PHOTOVOLTAIC AND SOLAR THERMAL ENERGY

Beemkumar N
Venkadeshwaran K

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KRISHNA NAGAR, DELHI

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BOOKS ARCADE
Regd. Office:
F-10/24, East Krishna Nagar, Near Vijay Chowk, Delhi-110051
Ph. No: +91-11-79669196, +91-9899073222
E-mail: info@booksarcade.co.in, booksarcade.pub@gmail.com
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CHAPTER 1

INTRODUCTION TO SOLAR ENERGY

Beemkumar N, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- n.beemkumar@jainuniversity.ac.in

The twenty-first century is shaping up to be the ideal energy storm. Increasing energy costs, declining energy supply and security, and rising environmental concerns are all transforming the global energy landscape. Energy and water are essential to contemporary living and create the foundation for long-term economic growth. For a variety of reasons, industrialised countries have grown more reliant on fossil fuels. Modern comforts, mechanised agriculture, and worldwide population increase have all been made possible by the use of cheap fossil fuels. fuels. Ensuring sustainable and future energy supply will be the most difficult problem for all civilizations in the twenty-first century.

Global energy consumption is expected to more than double during the first half of the twenty-first century and more than triple by the end of the century, due to a rising worldwide population and increased industrialization. The world's population is now nearing 7 billion, with forecasts for a global population surpassing 10 billion by 2050. Future energy needs can only be fulfilled by increasing the proportion of alternative fuels used. In order to fulfil this rising energy demand, incremental enhancements to current energy networks will be insufficient. Because of declining supplies and rising worries about the effect of burning carbon fuels on global climate change, fossil fuel sources cannot be used in the same way that they were in the past.

Obtaining adequate sources of clean and sustainable energy for the future is the most daunting task for global civilization in the twenty-first century. Renewable energy sources such as solar, wind, and biomass will play an increasingly vital part in the new global energy economy in the future. The main issue is how long it will take for this sustainable energy transition to take place. And how much environmental, political, and economic harm can be tolerated in the interim? If the twenty-first century's sustainable energy problem is not solved swiftly, increasing energy costs may cause significant famines and societal instability in many developing nations. Finally, the global economic order is at risk.

Roughly one-third of the world's population lives in rural areas without access to the electric grid, and around half of this population lacks access to safe and clean water. Solar energy is unique in that it can readily supply these people with power and pure water today with low infrastructure needs by using native energy resources that encourage local economic growth.

Regrettably, conventional fossil fuel energy consumption has had significant and escalating negative environmental consequences, including CO_2 emissions, global warming, air pollution, forestry, and overall global environmental deterioration. Moreover, fossil fuel deposits are not unlimited nor renewable; the supply is finite. Without a doubt, by the end of the twenty-first century, our society's current energy infrastructure will have undergone major modifications. A future energy mix that incorporates sustainable sources will benefit our economy and health. Our future energy demands must be fulfilled by a combination of environmentally friendly sustainable technology. Several of these technologies may utilise solar energy in all of its forms, allowing for a gradual transition to a hydrogen-based economy. Our best chance for a sustainable future is a renewable energy revolution.

Renewable energy for rural development

Considering that the demand for electricity rises more quicker in emerging countries than in industrialised ones, the shifting energy landscape will have a substantial influence on how power is delivered to developing areas. Industrialized nations must clean up their own energy production practises, while pushing emerging countries to not follow in their footsteps, but rather to leapfrog straight to clean energy technology. After three decades of large expenditures in electrification projects by less developed countries and multilaterals (sometimes at enormous environmental and social costs), approximately 2 billion people in poor areas throughout the world remain without power. Nearly a billion people do not have access to clean drinking water. For illumination, millions of homes depend primarily on kerosene lamps and throwaway batteries for radios. Most of these folks are unlikely to ever get energy from traditional grid sources. Yet, there is significant interest in utilising solar and wind energy to deliver power to developing nations. By using indigenous renewable energy resources and establishing long-term local employment and businesses, both solar and wind energy technologies provide energy independence and sustainable development.

The expense of providing electric power to unserved communities through transmission and distribution lines is high. This is mostly owing to limited residential electrical consumption and the fact that many settlements are situated far from the current grid, across tough terrain. Solar and wind energy systems may supply cost-effective, moderate quantities of electricity for lighting, communication, fans, freezers, water pumps, and other applications. Certain governments and national utilities, including those in Brazil, India, Central America, South Africa, Mexico, and others, have embraced PV and wind systems as an integrated development tool for electrification planning as either centralised or distributed solutions, using a least-cost methodology.

PV technology was virtually unknown two decades ago. The Dominican Republic was an early test bed for developing rural PV electrification projects. Enersol Associates, a non-profit organisation, started delivering technical support and training to Dominican enterprises in 1984. Nonprofits also attempted to create a market for rural PV technologies. Enersol started collaborating closely with the Peace Corps, utilising seed funds from the United States Agency for International Development (USAID) to establish a revolving fund that provides low-interest loans to rural farmers to acquire modest PV systems.

The activity of this nongovernmental organisation (NGO) ultimately morphed into commercial industry, with firms like Soluz forming in the Dominican Republic and Honduras. Small solar enterprises started to emerge gradually across the developing globe as PV module manufactures established distribution networks to service rural, unelectrified regions. With over 5 million systems deployed, the paradigm of rural off-grid PV systems has extended internationally. Each year, more total kiloWatts of grid-tie PV systems are built; however, numerically more tiny, off-grid systems are installed. The emphasis of PV projects has shifted throughout time. PV system installation for distant areas has grown to include the promotion of rural economic development via PV. PV energy is used to power distant water pumping, refrigeration, and water treatment in community water systems.

Individual home potable water demands may be met by solar distillation from even the most polluted and brackish water sources. For greater load needs, combining PV and wind technologies with diesel generators and battery storage has shown that hybrid systems give improved system dependability at a lower cost than any single technology alone. Solar thermal energy is the most cost-effective yet sometimes neglected solar technology alternative. Residential solar hot water heating systems generally have cost paybacks of 5 to 7 years, which is far better than grid-tied PV systems, where payback might take decades, if at all. Moreover, large-scale solar thermal concentrating solar power (CSP) facilities offer superior economies of scale than PV for utility power production, costing about half as much per kiloWatt-hour.

Solar and wind energy often offer the most cost-effective solutions for economic and community development of the rural areas across the world, producing power, generating local employment, and fostering economic growth with clean energy resources. PV installations in underdeveloped countries have improved the life of rural residents. Nonetheless, considerable work has to be done to educate, institutionalise, and integrate renewable technology for optimum benefit to everyone. One of the most difficult problems is to work on revising energy policies and regulatory frameworks in order to establish a climate that allows for the long-term growth of renewable energy technology.

Renewable Energy Solutions

There are several forms of energy. Kinetic energy is the energy accessible in the motion of particles, such as wind energy. Potential energy is the energy that is accessible due to the location of particles, such as water stored in a dam, energy in a coiled spring, and energy stored in molecules (gasoline). Mechanical, electrical, thermal, chemical, magnetic, nuclear, biological, tidal, geothermal, and other forms of energy exist. Renewable energy is defined as a nontoxic, clean energy source that cannot be depleted. The Sun, wind, biomass, tides, waves, and the heat of the Earth are the principal renewable energy sources (geothermal). Solar energy is known as renewable and/or sustainable energy since it is accessible as long as the Sun shines. The life of the Sun's main stage is estimated to be 4 to 5 billion years. Wind energy is obtained from the uneven heating of the Earth's surface caused by higher heat input near the equator, as well as the associated transport of water through evaporation and rain. In this way, rivers and hydropower dams store solar energy. Another element of solar energy is photosynthesis, which converts sunlight into biomass. This kind of solar energy is used to produce animal products such as whale oil and biogas from manure. Tidal energy is generated largely by the gravitational contact between the Earth and the moon. Geothermal energy is another renewable source, since it is created by the decay of radioactive particles from the formation of the solar system. Volcanoes are flaming manifestations of geothermal energy reaching the Earth's surface from its hot, molten core.

Altogether, biomass provides around 14% of the world's energy primarily wood and charcoal, but also agricultural leftovers and even cattle dung for cooking and heating. In underdeveloped nations, this leads to deforestation and topsoil erosion.

Solar energy from previous geological periods is stored in fossil fuels (i.e., ancient sunlight). While the amounts of oil, natural gas, and coal are huge, they are limited, and supplies are adequate to power the industrialised world for many decades to several centuries, depending on the resource. There are also significant environmental costs involved with fossil fuel use, ranging from habitat loss and devastation caused by strip mining and oil spills to warming temperatures brought on mostly by the combustion byproduct of carbon dioxide. Renewable energy has several benefits, including sustainability (it cannot be exhausted), universality (it can be found all over the globe, unlike fossil fuels and minerals), and the fact that it is virtually nonpolluting and carbon free. Renewable energy has the following drawbacks: unpredictability, poor density, and a usually higher initial cost for conversion gear. Other downsides or perceived difficulties with various kinds of renewable energy include: visual pollution, odour from biomass, claimed bird concerns with wind farms, vast acreage needs for solar conversion, and brine from several geothermal sources.

Global Solar Resource

Solar energy is the driving force behind all plant, animal, and human life on Earth. It offers a convincing answer for all cultures to satisfy their future demands for clean, plentiful energy sources. The nuclear interactions in the Sun's core are the source of solar energy, which derives from the conversion of hydrogen into helium. Sunshine is abundant, free of geopolitical disputes, and presents no damage to our ecosystem or global climate systems due to pollution emissions.

Solar energy is mostly transported to Earth in the form of electromagnetic waves, which may also be represented as particles (photons). The Earth is essentially a massive solar energy collector, receiving massive amounts of solar energy that manifest in various ways, such as direct sunlight used for plant photosynthesis, heated air masses causing wind, and ocean evaporation resulting in rain, which forms rivers and provides hydropower. Solar energy may be harnessed directly (through photovoltaics, for example), indirectly (by wind, biomass, and hydropower), or as fossil biomass fuels such as coal, natural gas, and oil. The sun is by far the most abundant carbon-free energy source on the planet. More energy from sunlight hits the Earth in one hour (4.3 1020 J) than the whole world consumes in a year (4.1 1020 J). While the Earth gets nearly ten times as much energy from sunshine each year as is contained in all known sources of coal, oil, natural gas, or uranium combined, most political and commercial leaders have given renewable energy a pathetically low priority.

In response to the building perfect energy storm of the twenty-first century, we are now seeing the beginning of a worldwide paradigm shift towards clean energy. As traditional energy costs climb, new and cleaner alternative will emerge, making them more economically viable. Future energy solutions are dependent on local, national, and global legislation. Individual actions and societal policies also have a role in finding solutions. This does not imply that we must live in caves to negate our energy inputs, but rather that we must make intelligent energy choices and save by, for example, driving fuel-efficient automobiles and insulating our houses. To face the ideal energy storm of the twenty-first century, we must all work together while performing our particular roles.

Solar Resource

Since worldwide energy consumption is predicted to quadruple over the first half of this century, our planet confronts tremendous problems in the twenty-first century. Faced with increasingly limited oil resources, mankind must turn to other energy sources such as solar to help fulfil rising energy demand. Energy consumption and efficiency are valuable indicators of a country's degree of development. Over use of fossil fuel energy has not only caused serious and escalating environmental harm from greenhouse gases and oil spills, but it has also driven nations into political crisis in the form of global resource wars and food shortages. Solar and other renewable energy sources provide a realistic, clean, and feasible answer to our planet's mounting environmental and energy issues. Solar radiation is the most essential natural energy resource since it powers all environmental processes that occur on the Earth's surface. The Sun delivers vast amounts of energy to the Earth. The energy stored in the seas helps keep the Earth's temperature at an equilibrium level, allowing for the stability of a wide variety of species.

Understandably, the Sun has always drawn humanity's attention and has been worshipped by various societies throughout the millennia, including the Egyptians, Incans, Greeks, and Mayans, among many others. The potential of solar energy to provide heat and power for our contemporary economies to use in a range of productive activities has been clearly proved, but it has yet to be broadly accepted globally owing to comparatively inexpensive fossil fuels. While solar energy is infinite and free, this is not the most practical energy source since it is not consistent over the day and cannot be sent quickly. Modern lives, on the other hand, need a consistent and dependable source of energy. Yet, there are techniques to compensate for these shortcomings. This chapter discusses the resources for understanding solar energy, such as energy irradiated from the Sun, the geometrical relationship between the Sun and the Earth, and the orientation of energy receivers, as well as the importance of acquiring reliable solar information for design process, operation, and management of solar technologies.

Sun–Earth Geometric Relationship

The quantity and intensity of solar radiation reaching the Earth's surface is determined by the Earth's geometric relationship to the Sun. This geometric connection and its ramifications for various seasons in both hemispheres are shown in Figure 1.1. The position of the Sun at every time and at any location on Earth may be estimated using two methods: first, basic equations using inputs such as the day of the year, time, latitude, and longitude, and second, advanced algorithms that provide the actual position of the Sun. Typically, such techniques are valid for a short time span ranging from 15 to 100 years; the best uncertainties obtained are more than 0.01. (Blanco-Muriel et al. 2001; Michalsky 1988). Ibrahim and Afshin detailed a step-by-step approach for applying an algorithm created by Meeus to determine the sun angles from 2000 B.C. to 6000 A.D., with errors of 0.0003. This chapter solely offers geometry calculations to help understand the nature of the variable incoming solar radiation.

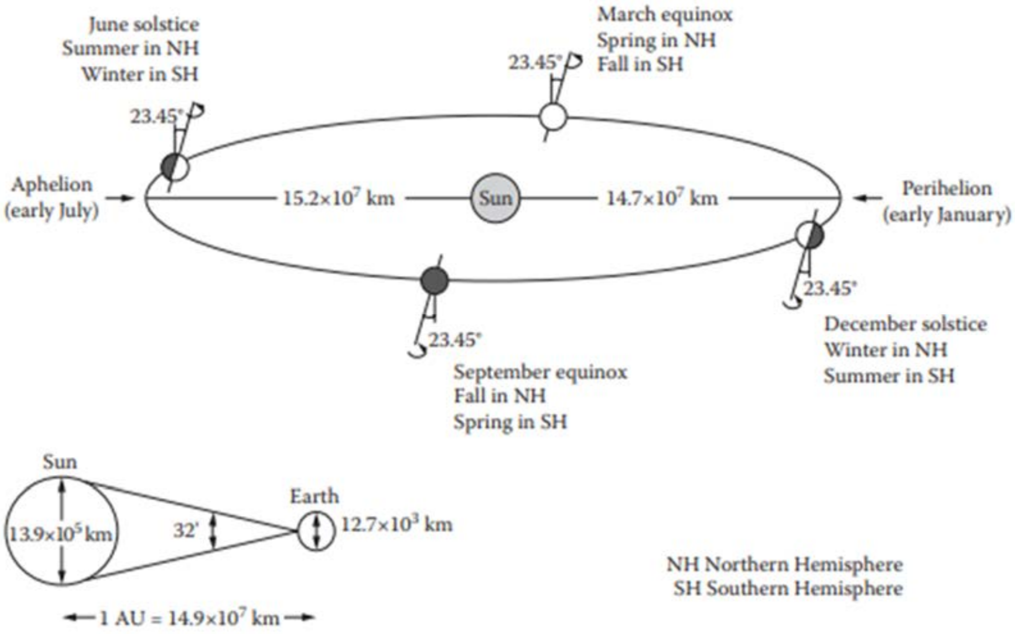


Figure 1.1 Represent the Earth–Sun geometric relationships.

The Earth's diameter is 12.7 103 km, which is roughly 110 times smaller than that of the Sun. Every 365 days, the Earth circles the Sun nearly once. The eccentricity of the Earth's orbit is relatively modest, roughly 0.0167, causing the elliptical route to be almost circular. The Earth's elliptical course fluctuates from 14.7 107 km in early January—the closest distance to the Sun, known as perihelion—to 15.2 107 km in early July—the furthest distance, known as aphelion. The astronomical unit (AU), which is used to calculate distances inside the solar system, is defined as the average Earth-Sun distance of 14.9 107 km. Yet, during perihelion, the Earth is around 4% closer to the Sun than at aphelion.

Apparent Path of the Sun

The Earth revolves on its axis at a very constant pace once every 24 hours. Such eastward rotation provides the impression that the Sun is moving in the other direction. The ecliptic is the visible route that the Sun takes in the sky as it moves from east to west throughout the day. The ecliptic plane is the geometric plane that contains the Earth's mean orbit around the Sun. Because of the total interacting forces between the planets, the Sun is not always precisely on such a plane, but may be a few arc seconds away from it.

the Earth's rotation axis is inclined 23.45° from perpendicular to the ecliptic plane and stays constant while the Earth circles the Sun. As a consequence, the angle between the Sun and a location on the Earth's surface fluctuates over the year, as does the length of the day. The duration of a solar day for a certain place might vary by up to 15 minutes every year, with an average of 24 hours. Seasons are also created by the Earth's continual tilt with regard to the ecliptic plane; when the northern axis points towards the Sun, it is summer in the Northern Hemisphere and winter in the Southern Hemisphere. Both hemispheres get the same quantity of light, but the Southern receives it at a more glancing angle, resulting in less concentration and less warming than the Northern. When the Earth's southern axis is oriented towards the Sun, the opposite is true. The Earth is also roughly 4% farther away from the Sun during the Southern Hemisphere winter than during the Northern Hemisphere winter, hence Southern winters are colder (Figure 1.2).

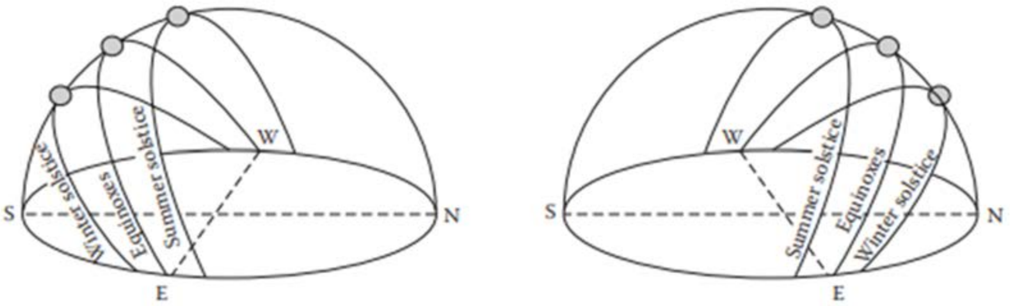


Figure 1.2 Represent the Apparent daily path of the Sun in the sky throughout the year for an observer in the Northern.

Winter days are brief in the Northern Hemisphere, and the Sun rises and sets at a low angle in the sky, rising just south of east and setting south of west. On December 21, the winter solstice, when the Sun is at its lowest in the southern sky, the shortest day of the year occurs. The Sun starts to rise closer to the east and set closer to the west each day following the winter solstice, until it rises precisely in the east and sets exactly in the west. The vernal or spring equinox occurs around March 21 and lasts for 12 hours.

