Now read the dial to its left, again recording the smaller of the two if it is between two digits.

Continue until the far left dial is recorded, then read the recorded number normally.

Notes

If the dial is between 0 and 1, 0 is the smaller number. However, if it is between 9 and 0, 9 is the smaller number (just like on a clock, where 12 is less than 1).

Remember that these dials are all interconnected. If it's unclear whether the dial has passed a number or not, read the dial to its right - if it has passed 0, the next dial is past the number.

The number given by the meter is measuring the electrical energy used (in kilowatt-hours, unless otherwise stated on the meter).

CIRCUIT BREAKER

Circuit breakers are electrical safety devices that protect electric circuits from overload electric current conditions. They do the same job as fuses, but are not destroyed when activated. During overload conditions a circuit breaker will open the circuit to prevent overload, and potential damage, like fires. Circuit breakers contain a switch to return to the closed position after they have been flipped.

Circuit Breaker Type

Description

The rma	Willrespondtotheexcessiveheatgeneratingduringoverloadcurrent conditions.
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I	
Ma gne tic	Will respond to the magnetic field generated during overload current conditions.
The rmo - mag neti c	Will respond to both the heat and magnetic field generated during overload current conditions. This is the circuit breaker equivalent to the slow blow fuse.

RACKING

Racking refers to the mounting apparatus which fixes the solar array to the ground or rooftop. Typically constructed from steel or aluminum, these apparatuses mechanically fix the solar panels in place with a high level of precision. Racking systems should be designed to withstand extreme weather events such as hurricane or tornado level wind speeds and/or high accumulations of snow. Another important feature of racking systems is to electrically bond and ground the solar array to prevent electrocution. Rooftop racking systems typically come in two variations including flat roof systems and pitched roof systems. For flat rooftops it is common for the racking system to include weighted

ballast to hold the array to the roof using gravity. On pitched rooftops, the racking system must be mechanically anchored to the roof structure. Ground mounted PV systems, as shown in figure 4, can also use either ballast or mechanical anchors to fix the array to the ground. Some ground mounted racking systems also incorporate tracking systems which use motors and sensors to track the Sun through the sky, increasing the amount of energy generated at a higher equipment and maintenance costs

Orientation & Inclination

Solar cells perform best when its surface is perpendicular to the sun's rays. This angle changes continuously over the course of the day and as the seasons change. Therefore, it is common practice for solar racking systems to fix solar arrays at the same angle as the latitude of the array's location to maximize annual energy production. This can be difficult to accomplish with roof mounted solar systems. To apply this knowledge with that variable in mind, it is important to have the solar array on the side of the roof that is facing the sun most often.

Roof Mounting

When a solar array is mounted on a rooftop, it is installed parallel to the roof with a few inches gap. If the rooftop is flat, then the racking system is installed so the solar array is aligned at an angle. In either case, the solar mounting system can be a part of initial construction of the building or be retrofitted to an existing roof.

Ground Mounting

Ground mounted solar panels are usually for large scale utility stations. The solar arrays are attached to the racking system with its foundation directly into the ground. In rare cases, these ground mounted solar arrays can be installed for residential use given the proper space allocation, lack of shading obstructions, and local/state regulations allow it.

BATTERY

Although still expensive, PV systems increasingly use rechargeable batteries to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high.

Common battery technologies used in today's PV systems include the valve regulated lead-acid battery— a modified version of the conventional lead-acid battery – nickel-cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self discharge as well as low investment and maintenance costs, they are currently the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid

batteries. Furthermore, as storage devices for PV systems are stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as, for example, in electric transportation. Other rechargeable batteries considered for distributed PV systems include sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively. In 2015, Tesla Motors launched the Powerwall, a rechargeable lithium-ion battery with the aim to revolutionize energy consumption.

PV systems with an integrated battery solution also need a charge controller, as the varying voltage and current from the solar array requires constant adjustment to prevent damage from overcharging. Basic charge controllers may simply turn the PV panels on and off, or may meter out pulses of energy as needed, a strategy called PWM or pulse-width modulation. More advanced charge controllers will incorporate MPPT logic into their battery charging algorithms. Charge controllers may also divert energy to some purpose other than battery charging. Rather than simply shut off the free PV energy when not needed, a user may choose to heat air or water once the battery is full.

OTHER COMPONENTS

The remaining components of a typical solar PV system include combiners, disconnects, breakers, meters and wiring. A solar combiner, as the name suggests, combines two or more electrical cables into one larger one. Combiners typically include fuses for protection and are used on all medium to large and utility-scale solar arrays. Disconnects are electrical gates or switches which allow for manual disconnection of an electrical wire. Typically used on either side of an inverter, namely the "DC disconnect" and "AC disconnect" these devices provide electrical isolation when an inverter needs to be installed or replaced. Circuit breakers or breakers protect electrical systems from over current or surges. Designed to trigger automatically when the current reaches a predetermined amount, breakers can also be operated manually, acting as an additional disconnect. An Electric meter measures the amount of energy that passes through it and is commonly used by electric utility companies to measure and charge customers. For solar PV systems, a special bi-directional electric meter is used to measure both the incoming energy from the utility, and the outgoing energy from the solar PV system. Finally, the wiring or electrical cables transport the electrical energy from and between each component and must be properly sized to carry the current. Wiring exposed to sunlight must have protection against UV exposure, and wires carrying DC current sometimes require metal sheathing for added protection

LIMITATIONS

Pollution and energy in PV production

PV has been a well-known method of generating clean, emission free electricity. PV systems are often made of PV modules and inverter (changing DC to AC). PV modules are mainly made of PV cells, which has no fundamental difference to the material for making computer chips. The process of producing PV cells (computer chips) is energy intensive and involves highly poisonous and environmental toxic chemicals.

There are few PV manufacturing plants around the world producing PV modules with energy produced from PV. This measure greatly reduces the carbon footprint during the manufacturing process. Managing the chemicals used in the manufacturing process is subject to the factories' local laws and regulations.

Impact on electricity network

With the increasing levels of rooftop photovoltaic systems, the energy flow becomes 2-way. When there is more local generation than consumption, electricity is exported to the grid. However, electricity network traditionally is not designed to deal with the 2- way energy transfer. Therefore, some technical issues may occur. For example, in Queensland Australia, there have been more than 30% of households with rooftop PV by the end of 2017. The famous Californian 2020 duck curve appears very often for a lot of communities from 2015 onwards. An over-voltage issue may come out as the electricity flows back to the network.[160] There are solutions to manage the over voltage issue, such as regulating PV inverter power factor, new voltage and energy control equipment at electricity distributor level, re-conductor the electricity wires, demand side management, etc. There are often limitations and costs related to these solutions.

Implication onto electricity bill management and energy investment

Customers have different specific situations, e.g. different comfort/convenience needs, different electricity tariffs, or different usage patterns. An electricity tariff may have a few elements, such as daily access and metering charge, energy charge (based on kWh, MWh) or peak demand charge (e.g. a price for the highest 30min energy consumption in a month). PV is a promising option for reducing energy charge when electricity price is reasonably high and continuously increasing, such as in Australia and Germany. However, for sites with peak demand charge in place, PV may be less attractive if peak demands mostly occur in the late afternoon to early evening, for example residential communities. Overall, energy investment is largely an economic decision and investment decisions are based on systematical evaluation of options in operational improvement, energy efficiency, onsite generation and energy storage.