Following the spring equinox, the Sun continues to rise higher in the sky as the days lengthen, until it reaches the highest point in the northern sky on the summer solstice, which happens on June 21. Today is the longest day of the year because the Sun takes the highest course across the sky and is directly above the Tropic of Cancer when the Northern Hemisphere is inclined towards the Sun to its greatest degree. Since this day is so lengthy, the Sun rises to the north of east and sets to the north of west, enabling it to stay above the horizon for more than 12 hours.

Following the summer solstice, the Sun moves lower in the sky each day until it reaches a place where it is visible for precisely 12 hours again. This is the autumn equinox. The Sun will rise precisely east and set exactly west, much as the spring equinox. The Sun will continue to follow a lower course across the sky after the autumn equinox, and the days will become shorter until it reaches its lowest path at the winter solstice. During the year, the Southern Hemisphere experiences the same cycle. The winter solstice, which occurs around June 21, is the shortest day. The Sun's height in the sky continues to rise, and the Southern Hemisphere spring equinox is achieved around September 21. Every location on Earth has a 12-hour day twice a year, during the spring and autumn equinoxes. Then, around December 21, the Sun reaches its highest position in the sky, marking the longest day of the year in the Southern Hemisphere, when it is squarely above the Tropic of Capricorn. Then, around March 21, the 12-hour day returns. Following then, the Sun continues to go lower in the sky until it completes the cycle for the Southern solstice.

Earth and Celestial Coordinate Systems

Latitude () and longitude () are two angles that characterise every position on Earth. Figure 1.3 depicts the Earth measurement system with continuous lines of latitude and longitude. The latitude is the elevation angle formed by a hypothetical line drawn from the centre of the Earth to any point on the surface and projected onto the equator plane. Latitude values range from 90° to 90°; zero at the equator, 90° at the northern pole, and 90° at the southern pole. In terms of the longitude angle, meridians are imaginary lines that run from pole to pole and are always at the same longitude. An angle is allocated to each meridian that crosses the equator's circle. The Prime Meridian is the meridian that passes through the former Royal Astronomical Observatory at Greenwich, England, and has been designated as zero longitude. Longitudes are measured from 0 to 180 degrees east of the Prime Meridian and 180 degrees west (or -180 degrees). The imaginary line that splits the sky in half and passes straight above is then the location's meridian. The phrases ante meridian and post meridian are abbreviated as a.m. and p.m., respectively.

More than latitude and longitude angles are required to calculate the quantity of solar energy received at every place on the Earth's surface. When the Earth coordinate system is extended to the celestial sphere, the precise location of the Sun with respect to a horizontal surface at any place on Earth may be calculated.

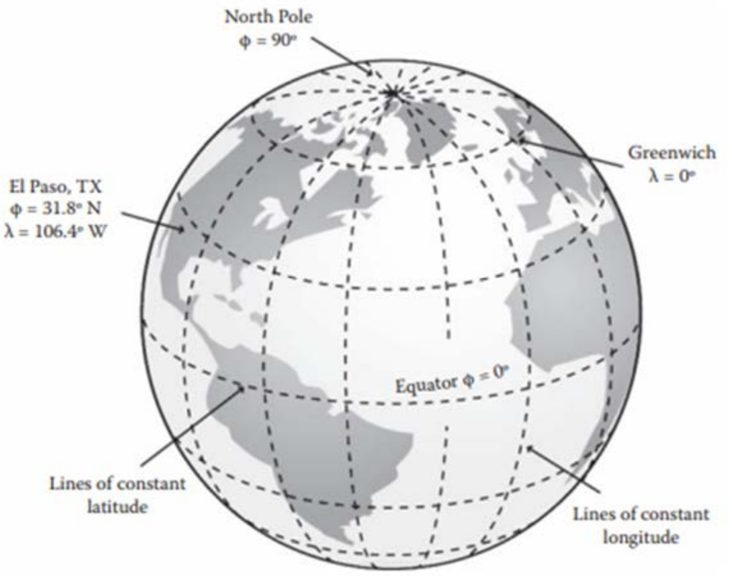


Figure 1.3 Represent Earth coordinate system.

The celestial sphere is a hypothetical sphere of unlimited radius, with the Earth at its centre and the stars projected on it. This notion is used to calculate the positions of stars in terms of angles, rather than distances. The celestial sphere's north and south celestial poles correspond to the Earth's north and south poles. The heavenly equator and the Earth's equator share the same plane. The right ascension angle () of an object on the blue sphere is measured eastward along the celestial equator, analogous to longitude on Earth; lines of constant right ascension run from one celestial pole to the other, defining = 0° for the March equinox—the location where the Sun is directly over Earth's equator.

Declination on the celestial sphere is measured northward or southerly from the celestial equator plane, similar to latitude on Earth. Constant declination lines run parallel to the celestial equator and have numerical values ranging from +90° to -90°. Due of the Earth's annual orbital motion, the Sun appears to circle the ecliptic up to an inclination of 23.45° to the equatorial plane for the equinoxes, -23.45° with = 0° at the equator for the solstices, and +23.45° for the June solstice (Figure 1.3).

Position of the Sun with Respect to a Horizontal Surface

In addition to the stable celestial coordinate systems on the sky, several angles dependent on Earth's coordinates must be known to represent the Sun's location with regard to a horizontal surface on Earth at any time: solar altitude (s), zenith (z), solar azimuth (s), and hour (hr) angles. Figure 1.4 depicts the geometric correlations between these angles that may be used to calculate the Sun's location in the sky at any moment. The solar height is measured in degrees from the horizon of the radiation beam's projection to the Sun's location. When the Sun is above the horizon, s equals 0°; when it is directly above, s equals 90°. The Sun will never be exactly above at most latitudes; this occurs exclusively in the tropics. Since the zenith is immediately above and 90 degrees distance.

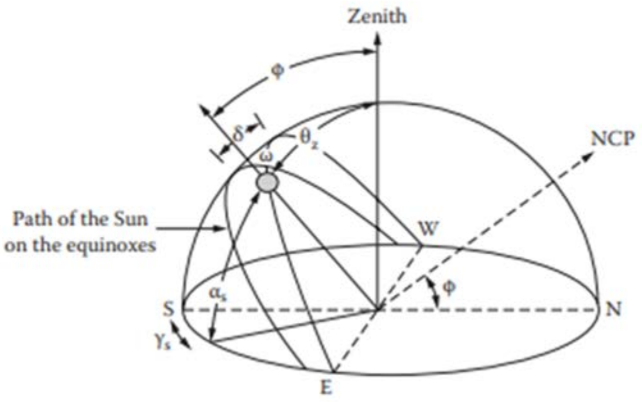


Figure 1.4 Represent the Position of the Sun in the sky relative to the solar angles.

CHAPTER 2

ELECTROMAGNETIC RADIATION

Venkadeshwaran K, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- k.venkadeswaran@jainuniversity.ac.in

Electromagnetic radiation propagates across space in the form of a wave with both electric and magnetic components. These components fluctuate in phase and at right angles with each other and with the direction of transmission. The wavelength () and frequency () of an electromagnetic wave define it. Since a wave is made up of consecutive troughs or crests, the wavelength is defined as the distance between two identical adjacent places in the propagating wave's repeating cycles, and the frequency is defined as the number of cycles per unit of time. The electromagnetic wave spectrum encompasses energy with wavelengths ranging from hundreds of metres, as in extremely long radio waves, to fractions of an atom, as in very short gamma ray waves. The wavelength units range from picometers (pm) to megameters (Mm); the frequency unit is the hertz (Hz), which is the inverse of time (1/second). According to, frequency is inversely proportional to wavelength (Figure 2.1).

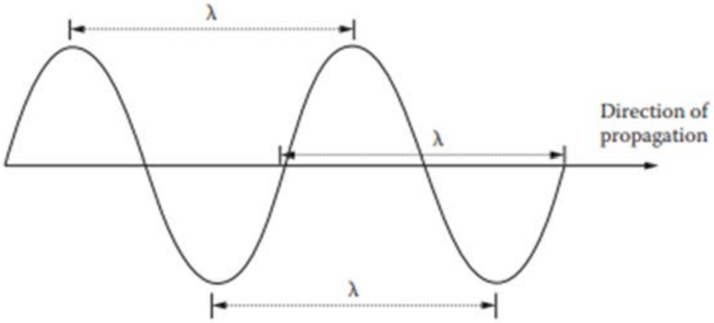


Figure 2.1 Represent the Electric and magnetic components of electromagnetic radiation.

Waves' speed and wavelength fluctuate when they traverse borders between mediums, but their frequencies stay constant. High-frequency electromagnetic waves have a short wavelength and a high energy, while low-frequency electromagnetic waves have a large wavelength and a low energy. Since the energy of an em phenomena is quantized, a wave is made up of discrete packets of energy known as photons. According to Planck's equation, its energy (E) is proportional to the frequency () of the electromagnetic waves:

Electrical energy, radio, microwave, infrared, the visible area we see as light, ultraviolet, x-rays, and gamma rays are the wavelength and frequency ranges that electromagnetic radiation is categorised into; their restrictions on wavelength and frequency There is no set boundary between areas; in actuality, there is often considerable overlap between surrounding forms of electromagnetic radiation.

Because of the mobility of electrons, all things at temperatures higher than 0 K produce energy as electromagnetic radiation. The notion of blackbody was established to examine the mechanics of energy exchange between radiation and mass. A blackbody is an ideal notion that refers to a perfect thermal radiation absorbing body with no reflection or transmission. When a thing is cold, it looks black because no light is reflected or transmitted. If the blackbody is hot, these characteristics make it an excellent generator of thermal radiation. The spectral absorption factor () is equal towards the emissivity () for a blackbody; this relationship is known as Kirchhoff's law of thermal radiation. The following equation thus applies to all wavelengths:

Solar Spectral Distribution

Electrical energy, radio, microwave, infrared, the visible area we see as light, ultraviolet, x-rays, and gamma rays are the wavelength and frequency ranges that electromagnetic radiation is categorised into; their restrictions on wavelength and frequency There is no set boundary between areas; in actuality, there is often considerable overlap between surrounding forms of electromagnetic radiation. Because of the mobility of electrons, all things at temperatures higher than 0 K produce energy as electromagnetic radiation. The notion of blackbody was established to examine the mechanics of energy exchange between radiation and mass. A blackbody is an ideal notion that refers to a perfect thermal radiation absorbing body with no reflection or transmission. When a thing is cold, it looks black because no light is reflected or transmitted. If the blackbody is hot, these characteristics make it an excellent generator of thermal radiation. The spectral absorption factor () is equal towards the emissivity () for a blackbody; this relationship is known as Kirchhoff's law of thermal radiation. The following equation thus applies to all wavelengths:

Terrestrial Solar Radiation

Solar radiation is almost constant in space; on Earth, it varies with the day of the year, time of day, latitude, and condition of the atmosphere. Solar collectors are surfaces that gather or deflect solar energy in solar engineering. The quantity of solar radiation that strikes solar collectors is also affected by the surface's location and the nearby terrain. Using a range of thermal and photovoltaic (PV) technologies, solar radiation may be turned into usable forms of energy such as heat and electricity. Thermal systems, among other things, create heat for heated water, cooking, heating, drying, melting, and steam engines. Photovoltaics provide power for grid-connected or stand-alone off-grid systems. UV sun radiation is also employed in chemical processes in certain applications.

The energy of electromagnetic waves is often transformed to heat when they are absorbed by an item. This is a well-known phenomenon because sunlight heats the surfaces it irradiates. This phenomena is often connected with infrared radiation, however any electromagnetic radiation will warm an object that absorbs it. Electromagnetic waves may also be reflected or dispersed, causing their energy to be diverted or redistributed. The total solar radiation incident on a horizontal (H) or slanted plane (I) consists of three components: beam radiation, diffuse radiation, and reflected radiation. Some of the sunlight that enters the atmosphere is absorbed, dispersed, and reflected by air molecules, water vapour, clouds, dust, and other particles. The measurement of the quantity of solar energy incoming to solar collectors may be expressed as irradiance and insolation for developing and designing solar energy systems. The instantaneous radiant power absorbed on a surface per unit area is referred to as irradiance. It is usually given as Watts per square metre. The insolation is calculated by integrating the irradiance over a certain time period. The integration typically represents hourly, daily, monthly, and annual data.

Another relevant definition of energy is the number of peak solar hours (PSH). This definition equates the power received by a 1 m2 horizontal surface during total daylight hours to the number of hours for which irradiance would have remained constant at one kW/m2. The PSH obtained on a clear day is The PSH is a helpful measure for comparing daily, monthly, seasonal, and annual energy changes for one site, as well as evaluating other locales. A solar resource map showing yearly or median PSH values is popular. The downside of solar-powered systems is that their energy supply is not continuous and stable during the day, and it also changes from day to day throughout the year. PSH is an energy metric that is used for sizing PV systems; the criteria range from (1) the month with the highest energy demand, (2) the month with the lowest PSH, or (3) the annual average PSH. Design choices are influenced by the investment, backup, cogeneration, and storage systems chosen.

The air mass (m) indicates the length of the route taken by solar radiation through the atmosphere. At sea level, m = 1 indicates that the Sun is directly above at the zenith, and radiation passes through a thickness of 1 atm (i.e., solar noon). Equation is a close approach to calculating air mass for zenith angles z ranging from 0 to 70° at sea level. The influence of the Earth's curvature becomes considerable at greater zenith angles and must be considered. At one air mass, the Earth's atmospheric gases scatter blue light more than red. Since most of the violet, blue, coloured, and yellow light is dispersed, the orange and red hues dominate for an observer on Earth during dawn or sunset, when sunlight's travel through the atmosphere is longest. Since the Sun's rays must travel through considerably more atmosphere, the hue changes. Refraction as the Sun sets may occasionally be seen as a "green flash" in the last seconds before the Sun disappears below the sky (e.g., over water in tropical regions).

The flow of energy from the sun is referred to as solar power. Heat and light are the two basic types of solar energy. The environment transforms and absorbs sunlight and heat in a variety of ways. Renewable energy flows such as biomass, wind, and waves are the outcome of some of these processes. Solar energy absorption in the environment also causes effects such as the jet stream, the Gulf Stream, and the water cycle. In the upper atmosphere, the Earth gets 174 petawatts (PW) of solar energy. 6% of the incoming solar energy (insolation) is reflected and 16% is absorbed as it travels through the atmosphere. Average air conditions (clouds, dust, pollutants) limit insolation by 20% by reflection and 3% via absorption. The absorption of solar energy by air convection (sensible heat transfer) and water vapour evaporation and condensation (latent heat transport) power the winds and the water cycle.

Atmospheric conditions not only restrict the amount of insolation reaching the Earth's surface, but they also impact its quality by scattering roughly 20% of the incoming light and modifying its spectrum. After travelling through the Earth's atmosphere, around half of the insolation is in the visible electromagnetic spectrum, with the other half predominantly in the infrared and ultraviolet range (Figure 2.2).

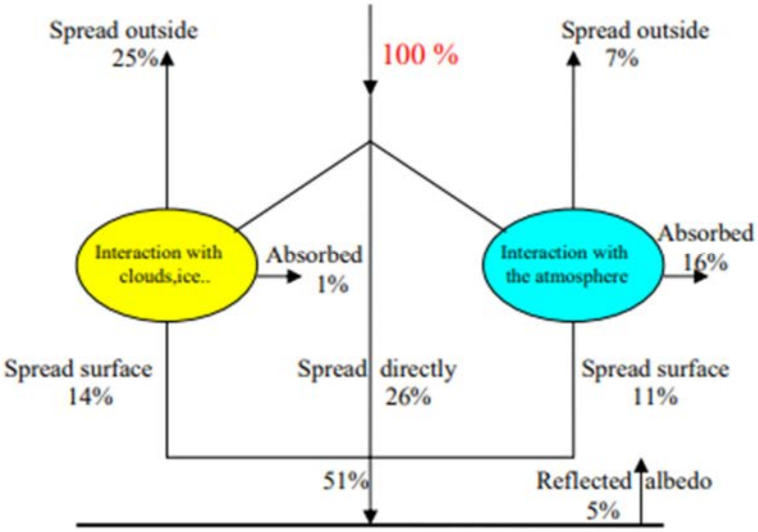


Figure 2.2 Represent the Incident Radiation.

Solar energy has immense potential, as shown by all of the prototypes, and predictions concerning this sort of technology indicate that the efficiency of these systems may be significantly boosted. Various active solar heating and solar thermal power generating processes are theoretically possible and financially effective, with some commercially accessible facilities producing up to 350MW. These systems are very reliant on the local environment and energy demands; this is a significant drawback since these systems can only be implemented in particular places.

The biggest impediment to the development of the these systems is the cheap cost of fossil fuels and their widespread availability, such as coal and biomass. Solar systems have a minimal environmental effect, and one of the most significant advantages is that they do not emit CO2 or other poisonous gases or radioactive material, which are created by present energy production systems. The sole expenditures of these energy systems are the building and maintenance of the plant; the energy source is free and, in principle, endless. These systems have almost little environmental effect. Other drawbacks include the fact that these systems may only be built in places where solar radiation is higher throughout the day and throughout the year. They are also inefficient in comparison to modern energy systems. These systems may be a mix of solar energy generators and traditional fossil fuel generators, which has the benefit of providing electricity even when there is no solar energy available.

Solar Thermal Energy Applications

Domestic Water Heating

A solar home hot water system collects solar energy using a flat-plate collector and transfers it to water or another liquid flowing via tubes. When you require hot water inside your house, the system pulls from this reservoir. This system is often used in conjunction with an existing gas or electric hot water system to minimise your energy cost and deliver 40-70% of your household's yearly hot water demands (Figure 2.3).

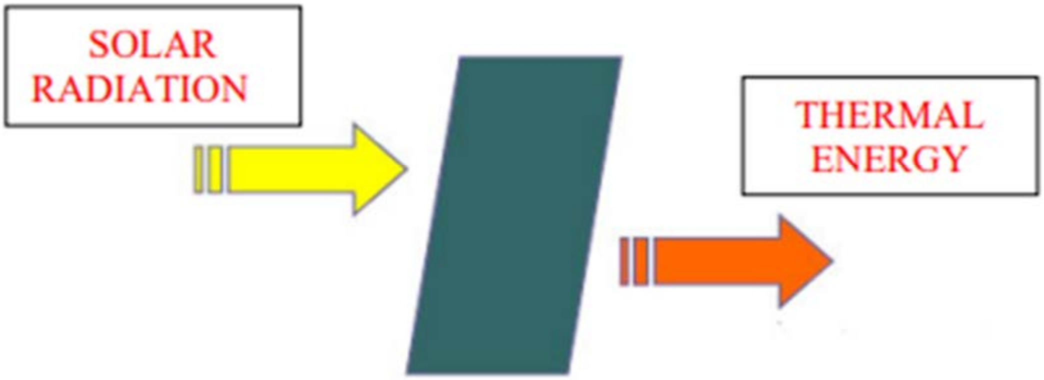


Figure 2.3 Represent the Domestic Water Heating process.

There are two types of solar hot water systems: active and passive. An active pumping system may be either open loop, in which the water is immediately heated by the solar concentrator, or closed loop, in which an antifreeze or glycol combination is heated before being transferred to the water through a heat exchanger. A drain back system is a common kind of closed loop system design. When freezing conditions prevail, its freeze-proof construction empties water back into a tiny holding tank. A passive solar system uses natural sources to heat water for home use, which is more common in warmer areas with less possibility of freezing.

A solar space heater captures the sun's energy via a solar collector and sends it into a "thermal mass" for later storage when the area is at its coldest. A thermal mass may be a brick wall, a floor, or other kind of storage drum that is especially designed to absorb and store energy. A distribution system and control devices are used in many systems to circulate heat throughout the room and prevent heat loss from the collection area. These systems may be paired with a solar-powered water heater and scaled to meet the needs of both. Solar heaters are more cost effective than electrical heating systems.

Solar Cooking

Solar cooking is a technique that has received a lot of interest in underdeveloped nations in recent years. The fundamental shape is that of a box with a glass lid. The box is insulated, and a reflecting surface is used to direct heat towards the pots. To aid heat absorption, the pots might be painted black. The sun radiation boosts the temperature enough to cause the contents of the pots to boil. Cooking time is often much longer than with traditional cooking stoves, but there is no fuel expenditure.

Numerous variants on this concept have been created, but the fundamental constraint has been lowering prices enough to allow broad adoption. The cooker also has restrictions in that it may only be used during hours of direct sunlight. Another cooking stove is frequently necessary when there is cloud cover or during the early or late afternoon hours. Solar cooking stove distribution programmes have been substantial and heavily subsidised in India, Pakistan, and China.

Crop Drying

Drying under controlled conditions is essential for a variety of crops and products, including grain, coffee, tobacco, fruits, vegetables, and fish. Their quality may be improved if drying is done correctly. Such materials may be dried with the help of solar thermal technology. The basic operating idea is to increase the temperature of the product, which is normally housed inside a compartments or box, while also6. moving air through the container to eliminate moisture. The'stack' effect, which takes use of the fact that heat rises and may therefore be pushed higher via a chimney while pulling in cooler air from below, is often used to enhance air flow. A fan may also be used as an alternative. The compartment's size and form vary from product to product and the size of the drying system. Big systems may make use of enormous barns, whilst smaller systems may just contain a few trays in a tiny wooden structure. Solar crop drying solutions may assist minimise environmental damage caused by crop drying with wood or fossil fuels, as well as the associated costs with these fuels and hence the cost of the output. Helping to develop and safeguard crops has a positive impact on health and nutrition.

Space Cooling

The bulk of the worlds developing nations, however, lie within the tropics and have minimal need of space heating. There is a demand, however, for space cooling. The majority of the globe warmclimate civilizations have again established classic, simple, elegant techniques for cooling their houses, typically utilising effects fostered by passive solar phenomena.

There are various strategies for limiting heat gain. They include sitting a structure in shadow or near water, employing vegetation or landscaping to guide wind into the building, smart town planning to optimise the prevailing wind and available shade. Structures may be designed for a certain environment - domed roofs and thermally massive structures in hot desert regions, shuttered and shaded windows to prevent heat gain, open structure bamboo homes in warm, humid areas. In certain nations homes are built underground and take advantage of the pretty modest and consistent temperature of the surrounding earth. There are as many possibilities as there are individuals.

Day-Lighting

Solar energy may be used to provide light in buildings, which is a basic and apparent use. Many contemporary structures, such as office buildings and commercial properties, are built with electric lighting in mind. should be given throughout the day to provide enough lighting for the activities going place therein. A clear improvement would be to construct structures such that the light of a sun may be utilised for this purpose. Energy savings are substantial, and natural illumination is often favoured over artificial electric lighting.

Solar heating that is active. To gather solar radiation, a separate solar collector, normally located on the top of a structure, is always used. Collectors are typically relatively simple, and the heat generated is low in temperature and utilised for home hot water or swimming pool heating.

Thermal solar engines.

These are an extension to active solar heating, often using a more complicated collector to generate temperatures high enough to operate a steam turbine to generate electricity. Solar thermal systems primarily employ air to circulate the gathered energy, typically without the need of pumps or fans; in fact, the collector is often an inherent component of the structure.

Absorber coating

There are two procedures: paints and selected surfaces: The black paintings absorb solar energy well, but have a high emission coefficient. They are less expensive than selective surfaces, but they deteriorate due to UV light. Selective surfaces are coatings that have a high absorption coefficient but a low emission coefficient. They have a superior overall performance. To prevent heat losses, the absorber is shielded on the rear side. Isolators for this purpose are often constructed of fibre glass or polyurethane. These isolators have the following characteristics: 34 Excellent performance at temperatures about 150o C 34 Aging 34 Good humidity resistance The housing protects the collector's many components. It possesses the following properties: 34 stiffness 34 resistance to temperature fluctuations corrosion resistanc protection against elements such as water, snow, and ice. The absorber plate has a very dark surface and a strong absorptivity. Most standard black pigments still reflect around 10% of incoming radiation. Some panels use a selective surface with high absorption in the visible area and low emissivity in the long-wave infrared region. In general, an absorber plate must have a high thermal conductivity in order to transmit the gathered energy to the water with the least amount of temperature loss.

Mounting

Roof-mounted solar collectors are often difficult to access for maintenance and repairs once installed. They must be resistant to internal corrosion and extreme temperature changes. A double-glazed collector has the potential to produce boiling water in the summer if the heat is not removed quickly enough.

Medium Temperature And High Temperature

The sun's rays are utilised to create heat in a solar power producing system. Similar to typical oil, coal, or nuclear power plants, these systems employ this energy to generate high temperatures that may boil water and drive steam machines to do mechanical work or operate electrical generators. There are two types of solar thermal efficiency: those with and those without sun ray concentration. The devices that concentrate sun rays employ mirrors or lenses to focus light into a specified zone in order to generate high temperatures. Once installed, roof-mounted solar collectors are sometimes difficult to reach for maintenance and repairs. Internal corrosion and significant temperature variations must be avoided. If the heat is not evacuated soon enough, a double-glazed collector may create boiling water in the summer.

Solar Towers

Also known as heliostat power plants or central receiver systems. An arrangement of adjustable mirrors that monitor the sun's course directs sunlight into the a boiler at the top of the centre tower in this facility. Because of their high thermal capacity and conductivity, this boiler heats liquid fuel or molten rock salt. This heat may be kept by those components for later use, and recent designs demonstrate that it can be stored for 3 to 13 hours. A solar tower may generate 30 to 200MW.

Parabolic Through Concentration Systems

Large fields of parabolic trough shaped mirrors with a tube running across their length at the focus point are used in this technique. The collectors heat synthetic oil to 390 degrees Celsius, which then produces high-temperature steam through a heat exchanger. This system has a solar to power conversion efficiency of 14 to 22% and a thermal efficiency of 60 to 80%. In the lack of sunlight, these plants rely on traditional power sources.Further components, such as condensers and accumulators, are required in hybrid systems. A typical parabolic trough plant may generate between 14 and 80 MW.

Parabolic Dish Concentrator Systems

This method places the engine in the centre of a parabolic dish-shaped reflector. Some advanced systems may achieve conversion efficiencies of up to 30%. The temperature at the focus point may exceed 3000 degrees Celsius, which can be utilised to generate power, melt steel, or create hydrogen fuel. This plant has a capacity of 7 to 25kW. The most frequent method for concentrating solar energy is to use parabolic mirrors, which reflect the sun's beams in parallel, allowing us to focus all of the reflections into one spot. The sun's rays may be concentrated in two ways: line focus, which concentrates the rays on a small area running across the width of the mirror, and point focus, which concentrates the sunlight in a pinpoint at the centre of the mirror. The alternative kind of system does not focus solar rays; instead, the area to be heated is exposed directly to the sun, with no auxiliary components. This results in less efficient systems, yet they are additionally simpler to build and maintain.

Solar Pond

A big saline lake is employed as a plate collector in this system. Solar energy may be absorbed at the lake's bottom with the proper salt content in the water. The heat is insulated by the varied densities of the water, and at the bottom, the temperature may reach 90 degrees Celsius, which is hot enough to power a vapour cycle engine, while at the top, the temperatures can reach 30 degrees Celsius. A solar pond contains three layers of water: the top layer, which has a lower concentration of salt, the intermediate layer, which works as a thermal insulator, and the bottom layer, which has a higher concentration of salt. These devices have a poor solar to electrical conversion efficiency of less than 15% (ambient temperature of 20 degrees Celsius and stored heat of 80 degrees Celsius). Since the heat is stored, this system may operate at any time of day or night if necessary. It may also be built in rural regions of underdeveloped nations because of its simplicity (Figure 2.4).

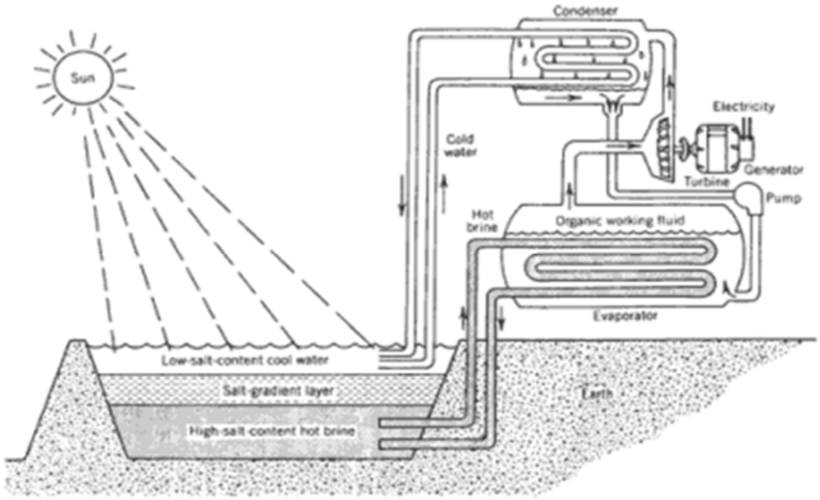


Figure 2.4 Solar Ponds.

A big saline lake serves as a plate collector in this arrangement. Solar energy may be absorbed at the lake's bottom with the proper salt content. The heat is insulated by the varied thicknesses of the water, and at the bottom, the temperature may reach 90 degrees Celsius, which is hot enough to power a vapour cycle engine; at the top of the pond, the temperature can reach 30 degrees Celsius. A solar pond includes three layers of water: the top layer, which contains less salt, the middle layer, which works as a thermal insulator, and the bottom layer, which has a high salt content. These systems have a poor solar to electricity conversion efficiency of less than 15% (ambient temperature of 20°C and stored heat of 80°C). Since the heat is stored, this system may operate day and week if necessary. It may also be built in rural locations in underdeveloped nations owing to its simplicity.

Passive Solar Heating

Passive solar solutions transform sunlight into useable heat, produce air movement for ventilation or cooling, or heat for future use, all without the need of external energy sources, and are the most cost-effective way of delivering heat to buildings. In general, the quantity of solar energy that falls on a home's roof exceeds the total energy utilised inside the building. Passive solar applications, when included into original building design, contribute little or nothing to the cost of a structure while achieving a decrease in operating expenses and equipment demand. It is dependable, mechanically simple, and a valuable addition to any household.

Passive solar systems have minimal to no running costs, generally need little maintenance, and generate no greenhouse emissions while in use. They must, however, be tuned to provide the optimum performance and economics. Energy conservation decreases the scale of any renewable or conventional energy system while considerably improving economics, hence it must come first. Passive solar systems often provide substantial solar savings percentages, particularly for space heating; when paired with active solar technologies like photovoltaics, even greater conventional energy savings may be realised.

A system refers to the mechanism of heating and cooling equipment. A building (home, apartment house) is created, and a heating/cooling system employing forced air equipment with air ducts; radiant floor using hot water; and so on are particularly developed for it. The system is incorporated into the building features and materials in passive building designs - the windows, walls, floors, and roof serve as the heat collecting, storing, releasing, or distributing system. These same features play an important role in passive cooling design, but in a totally different way. It should be noted that passive solar design does not necessarily imply the elimination of standard mechanical systems; however, recent designs coupled with high efficiency back-up heating systems greatly reduce the size of traditional heating systems and the amount of nonrenewable fuels required to maintain comfortable indoor temperatures, even in the coldest climates.

CHAPTER 3

DIRECT GAIN TECHNIQUE

Venkadeshwaran K, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- k.venkadeswaran@jainuniversity.ac.in

A direct gain design is the most basic technique. Sunlight is let into the room, and almost all of it is converted to heat energy. The walls and floor are employed for solar collecting and thermal storage by directly capturing and absorbing reflected or reradiated energy. Storage mass will transfer heat to their cores as long as the ambient temperature stays high in the interior area. As the outside temperature drops and the inside space cools at night, the heat flow into the storage masses reverses and heat is given up to the cabin space to achieve balance. This re-radiation of accumulated daytime heat may keep you warm on chilly evenings and last for many overcast days without needing to be recharged.

Direct gain design is basic in principle and may utilise a broad range of materials and concepts depending on the site and terrain; building placement and orientation; building form; and space utilisation. A direct gain design necessitates the use of thermal storage materials for about half to two-thirds of the total interior surface area. They may comprise floor, ceiling, and wall components made of masonry (concrete, adobe, brick) or water. Water confined inside a plastic or metal container and put directly in the direction of the sun's rays heats up faster and more evenly than stone walls during in the convection process. The convection mechanism also keeps surface temperatures from getting excessively high, which may happen when dark coloured brick surfaces are exposed to direct sunlight. The brick heating issue may be solved by utilising a glazing glass that distributes sunlight so that it is more uniformly dispersed across the storage masses on the walls, ceiling, and floor. This reduces the intensity of rays striking any particular surface but has no effect on the quantity of solar energy entering space.

Indirect Gain

This passive solar design strategy combines the fundamental aspects of heat collecting and storage with the convection process. Thermal energy storage materials are put between the interior livable area and the sun in this manner, so there is no direct heating. Instead, a dark-colored thermal storage wall is installed directly behind the south-facing glass (windows). Sunlight enters the storage wall via the glass and is instantly absorbed at the surface, where it is either stored or ultimately routed through the material mass to the inner area. Most masonry thermal storage masses are incapable of absorbing solar energy as quickly as it reaches the gap between the mass and the window area. Temperatures in this area may easily get beyond 37.78°C. This heat buildup may be used to warm an area by installing heat-distributing vents on the top of the wall. Cool air is pulled into the heating chamber via vents at the bottom of the wall, replacing the flowing hot air and taking up heat.

This passive solar design technique integrates heat collection and storage with the convection process. In this approach, energy-storing materials are placed between the interior habitable space and the sun, preventing direct heating. In place of the south-facing glass, a dark-colored thermal storage wall is built (windows). Sunlight enters the storage wall via the glass and is promptly absorbed at the surface, where it is either stored or channelled to the interior region through the material mass. The vast majority of brick thermal storage mass are incapable of collecting solar energy as soon as it reaches the space between the mass and the window area. Temperatures in this region are likely to exceed 37.78°C. By adding heat-distributing vents on the top of the wall, this heat accumulation may be utilised to warm a space. Cold air is drawn into the heat exchanger via vents on the floor, replenishing the circulating hot air and absorbing heat.

A water wall here between sun and the interior area is one version of the vented masonry wall concept. Water walls used in this manner do not need to be vented at the top and bottom and may be built in a variety of ways. Again, when the water heats up, convection swiftly spreads the heat throughout the bulk, and heat radiated from the wall warms the interior area. Another design strategy makes use of both the greenhouse effect and the direct gain storage wall. A "greenhouse area" facing south is built in front of a thermal storage wall exposed to direct sunlight. This wall would be located at the back of the greenhouse and in front of the main building. The thermal wall absorbs heat while the inner area of the greenhouse is heated. Heat may be discharged into the living area via convection if a vented brick wall is utilised as storage. This combination works well with an unvented water wall as well. The greenhouse is then heated directly while the residential space is heated indirectly. By heating from both sides of the thermal storagewall, a temper greenhouse condition may be maintained even on days when there is no sun.

The thermal pond technique, which employs water enclosed in UV ray blocking plastic beds emphasised with a dark colour and put on a roof, is an indirect gain design that offers both heating and cooling. In warm and temperate areas with little precipitation, the flat roof structure also functions as a direct ceiling for the living rooms below, allowing for direct transmission of heating and cooling. Attic ponds beneath steel roof glazing are beneficial in colder climates where heating is preferred. Winter heating happens when sunlight warms the water, which then radiates energy into the living area and absorbs heat inside the thermal mass of the water for nighttime distribution. A reverse process, explained later, happens throughout the summer. Roof ponds should be insulated (movable) to prevent heat from radiating and being lost to the outdoors. One of the key benefits of this strategy is that it enables every rooms to have their own radiating energy source without regard for structural orientation or ideal building design.

Concerns about climate change, high oil costs, and more government backing are driving an increase in renewable energy laws, incentives, and commercialization. Solar thermal energy is one of the most common kinds of renewable energy consumption. The most common applications are swimming pool heating, residential water heating, and building space heating. Current research and development efforts are focused on improving solar heating technologies to make them even more efficient and affordable, with a special emphasis on: 34 Testing materials for durability, including glazing and absorbers. 34 Conducting thermal analyses of solar water heating technologies that function in different climates. 34 Developing advanced applications such as low cost solar water heating and collectors. The solar savings portion is important when discussing solar energy since it is the amount of energy supplied by solar technology divided by the total energy needed. Passive solar systems often provide substantial solar saving fractions for space heating; when paired with active solar technologies, even greater conventional energy savings may be realised.

Solar energy production is another key element that is offered with various technologies such as solar towers and solar ponds. The solar dish/stearling engine, on the other hand, has the maximum energy efficiency. The one built at Sandia National Laboratories has a conversion efficiency of 40.7% and can generate up to 25kW of power. Since a solar power plant does not need any fuel, the cost is mostly comprised of capital and certain operating expenditures. If the plant's lifespan and interest rate are known, the cost per kWh may be determined. Solar technologies have the potential to make significant contributions to global energy supply. The capacity to dispatch electricity enables large-scale central solar technology to provide 50% or more of the world's energy demands in sunny locations. Large-scale solar technologies have the potential to stabilise energy prices while also providing great employment to the local community. Solar energy has the potential to become the most important home energy resource in the twenty-first century.

Introduction to Thermodynamics66

The term thermodynamics is made up of two words: thermo (heat) and dynamics (dynamics) (power). Thermodynamics is a discipline of physics that studies the nature of heat and how it might be converted into labour. It arose historically from the notion that a heated body can create work and the attempts to build. Heat engines that are more efficient devices that extract meaningful work from expanding hot gases. Thermodynamics nowadays is concerned with energy and the link between the characteristics of substances. The defining of various essential ideas leads to the formulation of fundamental laws in thermodynamics. These rules regulate the transformation of energy from one form to another, the passage of heat, and the availability of energy to accomplish work. As a result, in order to represent the rules of thermodynamics, certain qualities and ideas must be specified.

The border of a thermodynamic system defines it. Anything beyond the barrier is considered to be part of the surrounds or environment. The environment often comprises one or more idealised heat reservoirs—heat resources with limitless heat capacity that may give out or absorb heat without altering temperature. There are two kinds of systems: closed and open. A closed system (control mass) has a constant amount of matter. As a result, no mass breaches the system's border. The amount of mass in an open system (control volume) is not constant, and mass might transcend the border. The qualities of each system define it. Temperature, pressure, and specific volume are three key independent parameters that are often employed to define a system. Temperature, which is the measure of an object's relative warmth or coolness, is difficult to define precisely. We know the degree of temperature qualitatively using adjectives like cold, warm, hot, and so on, based on our physiological feelings. Since our senses may be deceiving, we cannot give numeric value to temperatures based only on our perceptions.

The zeroth law of thermodynamics establishes the accuracy of temperature measurement. This rule states that if two bodies are thermally balanced with a third body, they are likewise thermally balanced with each other. By replacing the third body with a thermostat or other device with a scale calibrated in degrees, the temperature of a system may be measured. The magnitude of a degree is determined on the temperature scale used.

Solar Thermal Systems and Applications

Sun thermal energy has been utilised for ages by ancient peoples to heat and dry their clothes. Solar energy has lately been developed for a broad range of thermal activities, including power production, water heating, motorized crop drying, and water purification. Given the range of working temperatures of solar thermal processes, the most important applications are:

1. For temperatures less than 100°C: water heating for domestic use swimming pools, heating of buildings, and evaporative systems such as distillation and dryers.
2. For temperatures less than 150°C: air conditioning, cooling, and heating of water, oil, or air for industrial use.
3. For temperatures between 200 and 2000°C: generation of electrical and mechanical power.
4. For temperatures greater than 2000°C: generation of electrical and mechanical power.

For operations requiring temperatures more than 100°C, the solar energy flow is insufficient to raise the working fluid temperature to such a high degree; instead, some sort of energy flux concentration utilising mirrors or lenses is necessary. The ratio of the energy flux generated for the energy absorber to that caught by the collector must thus be more than one, and designs may typically attain a concentration of hundreds of suns.

Solar Collectors

Low-, medium-, and high-temperature heat exchangers are the three types of solar collectors. Thermal solar collectors are classified into three types: flat plate, evacuated tube, and concentrating. Despite significant geometric changes, their aim remains the same: to transform solar radiation into heat to meet certain energy demands. Solar collector heat may either immediately provide energy demand or be stored. The thermal performance of the collector must be examined in order to balance demand and output of energy. The solar collector's instantaneous usable energy gathered (Q u) is the outcome of an energy balancing.

To appropriately estimate the quantity of energy generated by a solar collector, the physical qualities of the materials must be considered. Solar radiation, predominantly of short wavelength, enters the energy receiver via a transparent cover. Because of its strong transmissivity, low-iron glass is widely employed as a glazing cover; the cover also significantly minimises heat losses. The optical properties of the energy receiver must be as close to those of a blackbody as feasible, particularly strong absorbtivity.

Selective coatings may increase the properties of high heat conductivity. Together with the absorption of radiation, the temperature of the receiver rises; the shortwave radiation is then changed into long-wave radiation. In the new wavelength condition, the glazing material virtually becomes opaque, favouring the greenhouse effect. The combination of the cover's strong transmissivity towards solar radiation and the receiver's high absorbtivity results in great results for a well-designed solar collector.

Flat-Plate Collectors

A flat-plate solar collector is made out of a waterproof, metal or fiberglass-insulated box that houses a dark-colored absorber plate, which serves as the energy receiver, and one or more transparent glazings. Because of their high thermal conductivity, absorber plates are often composed of metal and sprayed with unique selective surface coatings to absorb and transmit heat better than standard black paint can. The glazing coverings decrease heat losses to the environment via convection and radiation. the basic components of a flat-plate collector. These systems are always fixed in place, maximising the energy gain for the individual application and area. Flat collectors may be fixed on a roof, installed in the roof, or stand alone. As solar radiation passes through the cover, the collector receives energy; both beam and diffuse solar radiation are utilised in the heat generation process. The higher the glazing's transmittance (), the more radiation reaches the absorber plate. This energy is absorbed in a proportion equal to the blackened-metal receiver's absorbtivity.

$$\dot{Q}_r = \dot{q}_r A_c = (\tau\alpha)_{eff} I_T A_c$$

here (τα) The effective optical fraction of the absorbed energy is eff, the incoming solar radiation on the tilted collector is IT, and the collector aperture area is Ac. The aperture is the collector's frontal entrance that collects the Sun's rays. Once absorbed, such radiation is transformed into thermal energy, which heats up the absorber plate (Figutre 3.1). In general, solar collectors have significant heat losses. While the glazing prevents infrared-thermal energy (long wavelength) from escaping, the temperature differential between the absorber surface and the ambient causes heat losses to the surroundings through convection (Q conv or qconv) according to the following equation:

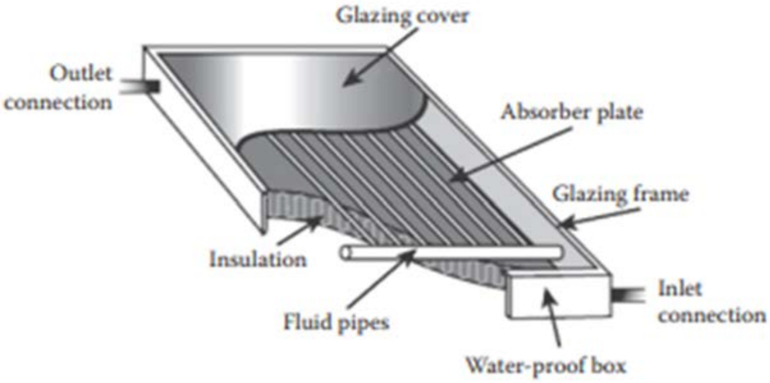


Figure 3.1 Represent the Main components of a flat-plate collector.

$$\dot{Q}_{conv} = \dot{q}_{conv} A_r = UA_r(T_r - T_a)$$

where Ar denotes the receiver's area, U denotes the total heat loss coefficient, Tr denotes the receiver's temperature, and Ta denotes the ambient temperature. In addition, some heat is lost via radiation (Q rad or qrad) owing to the temperature differential between the collector and the sky dome. For the sake of simplicity, the final value is considered to be the same as the ambient temperature.

Flat-Plate Collector Thermal Testing

The thermal FR, U, and ()eff parameters for each collector must be computed using a standard testing procedure to assess the performance of flat-plate solar collectors. The techniques specified in ASHRAE 93 (2003), ISO 9806-1 (1994), and EN12975-2 are the most extensively utilised (2001). Only certified collectors according to unique requirements are necessary for solar installations in the United States and the European Union. The Solar Ratings Certification Corporation (SRCC) of Florida is the primary certification authority in the United States for ASHRAE 93 solar thermal collectors.

The parameters of the three approaches are determined by doing a collector time constant () test, an instantaneous thermal efficiency () test, and an incidence angle modifier (Kb()) test. While the approaches are quite different, Rojas et al. (2008) showed excellent agreement when comparing the ASHRAE 93 and EN12975-2 standard testing procedures with the thermal findings achieved for a single-glazed flat-plate collector. The ASHRAE 93 standard test is a steady-state thermal procedure that must be performed outside in good weather. This is challenging since the quantities of irradiance, temperature, and wind speed must all fall within very limited limits. The test necessitates a minimum total solar irradiance of 790 W/m2, a maximum diffuse percentage of 20%, wind speeds ranging from 2.2 to 4.5 m/s, and an incidence angle modifier ranging from 98 to 102%. (normal incidence value). Such ecologically mandated circumstances, however, do not occur often in other regions. The EN12975-2 test, on the other hand, offers an alternate transient test technique that may be performed under a wider variety of environmental circumstances.

First, the environmental conditions must meet standard standards, and variations in irradiance and ambient temperature must be within 32 W/m2 and 1.5 K, respectively, for the -test. As the water is flowing, the collector is exposed to the Sun. The inflow water temperature must be set to be the same as the outdoor-air ambient dry bulb temperature, with a maximum variance of 1 K or 2%. The variance in volumetric flow rate might be the larger of 0.0005 gal/min or 2%. In these steady-state circumstances, the collector is suddenly covered with an opaque surface to limit irradiance absorption. The inlet-controlled and outlet-uncontrolled temperatures are immediately and constantly monitored. Since there is no energy gain, the temperature of the uncontrolled outlet begins to fall. The time it takes for the temperature differential between exit and inlet to fall to 0.368 (1/e) of its starting value is referred to as the time constant.

According to Equation, the instantaneous thermal efficiency of a collector is calculated as the ratio of the usable energy gain to the actual solar irradiation, I, collected by the collector area Ac. The thermal efficiency test is carried out at near normal incidence (i.e., with nearly little fluctuation in the incidence angle), and ()eff stays constant during the test. Moreover, at the measured temperature, both FR and U are constants since all other variables—radiation, flow rate, ambient temperature, and inlet temperature—have minimal variance.

The efficiency is a linear function when plotted against (Tin - Ta)/IT for a particular collector, Four distinct collector inlet temperatures are subjected to ASHRAE 93 efficiency testing. Moreover, to produce the efficiency curve, steady-state test requirements demand a minimum of 16 data points for the four distinct input temperatures. The lowest input temperature corresponds to the ambient temperature, while the highest is determined by the manufacturer's maximum working temperature. The efficiency is calculated using just data collected during steady state.

The efficiency plot's slope (FRU) shows the rate of heat loss from the collector; collectors with glazing covers have a lower slope than those without. The highest collecting efficiency, known as the optical efficiency ()eff, is obtained when the intake temperature is the same as the ambient temperature. The (Tin - Ta)/IT value for this condition is zero, and the intercept corresponds to FR()eff. The intercept of the curve with the (Tin - Ta)T/IT axis is also of relevance. This phase of operation is achieved when useable energy is no longer withdrawn from the collector as a result of working fluid stagnation. In this situation, the incoming optical energy equals the heat losses, necessitating a rise in absorber temperature until this equilibrium is achieved. This is known as the stagnation temperature. Stagnation temperatures in well-insulated collectors may reach very high levels, causing fluid to boil.

The optical efficiency of a parabolic trough collector declines with incidence angle for various reasons, including decreasing glazing transmission and absorber absorption, increased breadth of the solar image on the receiver, and spillover of light from limited length troughs. The instantaneous thermal efficiency of a solar collector decreases with irradiance incidence angle. Light transmission through the glazing diminishes at low incidence angles, but the breadth of the solar picture on the receiver grows. In the incidence angle modifier (Kb()) test, one inlet temperature is held constant at steady-state conditions throughout the test to assess collector efficiency at incidence angles of 0, 30, 45, and 60°. Adjusting the collector's azimuth angle (Figure 3.2).

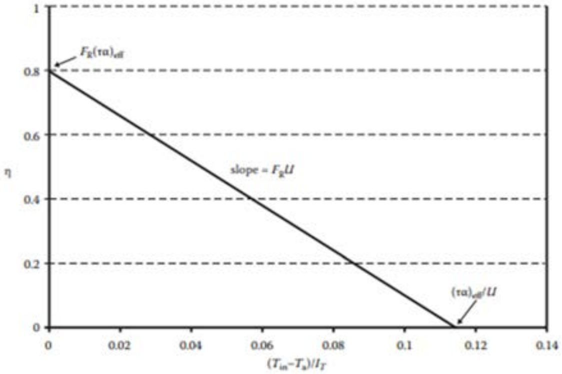


Figure 3.2 Represent the Instantaneous efficiency of a flat-plate collector.

Evacuated-Tube Solar Collectors

For high-temperature operation in the range of 77-170°C, evacuated-tube solar collectors outperform flat plate collectors. They are highly suited for commercial and industrial heating applications, as well as cooling applications that need the regeneration of refrigeration cycles. They might also be an effective alternative to flat-plate collectors for home space heating, particularly in foggy climates (e.g., New England, Germany, etc.). an evacuated-tube solar collector is made up of rows of parallel glass tubes joined by a header pipe (a, b). Each tube's air is evacuated, resulting in vacuum pressures of roughly 10-3 mbar. This generates high insulation conditions to limit heat loss via convection and radiation, allowing for greater temperatures than flat-plate collectors. A low thermal conductivity gas, such as xenon, may be used in place of the vacuum. Within each evacuated tube is an absorber surface. Evacuated-tube solar collectors are classified as direct-flow or heat-pipe depending on how heat is extracted from the absorber.

The working fluid travels through the absorber via direct-flow tubesThese collectors are classed based on their connecting-material joints, which might be glass-metal or glass-glass, as well as the arrangement of the tubes (such as concentric or U-pipe). A flat or curved metallic fin is linked to a copper or glass absorber pipe within each evacuated tube. The fin is covered with a selected thin layer whose optical characteristics allow for strong solar energy absorption while preventing radiative heat loss. While the glass-metal collector type is relatively effective, vacuum loss might occur owing to the junction of materials with significantly different thermal expansion coefficients. Within this kind, the fluid may take either a concentric or a U-shaped course; in both cases, the working fluid enters and exits at the same end (the header pipe). Even if the collector is oriented horizontally, the concentric structure might include a device that rotates each single-pair fin pipe up to the ideal tilt incidence angle. The U-pipe arrangement, on the other hand, is the most common direct-flow/evacuated-tube solar collector.

Tubes of the glass-glass type are made up of two concentric glass tubes that are fused together at one end. The area between the tubes is sealed up. The inner tube is additionally coated with a selective surface coating that absorbs solar energy while preventing heat loss via radiation. These collectors work effectively in overcast and cold weather situations. Solar tubes made of glass may be utilised in heat pipe or U-pipe arrangements. They are not as efficient as glass-metal tubes in general, but they are less expensive and more dependable. Glass-glass tubes may be more efficient than glass-metal tubes in high-temperature applications.

Each vacuum-sealed glass tube in a thermal tube collector is assigned one metal pipe, commonly copper, coupled to an absorber plate. The heat pipe is also under vacuum. A little amount of water is contained inside the heat pipe. Since water boils at a lower temperature when pressure is reduced, the vacuum's function is to quickly transition from the liquid phase to the vapour phase. Since vaporisation occurs at 25-30°C, when the heat pipe is heated above this temperature, vapour quickly climbs to the top of the heat pipe, transmitting heat. When heat is lost, the vapour condenses and falls to the bottom, where the process is repeated. Even though the vacuum reduces the boiling point, the freezing point stays constant (certain additives prevent freezing at nighttime low temperatures). Copper used in heat pipes must have a low oxygen concentration or it will leak out into the vacuum, generating pockets in the top of the heat pipe and causing poor performance.

When heat-pipe and U-pipe layouts are compared, their efficiency ratings are almost identical; nevertheless, the U-pipe has several benefits, such as being more inexpensive and compact than heat-pipe collectors. Moreover, U-pipe collectors may be positioned exactly vertical or horizontally, providing for a greater range of installation possibilities and enabling these photovoltaic cells to be utilised in places where other collectors cannot. Thermal collectors must be installed with a minimum tilt angle of roughly 25° so that the heat pipe's internal fluid may return to the hot absorber. Heat pipes are easier to install and maintain than direct-flow collectors since individual tubes may be substituted without emptying the whole system.

Optic Fundamentals for Solar Concentration

Transmission of light energy is assumed to go in straight lines in the ray approximation, unless when it reaches an obstacle, in which case reflection and refraction occur. When the size of the obstacles is large in comparison to the wavelength of the moving light, the assumption works well. When a light ray hits a transparent surfac6 a portion of the incident ray is reflected with an angle of approximately to the angle produced between the incident ray and the normal to the surface. Another component crosses the surface boundary and the difference in the refractive index (n) of the two materials, resulting in a change in light direction and speed (v). When n2 > n1, the splitting of the entering light beam into reflected and refracted light. Since the velocity of light in the second medium is lower (v2 v1), the angle of refraction, is smaller than the angle of incidence, 1. Snell's law describes the refraction process:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Basic optical devices like as mirrors and lenses are used to concentrate energy in a receiver so that as much energy as possible is absorbed and converted into useful energy. The optical focusing surfaces might be planar, parabolic, or spherical in6 shape. These devices are exclusively used to converge energy onto the receiver in solar energy applications.

CHAPTER 4

COMPOUND PARABOLIC CONCENTRATORS (CPCS)

Beemkumar N, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- n.beemkumar@jainuniversity.ac.in

The compound parabolic concentrator is a nonimaging concentrator, as opposed to the trough and dish concentrators, which plainly show a focus line or point. The light beams do not have to be parallel to the concentrator's axis in this configuration. A CPC collector is made up of two truncated parabolic reflectors, none of which retains its vertex point, but both rims must be angled towards the Sun. The geometric connection between the two parabola segments for the building of a CPC The acceptance angle (accep) is defined as the angle between the two parabolas with regard to reflection across the axis of the CPC. Light rays in a parabola must always be parallel to the parabola's axis; otherwise, the picture is out of focus and distorted. When the rim of a parabola is tilted towards the Sun, the light rays are redirected on the reflecting surface someplace below the focus; when it is slanted away from the Sun, the rays are reflected somewhere above the focus.

The half parabola angled away from the Sun is replaced in CPC designs with a similarly shaped parabola with a rim pointing towards the Sun. All incoming rays fall below the focal point of the parabola segments. The ray tracing for a CPC collector Light having an incidence angle less than one-half the acceptance angle is reflected through the receiver aperture; for bigger angles, light rays are directed to another spot on the reflecting surface rather than the receiver opening. Finally, the light beam is reflected back out via the CPC aperture.

The CPC structure is generated by translating its cross section shown in across a line. To catch the incoming sun rays, the receiver is placed below the focus of the two parabolic surfaces. Receivers may also have diverse geometries, such as flat plates at the intersection of two surfaces, or cylindrical or U-tubes going through the area below the focus. Moreover, evacuated tubes may be used with CPC collector. depicts the configuration of different CPC collectors.

CPC collectors give a geometric proportion (CRg) ranging from 1.5 to 10 times the solar radiation while requiring no monitoring throughout the day. A CPC's geometric concentration ratio is linked to its acceptance angle, accep, by To improve performance at high temperatures, the CRg must be raised; subsequently, using Equation 4.45, the acceptance angle of the CPC must be lowered. CPC receivers are typically positioned east-west, with their apertures inclined towards the south. They do not need hourly monitoring but must be updated on a regular basis throughout the year. The narrowing of the acceptance angle necessitates an increase in the number of tilt adjustments over the year.

A accep of 180° corresponds to the geometry of a flat-plate collector, whereas an accep of 0° relates to a parabolic concentrator. Temperatures in the 100-160°C range have been achieved with CRg larger than six, resulting in efficiencies of approximately 50% (Rabl, O'Gallagher, and Winston 1980). The collector performance is greater than that of a double-glazed flat-plate collector at about 70°C at lower CRg, but its output remains competitive at lower temperatures. Just a few research on immediate efficiency for CPCs have been undertaken.Carvalho et al. (1995) evaluated a CPC's effectiveness in determining efficiency curves for both north-south and east-west orientations. The findings change for each direction as predicted since the convection regime differs in both circumstances. In all examples, the linear and second-order lowest fits achieved.

Heliostats

A large-scale solar-thermal power plant collects energy by concentrating the Sun's rays onto a single focal point, producing high-temperature heat to power a steam turbine generator. Hundreds of huge sun-tracking mirrors known as heliostats are used to concentrate the radiation. To absorb heat, each heliostat directs sun radiation towards the highest point in a building where the receiver is positioned. Large power levels (1-500 MW) and high temperatures (540-840°C) characterise central receivers. High-quality heat transfer fluids are used to carry energy to a ground-based boiler, which produces steam for use in a typical power plant. The tracking angles and incidence angles for each heliostat may be calculated using vector methods in which the zenith, east, and north (z, e, n) directions are the suitable coordinates and the origin, O, is positioned at the base of the receiving tower. Depending on its position with relation to the energy receiver, each heliostat offers a unique value pair for the altitude (H) and azimuth (H) angles. To calculate such angles, three vectors must be defined: one indicating the direction of the Sun's ray striking the heliostat (S), one representing the heliostat normal (N), and a third one representing the redirection of the Sun's beam towards the point A, receiver (R). The three vectors are represented by the following equations (Figure 4.1).

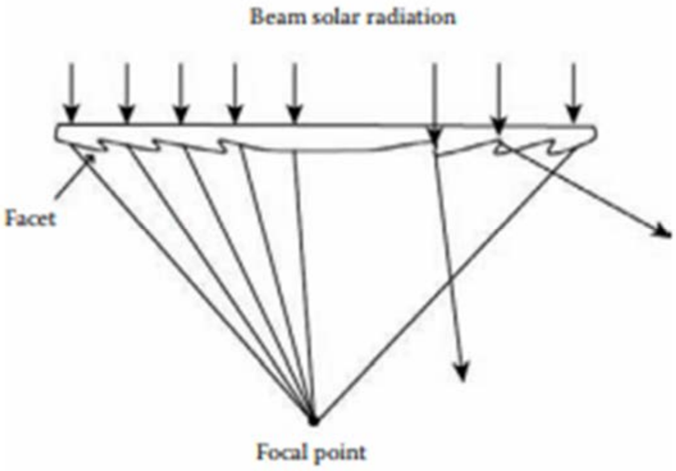


Figure 4.1 Reprsesent the Ray trace on a Fresnel lens.

Tracking Systems

The goal of employing reflecting surfaces or lenses is to divert incoming solar light to the object focal point so that as much energy as feasible is collected. The angle between the surface axis and the solar rays must be maintained at zero; to do this, a sun-tracking device must be used to keep the collector's aperture perpendicular to the light rays throughout the day. The collector may not move throughout the day because to the specific geometrics of the spherical surface with symmetrical rotation along its axis, but the receiver may. Sun trackers are used to enhance solar energy gain throughout the day for nonconcentrator collectors such as PV modules that generate power directly. Tracking systems are classified into two groups based on their movements. Following the Sun may be accomplished using either a single rotation axis (east-west or north-south) or two rotation axes, with the array pointing straight towards the Sun at all times and capable of rotating separately along both axes. Two-axis tracking arrays gather the most daily energy possible, but they are more costly and need considerable maintenance that wouldn't be worth the expense, particularly for lower size solar energy systems.

Solar Thermal Systems

Every sort of solar thermal collector is used to convert solar radiation into heat for use in a given application, whether household or industrial. The solar collecting system, a storage tank, pumps, and the load are the major components of the most general solar thermal systemA complete system comprises all of the required control systems and relief valves. The load may be employed in any application and will change depending on whether heat, cold, drying, or mechanical work is produced. calculates the usable energy collected from the collectors by subtracting the energy received by the collector from the heat losses due to convection and radiation. Using Tin as the inlet temperature, this equation becomes

$$\dot{Q}_u = \eta I A_c = I_T A_c F_R \left[(\tau\alpha)_{eff} - \frac{UA_r (T_{in} - T_a)}{I_T A_c} - \frac{\varepsilon_{eff} \sigma A_r (T_{in}^4 - T_a^4)}{I_T A_c} \right]$$

When heat loss by radiation is negligibleThe amount of energy collected from the solar collector field is determined by the intake temperature, which is determined by the load pattern and losses from the storage tank, pipelines, and relief valves. When modelling a solar thermal process with a rigorous calculation of Tin, energy losses through pipes might be approximated by solving the following mathematical problem for every pipe segment j:

$$\dot{Q}_j = m_j C_p \frac{dT_j}{dt} = -(UA)_j (T_j - T_a)$$

Passive and Active Solar Thermal Systems

Passive solar technologies employ sunlight to generate usable energy without the usage of active mechanical equipment. Thermal energy flow happens in such technologies by radiation, conduction, or natural convection. The heat acquired from sunlight is controlled via some form of thermal mass media such as moisture, air, rock, or oil to be utilised directly, dispersed, or stored with minimum need of other energy sources. Certain passive systems employ a tiny amount of conventional energy to regulate dampers, blinds, night insulation, and other devices that improve solar energy collecting, storage, and use while reducing unwanted heat transfer. Passive systems have the benefit of not being affected by power outages or electric pump failures. As a result, such systems are more dependable, simpler to operate, and may last longer than active systems.

Direct and indirect solar gain are examples of passive solar technology. The materials and design ideas used in both systems are the same. An indirect gain system, on the other hand, separates the solar collectors from the region where energy is required, with the thermal mass medium moving between the two. Active systems circulate water and other heat-transfer fluids via collectors using electric pumps, valves, and controls. They are normally more costly than passive systems, but they are more efficient. Since storage tanks are not required to be built above or near the collectors, active systems are frequently simpler to adapt than passive systems. An active system may work regardless of the power loss if it is powered by a PV panel.

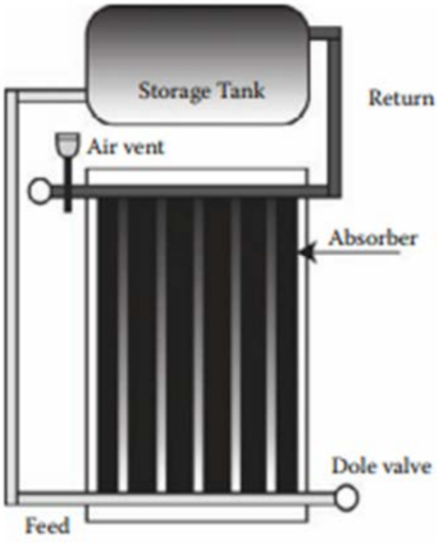
Solar Thermal Application: Water Heating for Domestic Use

The solar collector, storage, and heat delivery are the three basic components of a solar water heater. The heat transmission b6etween the solar collector and the storage tank, as well as the kind of freeze prevention, change across various layouts. The integrated collection and storage (ICS), thermosiphon, drain-back, and drain-down systems are the most successful solar warmers They are often backed up by a traditional system. In certain countries, solar equipment installation must adhere to municipal, state, and national construction regulations, roofing codes, plumbing rules, and national electrical codes.

The ICS and thermosiphon are passive solar water heaters that circulate fluid by natural convection, The energy obtained by the absorber from solar radiation is transmitted to the copper pipes. The incoming fluid is at the collector's bottom; when heat is gathered, the water within the pipes heats up. The hotter the water, the less thick it becomes and the better it circulates. As heated water rises to the top, colder, denser water from the storage tank descends to replace it in the collector. Circulation ceases when there is no or little insolation; the heated and less dense fluid stagnates inside the tank. The ICS is a self-contained solar collector and solar heated water storage tank that typically holds 30-40 gallons.

For warmer climes, both the ICS and thermosiphon heaters provide a low-cost alternative to an active-open-loop solar water system. Storage tanks ranging from 40 to 120 gallons are positioned vertically or horizontally above the collector in these systems. The water pushed through the collectors in open-loop systems is the same hot water that will be utilised. These systems are not advised for locations prone to freezing. These active open-loop systems are known as drain-down systems, and they may be operated manually or automatically To drain water, the drain-down system uses two solenoid valves. It requires the use of two temperature sensors, a timer, and a standard controller. The controller is linked to the freezing sensor in the collector's back and another at the collector's outlet, as well as the solenoid valves and the pump. As the pump begins, the system fills, the valves stay open, and the system empties when the pump stops.

While this design is economical and reduces running expenses, it is not suitable for hard or acidic water since corrosion and scale buildup ultimately disable the valves. It is very uncommon for utility providers to shut down specific parts for hours during heavy freezes; this poses a significant issue since the system relies on electrical valves. Likewise, if a spool valve has not been used in a long time in a hard water location, mineral deposits may have cemented it in a closed position and it may not open when required. Manual freeze prevention relies on occupants paying attention and stopping circulation and draining the system. When temperatures are high, drain-down systems frequently push air into the storage tank; an air vent must be installed at the highest point in the collector loop. When there is no solar radiation, the timer is utilised to turn off the system. Draining the collecting fluid out of the system is referred to as draining down; dumping the collector lymph fluid into the storage tank is referred to as draining back. While drain-back may be employed in unpressurized systems, it cannot be used in pressurised applications such as for a solar home water heater since storage always pressurizes (Figure 4.2).



Figrue 4.2 Represent the Thermosiphon water heater.

Closed-loop or active indirect systems circulate a heat-transfer fluid through the solar water heater, often water or a glycol-water antifreeze combination. Since they provide superior freeze protection, these systems are popular in places prone to protracted subzero conditions. Glycol antifreeze systems, on the other hand, are more costly to buy and install. Since it is non-toxic, propylene glycol is often utilised in household applications. Since this is an unpressurized system, the glycol does not need to be replaced, as it would in a pressurised system.

The solar collector, storage tank, and closed loop are the major components of a drain-back system, where the water-glycol combination is pumped through the collectors and a heat exchanger is positioned within the storage tank The closed loop is not pressurised and is not exposed to the environment. The heat transfer fluid transmits some of the gathered solar heat to the tank's water. Because of the high temperatures, the water in the storage tank is permitted to pressurise. To activate the pump in this system, a single-function controller is employed. The pump is shut off when the hot sensor detects a lower temperature than the cold sensor. The water in the collector and pipelines above the storage tank is then emptied back into the collector, guaranteeing freeze protection. Drainback systems need a high-head AC pump to begin at full speed and head. The pump must be installed under the fluid level in the tank and have enough head capacity to raise the fluid to the collector outlet at a low flow rate.

The pressurised glycol antifreeze system is another sort of closed-loop solar water heater. A water-glycol combination flows inside the closed loop to prevent freezing (Figure 4.3).

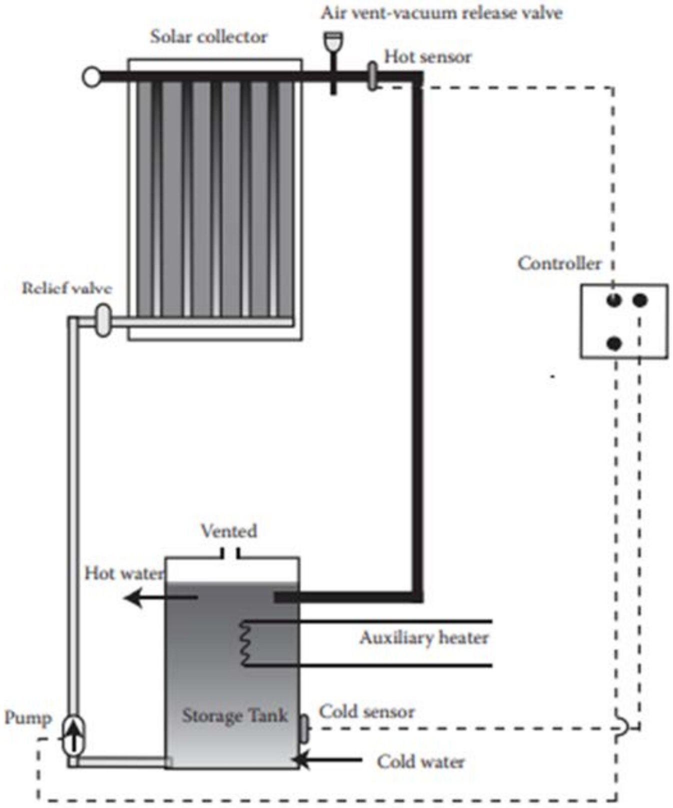


Figure 4.3 Represent the Drain-back system for domestic water heating.6

This system has the same basic components as drain-back systems: solar collectors, a circulation system, a storage tank, and a heat exchanger. The heat exchanger may be built inside the storage tank's wall, submerged as a coil, or used as an external exchanger. The glycol will need to be replaced every 3-5 years since heating causes it to become acidic.

The pressurised system is much more sophisticated than the drain-back system since it necessitates the employment of auxiliary components to safeguard the primary equipment. A differential controller, thermistors, and AC pumps comprise the antifreeze circulation system. A huge issue emerges if there is a blackout. After one hour of stagnation at high sun intensity, glycol becomes acidic. So it needs be changed sooner than it would typically be. The pump must be operational throughout the day to minimise stagnation. A DC photovoltaic pump should be fitted to guarantee this. In the same system, AC and DC pumps may be linked in parallel. A pressure gauge to monitor the quantity of antifreeze in the circulating system, an expansion tank, a check valve above the pump to prevent reverse-flow thermosiphoning at midnight, a pressure relief valve, and an air vent at the highest point in the system are all required components for this system.

Solar Thermal Application: Water Heating for Industrial Use

Heat production temperatures in industrial operations vary from 60 to 260°C. Solar thermal systems offer a wide variety of applications in this temperature range. The issue, however, is integrating a periodic, dilute, and changeable solar input into a broad range of industrial processes. The selection of collectors, working fluid, and component size are all issues in the integration. Adoption and creation of application-specific setups is necessary. Concentrating collectors, pressurised hot-water storage, and a load heat exchanger comprise the unique arrangement outlines probable industrial processes with favourable circumstances for solar technology implementation in accordance with their heat-quality generation. Meeting such large energy needs by adopting solar technology in both developed and developing nations is a crucial step to fit appropriately inside the present energy transition. Nevertheless, some technology replacement must occur, as must process efficiency improvements.

Despite the enormous success of solar energy in home applications, notably water heating, practically no adoption of solar energy in industrial processes has happened, owing to the large initial capital expenditures needed and a lack of understanding of the projected advantages. In industrial, heat is often supplied by hot water or low-pressure steam. For preheating fluids or generating steam from a fluid with lower working temperatures, hot water or steam at medium temperatures less than 150°C is employed. While operating temperatures are low, thermal efficiencies are always high owing to the removal of heat losses by radiation and a significant decrease in the convective and conductive regions. The solar collecting system is pressurised when temperatures over 100°C are necessary. The solar collecting array, circulating pumps, a gallon, as well as the appropriate controls and thermal relief valve, are all part of the industrial system. When the temperature of the water in the storage tank exceeds the process temperature, it is mixed with the colder water sources; when it is less, an auxiliary heater is utilised.

Case of Active Solar Drying: Sludge Drying

Handling and disposing of the hundreds of tonnes of sludge created every day in wastewater treatment facilities across the globe is not only a huge concern for human health and the environment, but also presents economic and technical obstacles. Sludge contains significant quantities of bacteria, viruses, and parasites, as well as organic and heavy metals Numerous studies have shown the potential for sludge usage to increase soil fertility owing to its high amount of macronutrients for flora—particularly nitrogen and phosphorous—as well as certain organic compounds that improve soil physicochemical properties Yet, its usage may have negative consequences for human health and the environment.

To decrease the expenses of processing and disposing of large quantities of sludge, mechanical techniques are used initially to remove 20-40% of the water; beyond this, only thermal methods can remove water. This results in massive fuel usage and greenhouse gas emissions. Luboschik described a solar sludge drier design capable of evaporating 800 kg of water per square metre per year while using very little electricity. Bux et al. (2002) created a solar dryer with continuous mixing that decreased total solids from 3 to 93% in 64 days. The energy usage was 78% lower than that of a standard system.

Salihoglu et al. (2007) computed a 4 year recovery period for a system in Bursa, Turkey. As sun radiation enters the dryer via a transparent cover, the functioning of a solar sludge drier starts. The sludge absorbs a large portion of this energy. Because of the greenhouse effect generated by the choice of building materials and the system's hermeticity.

Sludge and air temperatures are rising. This increase causes water to diffuse from the sludge surface to the air content inside the chamber. The difference in vapour pressure between both the sludge surface and the chamber acts as the driving force for this operation. As the amount of water in the air grows, so does the vapour pressure. To remove water faster, vapour pressure equilibrium must be avoided, and moist air must be eliminated. The larger the ability for mass movement from the sludge surface to the air in the chamber, the greater the saturation state of water in air. On the other side, the higher the vapour transfer, the hotter the system. The dryer should have a ventilation system to prevent temperature and humidity stratification. An extractor is used to remove the moistened air. As the water content of the air in the chamber reaches a critical level, the system returns to a closed system in terms of mass. Due of the hazardous properties of the substance to be dried, the system must be automatically regulated.

Temperature and humidity changes between inside and exterior environments regulate the automated functioning. Solar sludge drying, according to Cota and Ponce, is an alternative and low-cost approach for disinfecting sludge with a high concentration of harmful microorganisms. The total efficacy of the solar dryer was assessed in their research by evaluating thermal and microbiological performance. The water content of the sludge throughout the operation was utilised as a measure of thermal efficacy; the findings revealed an exponential decline of water content with up to a 99% decrease. In terms of microbiological removal efficacy, there was a substantial relationship between the quantity of bacteria present and the sludge's water content. As a result of removing 96% of the water, the elimination of faecal coliforms was reduced from 3.8 106 to 1.6 MPN (most likely number) per gramme of dry sludge; for Salmonella spp., the decrease was from 1.5 1013 to 1.9 103 MPN per gramme of dried sludge.

Solar Thermal Application: Solar Distillation

Distillation is a method that permits certain elements of a solution to be purified based on changes in volatilities. In general, when solutes have considerably lower volatilities than the solvent, distillation is performed by evaporating the solvent in one section of the device and then condensing the vapour in another to achieve the purest solvent possible. Solar distillation is the process through which conventional energy is replaced by sun radiation. The traditional process maintains a steady production rate under stable circumstances of pressure, temperature, energy consumption, incoming stream composition, and flow rate. While predictable, the solar process changes throughout the day, peaking during the hours with the greatest irradiance. During the course of the year, the volatility is not just hourly but even daily.

Water purification has been the most extensively utilised application for solar water distillation. The benefit of solar over traditional systems in the cleaning of simple substances such as brine or well fluids is that operation and maintenance are low due to the absence of moving components. Solar distillation also uses no fossil fuels, resulting in zero greenhouse-gas emissions. Most crucially, these systems may be erected in distant locations to meet the freshwater demands of tiny settlements without traditional electric connections.

Solar distillation is one of the most basic but successful solar thermal methods. Many solar prototypes are still in existence; the distinctions are in their geometry and construction materials. The same operating principles and three distinct parts characterise all designs: solar collector, evaporator, and condenser. Solar distillation mimics the natural process of creating fresh water. A solar still is an isolated container with a blackened surface with high heat absorbtivity on the bottom and a transparent material, often tempered glass, on the lid. As solar radiation passes through the glazing cover and reaches the solar, the black surface, the bulk of the energy is absorbed. The electromagnetic radiation is transformed into heat during this process, generating an increase in the temperature of the collector, which is then ready to be transmitted into the water. Because of the greenhouse effect, heat is trapped inside the system. Adequate insulation should be used to reduce convective heat losses to the environment (Figure 4.4).

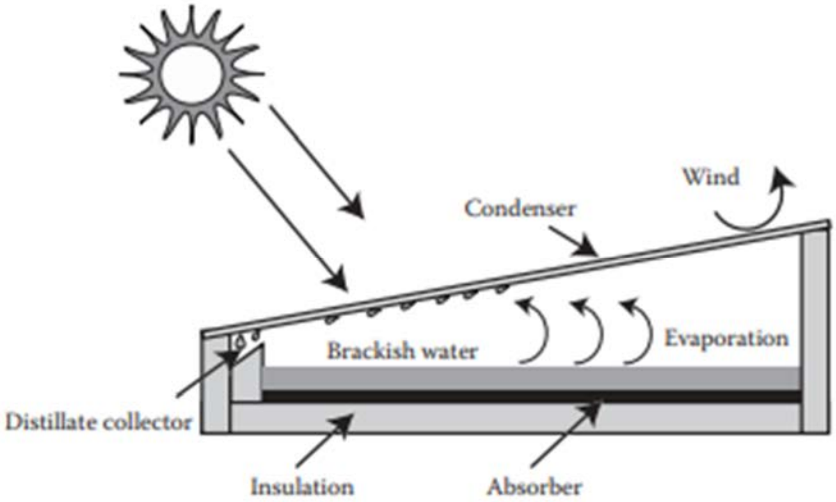


Figure 4.4 represent the Basic operation of a solar still.

The temperature increases because radiation is constantly entering the system. When the temperature of the water increases, water begins to diffuse into the air. Since the greatest temperatures encountered are usually below 80°C, evaporation occurs rather than boiling. These circumstances promote water not transferring greater solubility components or suspended particles. Since it is in direct touch with the environment, the temperature of the glazing is lower than that of the collector and the water. Condensation happens more readily at cooler surfaces. To allow the distilled water to move towards a collecting system, the glazing cover must be tilted. This technique eliminates contaminants like salts and heavy metals while also killing microbiological organisms. The most popular kind of solar still is a passive single basin solar distiller that operates only on sunlight.

The amount of solar energy that falls on the still is the single most critical factor influencing output. The daily distilled-water output (Me [=] kg/m2/day) is the difference between the amount of energy used in vaporising water in the still (Qe [=] J/m2/day) and the latent heat of vaporisation of water (L [=] J/ kg). Solar still efficiency () is defined as the amount of energy used to vaporise water in the still divided by the quantity of incident solar energy on the still (Qt [=] J/m2/day). They may be phrased as follows:

$$M_e = \frac{Q_e}{L}$$

Single-basin solar stills typically have efficiency of over 60%. The creation of solar stills is affected by both sun energy and ambient temperature. For example, in sunny places such as the southwestern United States, Australia, or the Middle East, output rates per square metre might average about 6 l each day. day in the cold to more than 15 litres per day in the summer.

Distillation is the only stand-alone point-of-use (POU) method having worldwide arsenic removal certification from the United States National Sanitation Foundation (NSF) under Standard 62. All salts, as well as microbiological pollutants such as bacteria, parasites, and viruses, are removed by solar distillation. the results of single-basin solar still testing done by New Mexico State University and Sandia National Laboratories (SNL) (Zachritz, 2000; Zirzow, 1992). The findings show that solar stills are very successful at removing microbiological contaminants and salts. After introducing more than 10,000 live bacteria per litre into the feed water, the distillate contained between 4 and 25 viable cells per litre. The addition of a billion or more live Escherichia coli cells each day for five days had no effect on the amount of viable cell numbers discovered in the distillate, nor was E. coli recovered in the distillate.

SNL experiments were carried out using source water concentrations of 13 and 16%. (standard saltwater). All salts were thoroughly eliminated by the stills. The water's dissolved solids salts (TDS) content dropped from 36,000 to 48,000 TDS to less than 1 TDS.

CHAPTER 5

PASSIVE SOLAR INDIRECT DRYING: FOOD DRYING

Beemkumar N, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- n.beemkumar@jainuniversity.ac.in

Drying is the oldest technique of food preservation, and solar food dryers are a sustainable food preservation technology. Bacteria, yeast, mould, and enzymes are all prevented from rotting food by lowering its moisture level to between 10 and 20%. The taste and the majority of the nutritional content are retained and intensified. In many circumstances, vegetables, fruits, meat, fish, and herbs may all be dried and stored for many years. Solar dryers, like other low-temperature solar thermal energy conversion devices, contain the same fundamental components. Temperature, humidity, and air flow are three important elements that influence food drying. Expanding the vent area by opening vent covers lowers the temperature and increases air flow without affecting the relative humidity of the incoming air much. More air flow is often preferred in the early stages of drying to eliminate loose water or water surrounding the cells as well as the surface. When the vent area is reduced by partly covering the vent covers, the temperature and relative humidity of the incoming air and air flow rise. At the final phases of drying, when the bound water needs to be forced out of the cells and to the surface, this would be the optimum arrangement.

Active Solar Chemical Process: Water Detoxification

The presence of caustic chemicals, solvents, organic compounds, metals, and other contaminants in surface waters is a major concern globally. Existing techniques for removing polluted substances from water are either costly, ineffective, or only address one side of the issue. Disinfection procedures, for example, kill pathogenic organisms but do not breakdown organic pollutant agents, and chlorination processes generate carcinogenic by-products. Photocatalysis is an alternate approach for destroying remnants of priority organic contaminants in wastewater or subsurface fluids. Unlike previous approaches, photocatalysis allows for complete mineralization of organic molecules without the formation of hazardous intermediates.

The photocatalytic system's operating concept is based on the collection of UV solar radiation by a parabolic trough concentrator, which concentrates the Sun's energy on a receiver transparent tube situated along the trough's focal line and serving as an axial chemical reactor. The dirty water runs along the photoreactor with a catalyst—typically titanium dioxide (TiO2). Hence, solar deterioration occurs when a strong flow of UV radiation acts on the active sites on the catalyst's surface. This generates very powerful oxidant free radicals, which convert organic molecules into water, carbon dioxide, and diluted acids in a series of oxidereduction processes.

Jimenez et al. studied the sun photocatalytic activities and discovered ways to maximise full breakdown of organic molecules. Because of its extensive usage in the manufacture of items such as toothpaste, bath soaps, and shampoos, sodium dodecylbenzene sulfonate (DBSNa) was chosen as the polluting agent for this study. This synthetic ingredient has an advantage over biodegradable soap in that it creates foam even in hard water. Because of this property, DBSNa is widely utilised, and large quantities of this surfactant are frequent in industrial and municipal effluents. A parabolic trough reflector, a photoreactor, and a fluid circulation system were used in the experiment. The features of the solar concentrator and photoreactor design. To optimise the TiO_2 concentration during DBSNa photocatalytic degradation, catalyst concentrations were changed from 0.05 to 1.5 wt% for a given DBSNa concentration. The effect of an oxidising agent in the catalytic process was also investigated; H_2O_2 concentrations ranged from 0 to 15,000 ppm at a weight percentage of TiO2 of 0.2. In this investigation, 37 tests were performed, and the starting concentration of DBSNa in all of them was 37 mg/L.

The methylene blue active substances technique was used to determine the ultimate concentrations of the anionic surfactant at various resident periods. During these experiments, the recorded solar energy was constantly between 850 and 945 W/m2, and with the 41 suns focused, a minimum UV photonic density of 1.253 1022 photons/m2-s was guaranteed. When curves (a) and (b) are compared, it is discovered that DBSNa deterioration is more fully realised in the continuous recirculation mode than in the stationary operating state. This may be explained by the fact that the continuous recirculation mode allows for better particle dispersion rather than particle precipitation and more OH generation. It should also be noted that the continuous recirculation mode includes agitating the aqueous solution and exposing it to the outside air.

Experiments were carried out to establish the function of the catalyst in the absence of an oxidant agent throughout the degradation process. The % degradation curves of DBSNa as a function of TiO2 concentration after 10-, 20-, 30-, 40-, 50-, and 60-min exposure times. In curve (a), we see a 26% increase in fast deterioration using just 0.05 wt% TiO2. Degradation reaches a peak of 69% at 0.3 wt%. Degradation accounts for just 27% at 0.5 wt%, which is similar to the value found at 0.05 wt%. Ultimately, above 0.5 wt%, the curve slope gradually decreases, reaching 13% at 1.5 wt%. The following results were obtained for 0.3 wt% TiO2 concentrations independent of exposure time: 71% (20 min), 79% (30 min), 93% (40 min), 93% (50 min), and 94% (50 min) (60 min).

At 0.4 wt% TiO2, the degradation rate quickly decreases to about 0.05 wt%. Curves (c)-(f) seem to be fairly symmetric and centred at 0.3 weight percent. The degradation curves indicate a very sluggish drop above 0.5 wt%, with ultimate values of 17, 19, 22, 32, 54, and 59% at 1.5 wt% (curves a–f, respectively). It is worth noting that curve (f) has a flatter maximum behaviour than the other curves. This demonstrates that, at longer timeframes, a range of TiO2 concentrations maximises DBSNa degradation rather than a single value (0.3 wt%), as shown at the start of the process (curves a and b). clearly demonstrates that a TiO2 concentration of 0.2 to 0.4 wt% optimises the photocatalytic reaction. Over 0.4 wt%, the catalyst may interfere with the diffusion of reactants and products, slowing the reaction; below that number, there may not be enough catalyst to complete the degrading process.

Photovoltaic Cells

Electrical power is so important in modern civilization that it is considered a fundamental requirement. Power is often provided by the electrical grid; nevertheless, in situations where there is no access to the electric grid, such as outer space, distant rural areas, or poor countries, power sources are troublesome, and solar provides the most cost-effective power alternative. Photovoltaics can solve a variety of power supply issues in both space and distant terrestrial applications. Portable electronic gadgets, in addition to bigger power uses, may charge their batteries or receive power directly from solar cells.

The PV effect, where "photo" refers to light and "voltaic" refers to voltage, may generate electricity from sunshine. The word refers to a technique that generates direct electrical current from the Sun's radiant radiation. The PV effect may occur in solid, liquid, or gaseous materials; however, satisfactory conversion efficiencies have been observed in solids, particularly semiconductor materials. Solar cells are constructed of several semiconductor materials that have been coated with unique additions. Crystalline silicon is the most frequently utilised material for different kinds of manufacturing, accounting for more than 90% of worldwide commercial PV module output in its many forms.

Under full daylight, a standard silicon cell with a diameter of 4 in. may generate more than 1 W of direct current (DC) electrical power. To produce appropriate voltages and currents, individual solar cells may be coupled in series and parallel. These cell groups are packed into standard modules that protect the cells while producing functional voltages and currents. Since PV modules are solid state and have no moving components, they are exceedingly dependable. Silicon PV cells made nowadays have a useful service life of more than 40 years.] PV devices, often known as solar cells, are built of semiconductor materials. Semiconductor materials are elements or combinations with conductivity midway between metals and insulators.

Crystal Structure

On a microscopic scale, silicon and many amorphous silicon are crystalline formations ordered in an orderly way from the atoms that make them up. The basic cell is the smallest subdivision of this ordered arrangement that allows the whole structure to be replicated without voids or overlaps. Since primitive cells sometimes have problematic forms, we employ a simpler unit cell, which is generally specified by three orthogonal axes such as x, y, and z, with unit vectors positioned along each axis. The length of the unit cell's edge is referred to as the lattice constant (Figure 5.1).

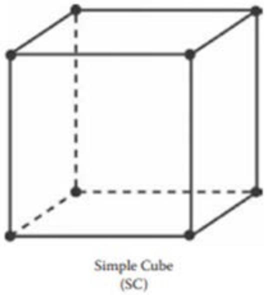


Figure 5.1 Represent the Simple cube crystal lattice.

(1) Amorphous, with no order or rhythm within the compound; (2) polycrystalline, with local order, apparent grain borders, and blue colour; and (3) single (or mono) crystalline, which is

characterised by long-range order and periodicity and is practically black with no visible grain boundaries. The crystalline structure of a semiconductor is crucial because when impurities (other elements such as phosphorus or boron) are introduced into in the lattice, the conducting characteristics of the material may vary dramatically. The idea of energy bands inside the crystalline structure is used to explain how this conduction happens (Figure 5.2).

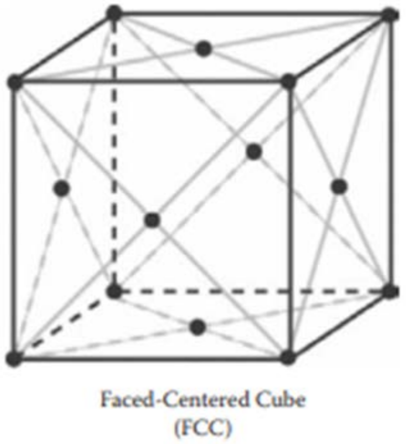


Figure 5.2 Represent the Face-centered cube crystal lattice.

Cell Physics

Particles are classified into two types: fermions and bosons, which have significantly distinct qualities in terms of energy state number. When two fermions are near together in a material, they cannot be in the same energy state, but bosons may. Fermions are electrons. Bosons are photons. The electron structure of materials, in general, and the outer electron structure in particular, may explain the majority of their characteristics (mechanical, electrically, thermal, chemical, and biological). Electric fields, E, are formed by charged particles, and when a charged particle is put in an external electric field, it experiences a force that causes it to move. Then there is energy or job accessible. The energy/charge is represented by the electric potential, V. Among the electrical terminologies are:

1. Coulombs, charge, Q or q (C) 1 C Equals 1.6 * 10-19 C, positive or negative.
2. Volt (V) = Joule (J)/Coulomb; energy = V * Q.
3. resistance (R) = V/I Ohm = Volt/Ampere power (P) = V * I Watt = Volt * Ampere current (I) = dq/dt, amount of charges passing through a point in 1 s, Ampere (A) = Coulomb/second
4. electronic Volt (eV) = the energy gained by one electron travelling across a voltage of one volt; a unit of energy defined as 1 eV = 1.6 * 10-19 J.

Energy Bands

To illustrate the concept of energy bands envision a huge number of similar atoms situated far enough away from each other that they have little or no interaction. Electrical interactions occur between them when they are pushed closer together in a consistent manner. Due of these electrical interactions and the Pauli exclusion principle (no two electrons can be in the same quantum state at the same time), the quantum mechanical wave functions begin to distort, particularly those of the outer (or valence) electrons. The valence electron wave functions stretch across more and more atoms, transforming the substance's energy level from crisp and distinct to a collection of energy levels or bands. A wave function is a kind of description (Figure 5.3).

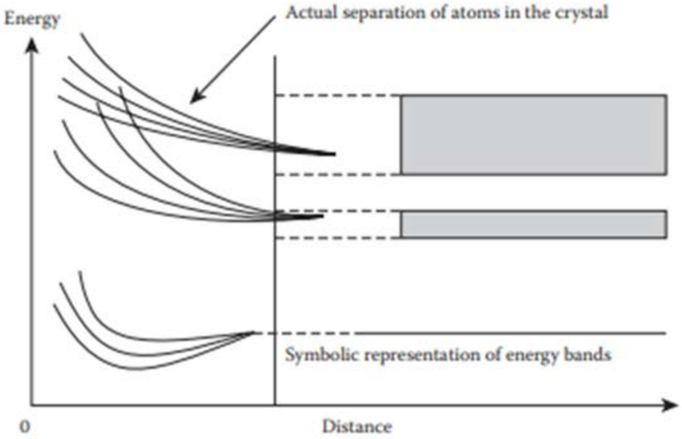


Figure 5.3 Represent the Energy bands in a solid.

Kinematic rather than spatial point descriptors are used to describe the motion of an electron. That is comparable to how sound and electromagnetic waves are described. Since a material medium is required for propagation, the wave function describes the particle but cannot be described in terms of the function itself. in terms of anything tangible. It can only explain the relationship between it and physically visible results.

The energy bands in a material dictate whether it is a conductor, an insulator, or a semiconductor. At absolute zero, an insulator has a completely full valence band and a completely empty conduction band (the next higher band); at absolute zero, a semiconductor also has a full valence band and an empty conduction band, but the gap between the conduction and valence bands is much smaller in the semiconductor. A band gap is the space between valence and conduction energy bands. Since the gap between bands is narrower, thermal energy may allow an electron to "jump" from the valence band to the conduction band. When the temperature rises, the conduction band quickly fills, increasing the material's conductivity.

Even at absolute zero, electrons in a conductor are in the conduction band. The conduction band is so called because it is frequently partly populated by electrons, implying that it is favourable to electron mobility and consequently electrical conduction. The valence band is the band containing electrons at lower energy levels. The prohibited energy gap, or simply the forbidden gap, exists between the valence and conduction bands. Based on quantum physics, it is a range of energy levels that an electron is not permitted to inhabit.

The three major kinds of materials may be explained using energy bands: Conductors have free electrons that can flow, semiconductors have a few free electrons, and insulators have none. Since the conduction band in a conductor is partly filled with electrons, energy levels are accessible for free electrons. Metals are excellent conductors. At normal temperature, some electrons have enough energy to enter the valance band, leaving a hole in the conduction band. The band gap is narrow. Another route for the electron to get energy is by the absorption of light: a photon. There are no free electrons in an insulator such as glass since all electron states are occupied and the band-gap energy is enormous.

Electrons and Holes

Conduction in a semiconductor is caused by the movement of holes in the valence band as well as electrons in the conduction band. When an electron obtains enough energy to break its covalent link and "jump" from the valence band into the conduction band, it leaves a hole in the valence band. The mobility of both holes and electrons in a semiconductor is sometimes shown using the example of a two-level parking garage. If the parking structure's bottom floor is completely occupied, there is no place for movement until one or more automobiles move to the next level. Instead of seeing the automobiles on the lower level going ahead, imagine the space moving. This is analogous to the inability of an electron to travel in a full valence band until it moves to the valence band.

A soap bubble in liquid is another illustration for hole movement. Holes are vacancies that behave in the valence band like positively charged particles, despite the fact that the charged particles are electrons. As an electron moves from the valence to the conduction bands, it creates a hole in the valence band, resulting in a pair of electron and hole known as an electron-hole pair (EHP). In the conduction band, electrons are assumed to move in one direction, whereas holes move in the opposite way in the valence band.

Direct and Indirect Band-Gap Materials

Semiconductors may have either a direct or indirect band gap. An E versus k (or k-space) diagram is commonly used to describe this phenomena. A k-space diagram is a depiction of electron in a crystal vs k, where k is a parameter that accounts for crystal motion momentum. Figure 5.6 depicts an E vs k diagram of arsenide (GaAs), a direct band-gap semiconductor material. Take note of the minimum conduction (Figure 5.4).

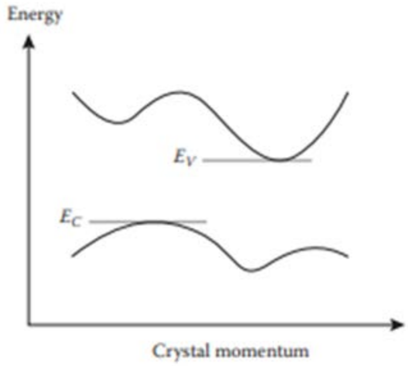


Figure 5.4 Represent the k-Space diagram of a direct band gap.

Maximum valence band energy and band energy exist at the same k value, facilitating more effective photon absorption. An indirect band-gap material is a semiconductor in which the greatest valence band energy and lowest conduction band potential do not occur at the same k value (. Silicon is an example of an indirect band-gap material.

Doping

Doping is the deliberate insertion of impurities into a semiconductor material to alter its electronic characteristics by manipulating the amount of electrons in the conduction band. There are two techniques to add impurity atoms into a material. They may be squeezed into the interstitial spaces between the atoms of the host crystal (referred to as interstitial impurities), or they can substitute for one atom of the host crystal while retaining the regular crystalline atomic structure (referred to as substitutional impurities). To demonstrate this notion, depicts a bond model with a family V atom substituting a silicon (Si) atom. It is worth noting that the energy necessary to release this electron is substantially lower than the energy needed for releasing one in a covalent bond.

This fifth electron's energy level corresponds to an isolated energy level in the prohibited gap area. This level is known as a donor level, and the impurity atom responsible is known as a donor. Conduction owing to a concentration many donors may dramatically enhance conductivity (Figure 5.5).

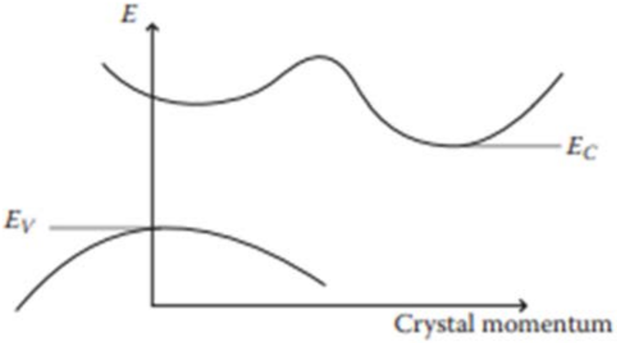


Figure 5.5 Represent the Indirect bandgap illustration.

Impurities take over as the primary conductance mechanism. The conductivity in this scenario is nearly completely owing to negative charge (electron) transport, and the material is known as an n-type semiconductor. Similarly, when a group III defect (boron) is added, the material has an affinity to draw electrons from the substance, leaving a hole. Together, hole motions generate an energy level in the forbidden gap near the valence band. This level is known as an acceptor level, and the impurity atom responsible is known as an acceptor. The substance is known as a p-type positive semiconductors with p-type impurities.

The p–n Junction

Just as there are several uses for solar cells, there are numerous techniques for producing them. While the technology used to manufacture and test space solar cells is more sophisticated than that utilised for terrestrial purposes, the same fundamental operating principle applies to all varieties. The most common solar cells are huge p-n (positive-negative) junction diodes that utilise light energy (photons) to generate direct current (DC). When the cells are lighted, no voltage is provided across the junction; instead, a current is created in the associated load. A diode is a kind of electrical device that allows unidirectional current flow. The solar cell is made up of n- and p-layers that form a junction. Combining doped semiconductor materials such as Si or GaAs results in the formation of a p-n junction.

A solar cell's energy conversion process consists of two critical phases. Initially, proper wavelength light absorption produces an electron-hole pair. The annihilation or absorption of photons by the excitation of an electron from the valence band to the conduction band is referred to as light absorption. Electrons pass easily through n-type materials, whereas holes pass easily through p-type materials. The electrical structure of the device separates the light-generated electron and hole: electrons to the negative terminal and holes to the positive terminal. Metal (ohmic) contacts on the front and rear of the cell gather electrical power. The rear contact is typically solid metal, whereas the front contact is a metal grid. The existence of electrons and holes generates net negative and positive charges, which cause an electric field to form in the vicinity of the metallurgical junction. The electric field "sweeps away" the electrons and holes to form the depletion area. These words and approaches apply to the vast majority of p-n junction diodes. To increase efficiency, the materials should be changed to have band-gap energies for visible photons. The infrared to ultraviolet spectrum ranges from 0.5 to around 2.9 eV (Figure 5.6).

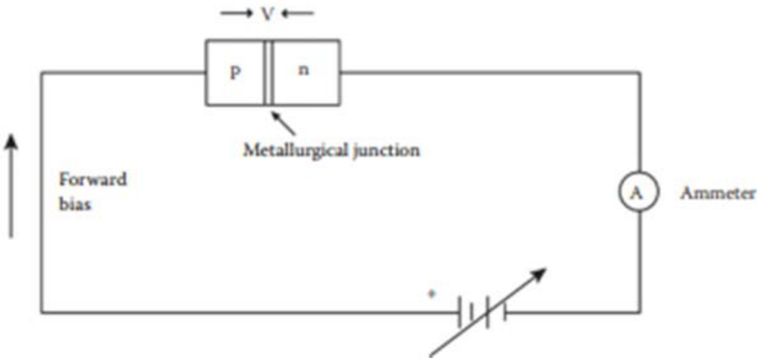


Figure 5.6 Represent the 0 p–n junction in a simple circuit.

Type and Purity of Material

Solar cells for terrestrial purposes are commonly constructed of silicon in the form of single crystals, polycrystalline solids, or amorphous solids. Since the crystal is devoid of grain boundaries, which are imperfections in the crystal structure produced by changes in the lattice that tend to impair the material's electrical and thermal conductivity, single-crystal silicon is the most efficient. They may be thought of as electron flow barriers. Polycrystalline silicon has visible grain boundaries; single crystal parts are visible to the human eye. Amorphous silicon (a-Si) is a noncrystalline type of silicon in which the atoms are grouped haphazardly. Since the material is disordered, certain atoms have a dangling link that hinders electron transport. A dangling bond develops when an atom lacks a neighbour to which it may attach. Amorphous silicon has the lowest power conversion efficiency of the three varieties, yet it is the cheapest to make. these solids graphically.

Silicon that is monocrystalline. Cells are constructed from an ingot of a single crystal of silicon that has been produced in high-tech laboratories, sliced, doped, and etched. Efficiency for commercial terrestrial modules generally ranges between 15-20%. This sort of cell-based module is the most mature on the market. Reputable PV module manufacturers provide warranties of up to 20-25 years at 80% of nameplate rating. Silicon that is polycrystalline. These cells are constructed using a variety of silicon crystals produced from an ingot. They are also cut, doped, and engraved. They have somewhat lower conversion efficiency than monocrystalline cells, ranging from 13 to 15%. Polycrystalline PV modules are generally guaranteed for 20 years by reputable manufacturers.

Silicon that is amorphous. The absence of any geometrical cell structure is referred to as amorphous. Amorphous modules lack the ordered pattern typical of crystals, like crystalline silicon does. Conversion efficiency for commercial modules generally range from 5 to 10%. Depending on the manufacturer, most product warranties are for 10 years. Because of the shorter lives caused by increased cell deterioration in sunlight (degradation to 80% of original output in most instances), the technology has yet to acquire mainstream adoption for higher power applications. Nonetheless, amorphous PV has gained widespread acceptance for usage in consumer electronics (e.g., watches and calculators). Higher voltage modules may be made more inexpensively than crystalline equivalents, which is advantageous for certain grid-connected or water-pumping applications. Another issue restricting efficiency is the presence of traps as in material. Traps are semiconductor material imperfections in the depletion zone that may significantly enhance electron and hole recombination. Recombination lowers Voc, which lowers the fill factor and efficiency.

CHAPTER 6

TANDEM CELLS

Venkadeshwaran K, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- k.venkadeswaran@jainuniversity.ac.in

These more effective heterojunction cells use a sequence of changing band-gap cells layered on top of one another, with the material having the widest band-gap material on top. High-energy photons are absorbed in the material with a bigger band gap, while lower-energy photons flow through the stack until they reach a cell with a low enough band gap to use them. Tandem cells are frequently linked in series to simplify circuit complexity. Since both current and voltage might fluctuate with each cell, the current is restricted by the lowest value. Tandem cell efficiencies are usually stated to be about 30% when composed of layers such as GaInP/GaAs/Ge, which is a significant increase above polycrystalline silicon standards. A heterojunction is an interface formed by two different crystalline semiconductor layers or areas. In contrast to homojunctions, which are formed of the same semiconductor material, both semiconducting materials have asymmetrical band gaps.

In addition to traditional (Ge/GaAs/InGaP) tandem PV cells, Stanford University, the National Renewable Energy Laboratory, and the University of New South Wales have suggested early laboratory research into silicon tandem cells employing quantum dots. It was proposed to "create an innovative Photo voltaic device based on integrating low-cost polycrystalline silicon thin films with higher band-gap oxide semiconductors synthesised using silicon quantum dots embedded in a matrix of silicon oxide, nitride, or carbide to produce two- or three-cell tandem stacks**.**

Thin Film Technologies

Semiconductor materials are often placed as a thin layer on a substrate, which is typically glass or ceramics. Rather of developing a crystal, the chemical is sputtered onto the substrate, allowing for very portable devices. Devices constructed in this way are not as efficient as the previously stated cell types, but they are successful in lowering costs by decreasing the quantity of material consumed and effort in connecting the cells together and in modules. This manufacturing approach is also referred to as "second generation." Copper indium gallium diselenide devices, or CIGS (Cu/In/Ga/Se2), are heterojunction devices, as the name implies. Billy Stanbury discovered the CIGS phenomena while working at Boeing: nanostructured domains operating as p-n junctions with a trend towards high electron producing efficiency; this was later dubbed the Stanbury model. CIGS are direct band-gap semiconductors that may be employed in building Photovoltaics (BIPV) applications such as integral shingles and windows, as well as inside window curtains. CIGS show a lot of potential in terms of conversion efficiency and production.

Quantum Dots

Quantum dots are small semiconductor crystals just a few nanometers broad Since electron-hole pairs in quantum dots are restricted in three dimensions, their characteristics vary from those of conventional semiconductors. The addition of quantum dots to a solar cell improves the cell's capacity to react to a specific wavelength of light. Instead of releasing one electron for each photon of light, two or more electrons are released by a single photon, improving electrical current and hence efficiency. Since quantum dots may be created via relatively simple chemical processes, incorporating them into solar cells may lower costs; nevertheless, the majority of this technique is still in the research phase.

Utility Power Generation

Several firms are opting for "green power" (the use of renewable technologies to produce electricity), maybe to increase their public appeal. Google may not need to improve its public image, but it is redesigning its headquarters tp reflect this trend. Google switched a portion of its Googleplex offices in Silicon Valley to solar power by installing over 9,000 solar panels, enough to power 1,000 households. The project is now operational. Moreover, in December 2007, the US government constructed a 14 MW 140-acre solar farm at Nellis Air Force Base featuring panels of silicon wafers can rotate to follow the sun across the sky. Several nations are also using PV technology to offset power expenses.

Solar-Powered Products

PV cells are used in many contemporary goods to function independently of other electrical suppliers. Calculators, watches and clocks, battery chargers, warning devices, and units for rotating plants and shop window displays are examples of indoor items. Path and accent lighting, aquatic items such as fountains, small-animal garden deterrents, greenhouse vents, car air vents, and radios are examples of outdoor products. Amorphous silicon impregnated backpacks may be used to charge mobile phones with GPS service, providing an additional safety feature for extended hiking expeditions. Moreover, solar panels that resemble tinted glass are aesthetically appealing. To summarise, PV device technology has been proved over many decades. While advances have shown the viability of numerous applications, solar cell efficiency remain lower than expected. To improve efficiency, relevant research and subsequent production must be accomplished within budgeted time frames. A careful balance must be maintained, and trade-offs in both research and production may be necessary to boost efficiency and drive down costs.

Photovoltaic Conversion Systems

Solar energy is an unlimited source of clean energy that allows for local energy independence, and photovoltaics (PV) is the only technology that makes electric power accessible to everybody, almost everywhere on the earth. Sun is the energy source that keeps all plants, animals, and humans alive on Earth. The Earth is basically a big solar collector that gathers radiant energy from the Sun in the form of electromagnetic radiation because it is located at the right distance and orbit from the Sun. , the Sun's power flow to Earth is normally about 1,000 W/m2, however availability varies depending on location and time of year.

Solar energy may be transformed chemically (through photosynthesis), thermally, or electrically (via PV). Harvesting solar energy often necessitates the purchase of equipment with a somewhat high initial capital cost. Yet, when compared to traditional energy sources, these systems may show to be cost competitive throughout the lifespan of the solar equipment, particularly since there are no recurrent fuel expenditures. Solar electric power, or PV systems, is a cost-effective and practical method for supplying energy to sites that have not been connected to the traditional electrical grid. PV power systems have been used practically everywhere, literally from pole to pole. Nevertheless, since PV has a greater initial cost, it is most cost efficient for distant locations where other, more traditional solutions are not competitive.

Since there are many misconceptions about what defines a good candidate PV application and site, extensive site analysis is required to exclude inappropriate areas. PV systems offer both benefits and downsides that should be carefully examined by the project implementer and the end user, for example, projects that demand significant quantities of electricity are typically deal breakers for PV consideration. both the implementer and the end user PV is utilised in everything from calculators and watches to big systems for power utilities. Although though PV systems are costly, they are financially effective in a variety of applications, particularly for stand-alone systems located some distance from the utility grid. Since the cost of a transformer exceeds the cost of the PV system, small power applications near the utility grid may also be cost viable. A flashing light for school lane crossings is one example.

PV project success is closely tied to a thorough grasp of site conditions and resources, as well as PV capabilities and constraints. What makes a location suitable for solar energy? What are the resource disparities across sites? What is the estimated cost of the system? These are some of the questions a project developer should be able to answer. This chapter gives some fundamental tools to assist in answering these questions. The PV sector, on the other hand, is continually expanding, and no book can substitute consulting with an expert with genuine field experience. A solar energy project needs both time and money. Since the initial expenditure is quite significant, the project should be carefully planned and developed to minimise any future disappointments. While creating a project, the following fundamental aspects.

Energy Alternative

The first issue to evaluate is the availability of alternative energy sources. For example, if energy needs are high, the distance to the electric grid and availability of internal combustion engines should be investigated since it may be more cost effective to extend the grid connection to a nearby location or utilise an available internal combustion engine. In the event of grid expansion, an obvious concern arises: How far should the grid line be from the site to guarantee that the extension is cost effective. The response varies. Grid expansion may cost $10,000+ per kilometre ($16,000+ per mile) in comparatively level terrain, but can cost up to $20,000+ per kilometre ($32,000+ per mile) in more challenging terrain. Crossing a valley, mountain, or other challenging terrain is more expensive. Nonetheless, prices vary per nation. Solar is often regarded practicable for most small and medium-sized energy projects if the grid is more than a kilometre away.

Communities should be at minimum a couple of kilometres from the closest electricity service for village power systems; the farther they are, the more competitive the solar alternative will be. If there is local electrical service, extending the electrical line and purchasing a transformer is typically a less expensive choice. This might also pave the way for community-wide electricity.

This criteria, however, is occasionally misunderstood. For example, if development funding are exclusively available for renewable energy sources, conventional power may be the best option, but the technological selection is skewed towards PV. In general, the dynamic of required rather than best-option technology selection should be avoided in project design. Moreover, even in electrified regions, communities are generally drawn towards PV since this arrangement relieves them of any future power expenditures. This may not be the lovely solution it looks to be: The financial burden is simply added to the original project cost incurred by the giving agency, and decreasing community involvement over time might contradict sustainability ideals. To stimulate and establish the habit of regular payment of electricity bills, communities need continuing costs.

PV Electrical Characteristic

PV cells are coupled in series and parallel electrical configurations to supply the appropriate current or voltage to operate electrical loads in order to create useable electricity. PV cells are linked in series, aggregated, laminated, and packed between plastic and glass sheets to produce a PV module. The module features a frame (often made of aluminium) that provides stiffness and enables for easy handling and installation. Junction boxes are situated on the backs of PV modules, where conductor connections are formed to transport electricity from modules to loads.

The number of cells in a module varies depending on the application. Many terrestrial solar modules are nominally rated at 12 V since they were initially intended to charge 12 V lead-acid batteries. These PV modules normally include 36 series-connected cells, however self-regulating modules with less cells are also available. These modules provide enough power to charge 12 V batteries while also compensating for voltage dips in electrical circuits and energy control and management systems. With the rising rise of grid-tied PV in recent years, there is a growing selection of bigger modules (e.g., 300 Wp) with more cells and higher voltages for these applications. All PV modules generate direct current (DC). In AC applications, the array voltage must be matched to that of the inverter under real-world operating settings rather than conventional test conditions (STCs). There are several "AC modules" on the market, but the inverter is really incorporated into the rear of the module junction box; the PV cells always provide DC electricity.

The most common solar cells are huge p-n (positive-negative) junction diodes that utilise light energy (photons) to generate direct current (DC). When the cells are lighted, no voltage is provided across the junction; instead, a current is created in the associated load. A current versus voltage curve is often used to describe the electrical behaviour of PV modules (I-V curve). A power curve is constructed similarly by multiplying current and voltage at each point on the I-V curve. Yet, the maximum power point is the sole point desired to operate on this curve.

I-V Curve

Curves are used to represent current-voltage relationships, which are utilised to measure the electrical properties of PV devices. The current-voltage, or I-V, curve depicts current against voltage from short circuit current Isc to open loop voltage Voc through loading. Curves are used to calculate performance (Figure 6.1).

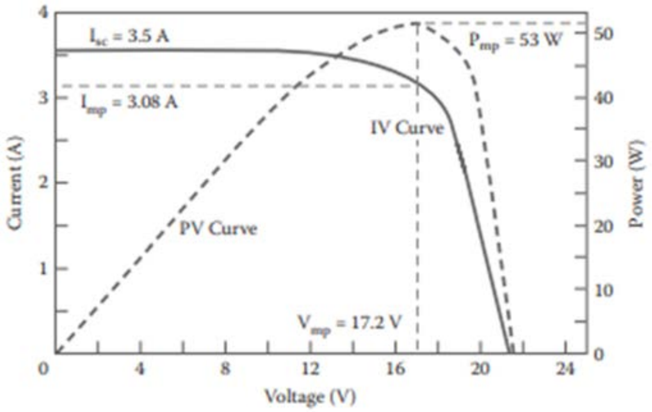


Figure 6.1 Typical I-V and power curves for a crystalline PV module operating at 1,000 W/m2 (STC).

PV system performance levels (cells, modules, arrays). Tight equipment and procedural requirements are required to provide high-quality, consistent outcomes. Experiment with the I-V curve by exposing the PV cell or module to a consistent amount of irradiance while keeping a steady cell temperature, adjusting the load resistance, and measuring the current generated. The horizontal and vertical axes are used to monitor voltage and current. The I-V curve usually has two ends: the short-circuit current, Isc, and the open-circuit voltage, Voc. The Isc is the current generated by shorting the cell's positive and negative terminals; the voltage between the terminals is zero, corresponding to zero load resistance.

The voltage between the positive and negative terminals in inviting circumstances with no current, corresponding to infinite load resistance, is defined as the Voc. I-V curves may display the peak power point at the furthest top right corner of the rectangular region beneath the curve. The PV cell may function at a variety of voltages. It is feasible to find the optimum efficiency as the point where the cell generates maximum power by simply adjusting the load resistance from zero (a short circuit) to infinity (an open circuit). Since power is the product of voltage times current, the maximum-power point (Pm) is located on the I-V curve at the point where the product of current (Imp) times voltage (Vmp) is at its maximum. Since no power is created at short-circuit current with no voltage or open-circuit voltage with no current, maximum power production is assumed to be somewhere in the middle. It is worth noting that maximum power is created at just one position on the power curve; this is near the curve's knee. This point shows the device's highest efficiency in converting sunlight into energy. The majority of nominal 12 V units have a peak voltage (Vp) ranging from 15 V (30 cells in series) to 17.5 V. (36 cells in series). The manufacturer has put a sticker on the rear side of each module that specifies the electrical parameters. for example, shows the sticker on the rear of a BP b VLX-53 module whose features are listed.

Two major elements influence the electricity generated by a crystalline PV module: solar irradiation and module temperature. The lower the sun irradiation, the lower the current output and hence the peak power point. Voltage is practically constant. The quantity of current generated grows in direct proportion to the intensity of solar light. Voc, in essence, does not vary; its behaviour remains largely consistent even if the intensity of solar light varies.

the influence of temperature on a module's power generating capability. When module operating temperature rises, module voltage falls but current remains practically constant. PV module operating voltage is lowered by roughly 0.5% for every degree Celsius over STC (i.e., 25°) for crystalline modules. Consequently, a 100 Wp crystalline module under STC will lose roughly 15% of its power rating and generate about 85 W of useable electricity while running at a more realistic 55°C with no modification to solar irradiation. STC should be expected to reduce module power by 15-20% when sizing terrestrial PV systems. This is critical to keep in mind when estimating daily real energy output. The NASA Jet Propulsion Laboratory (JPL) previously set PV cell requirements for interplanetary uses, and the notation stayed. Remember that the temperature impact for crystalline modules will degrade module performance in real-world operation settings. In contrast, a module running at temperatures below 25°C will provide more power than is rated.

The PV module is the most dependable component of any PV system. The quality of installation as well as other components, such as electrical connections between modules, motors, and so on, will ultimately decide the PV system's overall dependability. Nonetheless, only a tiny percentage of PV systems in the context have failed owing to module problems (less than 1%).

Increasing Voltage

To achieve larger output voltages, PV modules are coupled in series. The total of the voltages produced by each module determines the output voltage, Vo, of modules linked in series:

$$Vo = V1 + V2 + V3$$

The parallel between a steering pump and an electrical system presented is a simple method to comprehend the notion of series-connected systems. Water descending from four times the 12 m height provides four times the pressure of water dropping from the first level, as shown in the hydraulic system (left side). This is equivalent to the 48 V reached by the electrical system (right side) after sending a current of 2 A through four series-connected modules. Since both stay constant inside their respective circuits, the current and flow may be compared, and the voltage is equivalent to the function of pressure in the hydraulic system.

Increasing Current

PV modules are linked in parallel to increase current. The parallel-connected modules have the same voltage as a single module, but the output current, Io, is the total of the currents from each unit linked in parallel: Systems linked in parallel may be compared to hydraulic systems, such as the one , in the same way as systems connected in series can. Water falling from the same height produces the same pressure as each individual pump in the hydraulic system (top), but the flow is equal to the overall flow from all of the pumps. The voltage stays constant in the electrical system, and the power flow of the four modules is summed, yielding 8 A of current and 12 V.

V Array Tilt

When the Sun's rays reach the receiving surface perpendicularly, the maximum energy is obtained. In the case of PV arrays, perpendicularity between the Sun's beams and the modules can be accomplished only if the mounting structure of the modules can follow the Sun's motions (i.e., track the Sun).

There are mounting systems that adjusts for azimuth and height. Trackers are structures of this kind. Typically, the array's elevation angle is fixed. Azimuth-adjusting trackers are employed in various instances. In temperate regions, azimuth-adjusting trackers may boost yearly average insolation received by up to 25% depending on the latitude of the location.

In the absence of a tracker, the array is placed on a permanent structure, This structure has the virtue of being simple. Since the Sun's angle of elevation fluctuates throughout the year, the array's fixed-tilt angle should be set to ensure optimal energy output. The Sun follows the Earth's ecliptic in the Northern Hemisphere (Figure 6.2). predominantly over the southern sky; as a result, stationary PV arrays should be oriented (from horizontal) southward. The array's inclination angle is chosen to meet the energy requirement during the crucial design month. If maximum energy production throughout the course of the year is desired, the tilt angle of the array should be equal to the latitudes of the location. Winter output may be increased by tilting the array 10-15 degrees higher than latitude. Similarly, summertime output may be increased by tilting the array 10-15° lower than latitude.

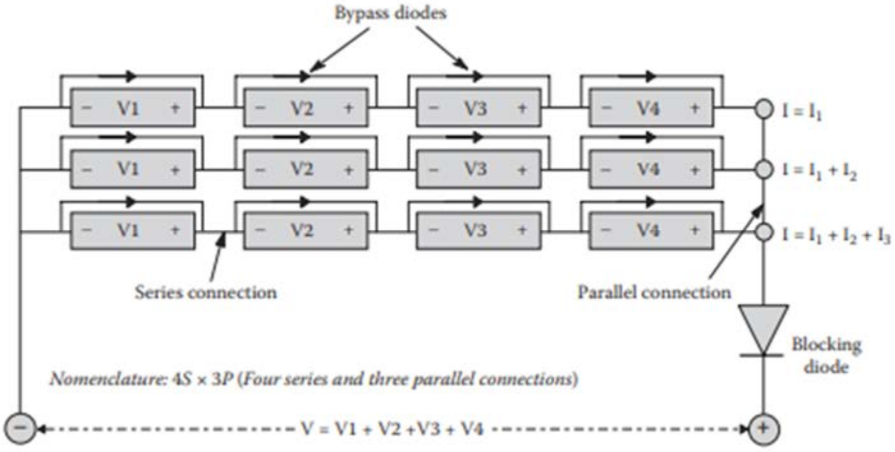


Figure 6.2 The 6 Connection of PV modules in series and parallel, increasing both voltage and current.

PV Balance of Systems

PV systems are comprised of several components such as arrays, wiring, fuses, controllers, batteries, trackers, and inverters. The components will vary somewhat based on the application. Since PV systems are modular in design, they may be easily extended and components fixed or changed as required. PV systems are now cost-effective for many distant power applications, as well as tiny stand-alone power applications close to existing power sources.

Good electrical design techniques, such as the National Electrical Code (NEC) or its equivalent, should be used for these system Electricity flowing through an electricity system must pass via a number of devices and cables connecting the system components. Balance of system (BOS) refers to all system components other than the PV modules in a PV system. These components may account for half of the system cost and the majority of system upkeep. Structures, enclosures, wire connections to connect various hardware components, switch gear, fuses, ground fault detectors, charge controllers, general controllers, batteries, inverters, and dials and metres to monitor system performance and status are examples of BOS components.

The choice of excellent BOS components is just as critical as the choice of PV modules. Low-quality BOS is often responsible for many preventable maintenance issues for PV systems in distant places, and it may lead to premature failure and system misuse. The objective of the PV industry is to deliver PV systems with functional life spans of 25 years or more. Despite this, untrained system designers and installers continue to use connectors, cable, and other components for PV systems, with predictable effects.

Inverters and Converters

Inverters receive one kind of electrical current and output another type of electricity. A rectifier transforms AC into DC, while an inverter turns DC into AC. There are also DC-DC converters, which increase or decrease the voltage of a direct current. Inverters convert direct current (DC) electricity from batteries or a solar array into 60 or 50 Hz alternating current (AC). Inverters might be of the transformer or high-frequency switching kind. Inverters may be standalone, utility-connected, or a mix of the two. Inverters, like all other power system components, waste energy owing to inefficiencies. Inverter efficiency is typically over 90%; however, inverters that are poorly linked to array and loads may run at much lower efficiency (Figure 6.3).

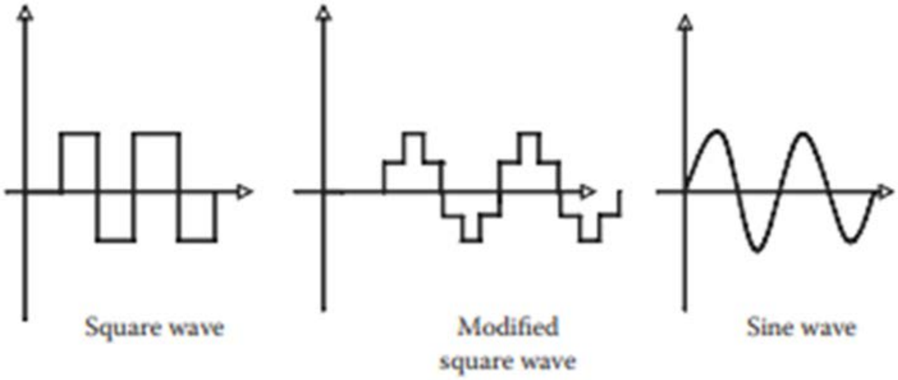


Figure 6.3 Represent the Inverter wave outputs.

Most PV systems built in grid-connected or dispersed applications use inverters. Inverters are usually the most costly component of an installed PV system, apart from the panels themselves, and are frequently the essential element in terms of total system dependability and function. During the next 50 years, utility-interactive PV systems installed in homes and commercial buildings will become a modest but significant source of electricity production. A shift from large-scale central generating to small-scale scattered generation is a novel notion in utility power production. The core technology is straightforward, with a PV array providing DC power that is converted to AC electricity and sent into the grid through an inverter—very simple, but beautiful. Inverters may generate alternating current using square, modified-sine, or quasi-sine waves, as well as pure sine waves. The pure sine wave is the most expensive, most efficient, and has the finest power quality.

Modified sine wave is in the middle of the cost, quality, and efficiency spectrum. Square wave is inexpensive in cost and efficiency, with poor power quality that might be helpful in certain applications. Due to high-voltage harmonic distortion, square wave transmissions may be hazardous to certain electrical devices. Electromagnetic noise is produced by all inverters. This noise might interfere with audio and video devices. Grounding the inverter casing, which is also a regulatory requirement for safety reasons, is one technique of attenuating this electromagnetic noise in certain circumstances.

The structure of the distorted wave governs the harmonic frequencies and magnitudes that occur on a system. An inverter's output capacity is measured in volt-amperes (VA). There are two types of output capacity specifications: continuous output and beginning (or spike) output. Continuous output must be sufficient to power all AC loads at same time. Devices such as motors need a VA power input many times larger than continuous power at startup. This demand is only present for a limited time. Motor starting current ranges from two to six times steady state; induction motors such as compressors and pumps that start under load are the most difficult to start, while capacitor start motors (drill press, band saw) can only start up to one horsepower. With modified sine wave, most motors consume 20% more power and operate hotter than with pure sine wave.

Inverters often have beginning outputs that are many times larger than continuous outputs. Inverters often safeguard themselves by disconnecting loads if the output capacity is ever exceeded. In most cases, a manual reset or fuse replacement is required to get the inverter working again. Stand-alone inverters are intended for use in off-grid systems. Load compatibility, power rating, power quality, and battery health are all important design considerations. Since inverters are linked directly to batteries in stand-alone systems, an overcurrent safety device (such as a fuse or automatic breaker) must be put between the batteries and the inverter. Inverters are also used in other distributed energy sources such as fuel cells and microturbines. The majority of inverters for this purpose are rated at a few kiloWatts. Since the inverter has a minimum threshold for starting up, very modest loads may not keep it operating (may cycle the inverter). A separate low-voltage disconnect is not required for stand-alone inverters since the inverter disconnects the load to safeguard batteries from overdischarge. Low voltage disconnect (LVD) is determined by the inverter based on the battery voltage, current, and capacity input.

Stand-alone inverters are power conversion devices that are placed in accordance with the electrical code, which often mandates the use of set input and output wiring techniques. A stand-alone PV inverter should include facilities for hardwiring at least the DC input/outputs and perhaps the AC input/outputs, however depending on the inverter size and construction, these may be simple plug-in connections.

The AC outputs of stand-alone inverters are linked to an AC load centre (either a series of circuit breakers in a PV power centre or a normal AC load center—panel board—in a house or building) in practically all stand-alone installations (no utility connection). When the main disconnect is not collocated the with load circuit breakers, as in a mobile home, the connection between AC neutral and the grounding system is generally created in these panel boards or in a similar region such as the main disconnect enclosure. The load centre connects stand-alone inverters to batteries. To reduce voltage loss and the number of disconnects and overcurrent devices, the wires between the inverter and the batteries are normally maintained as short as feasible.

Grid-tied inverters are frequently used to connect PV systems to the electric utility grid in Europe, Japan, and the United States. In synchrony with the electric grid, these inverters convert DC electricity to AC power (UL 1741). When the power is off, the inverters turn off by design. Utility connectivity issues for PV systems include safety, anti-islanding, and power quality. PV system islanding occurs when the utility power grid fails and the inverter tries to power the grid. When an islanding protected inverter detects a lack of AC power from the grid, it does not back-feed into the grid system. All AC grid-connected inverters are anti-islanding, and the voltage on the inverting input must drop to zero within 2 seconds of the grid failing. The inverter should be connected properly according to the manufacturer's specifications, with the appropriate wire diameters, fuses, and breaker sizes and kinds. Grid shorted, grid open, pro inversion synchronisation, over or under frequency, and over or under voltage are all techniques of PV system anti-islanding protection.

CHAPTER 7

BASICS OF NET METERING

Venkadeshwaran K, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- k.venkadeswaran@jainuniversity.ac.in

Net metering, often known as net energy billing, is the practise of reading the utility metre, which runs forward and backward, at the conclusion of a defined time period. The time span might range from a month to a year. The consumer pays the utilities for net energy bought, and if more energy is generated than is used, the utility reimburses the client for the difference. When energy generated on-site is not utilised immediately but offsets energy from utility provider later, such energy is worth the retail rate. If net metering is used throughout the year, the client obtains the retail rate during periods of low renewable energy output. The majority of the states here in the USA permit net metering. It allows for the installation of customer-connected power generation equipment without the need to replace the existing metre. When electricity produced by the client is supplied to the utility, the metre may spin backward. The client must safely wire the PV system and utility interconnections in accordance with NEC and local requirements; install equipment that meets appropriate IEEE design and operation standards; and install equipment that is UL rated for safety.

Before connecting to the utility system, make sure to:

1. obtain permission from the local electric utility.
2. obtain technical rules for interconnection.
3. obtain rates for installation of metering equipment and cost of service.
4. be prepared provide the full details and documentation of the proposed PV installation. including sell-back methods if desired; and learn the details before installing the system.

Photovoltaic System Sizing and Design

To size and construct a solar energy system, a fair evaluation of the energy demand that the system must satisfy is required. Using this data, a realistic estimate for the size of a PV system necessary to deliver the required energy may be produced. The section that follows describes the normal design and installation procedure for PV power systems.

The energy consumption in PV systems is given on a per-day basis, which leads to the next item to consider: the intended use of the energy. Is there enough energy to run a regional telecommunications system 24 hours a day, seven days a week? Is it exclusively for night lights? Maybe it is for a water-pumping system that will be mostly used during the hot summer months. PV systems are often used in situations where the power demand is low, such as supplying drinking water for cattle and drinking water for humans. Flood irrigation of agriculture is often not cost efficient owing to high water consumption and poor produce value. When it comes to solar power system sizing and design, one size does not fit all. The goal is to first reduce energy usage by employing the most energy-efficient equipment, and then construct a solar power system around the energy-efficient system.

Solar Resource Sizing Considerations

Understanding the local sun resource is necessary for effectively predicting the size of a solar energy system. These resources might differ greatly based on region. The sun resource is accessible practically everywhere on the earth and is more than sufficient in most temperate and tropical places to be used productively. Areas where total cloud cover occurs consistently for weeks at a time (e.g., tropical highland rain forests) may create issues, and PV systems must be bigger to satisfy energy demands. Even under gloomy situations, some electricity may be created, but only a fraction (10%) of what is available in bright, clear-sky conditions. Concentrated solar energy systems can only function when direct sunshine is available.

Vegetation, such as that seen in desert regions (e.g., cactus thrive when it is sunny and dry), may be a good indication of solar availability. Tropical locations have a less changeable solar supply over the course of a year than higher latitude temperate regions with long summer days and short winter days. There are maps and tables available for many different geographic places that reflect average monthly solar insolation (i.e., energy). The usual unit for insolation is kiloWatt-hour per square metre (kWh/m2), often known as a sun-hour. Appendix A offers a table with insolation values for different geographic locations. Other suitable Web sites, such as those run by NREL or NASA, also give solar insolation statistics. The insolation number that best matches the project site should be utilised. When in doubt, it is best to be cautious (i.e., utilise less sun-hours).

The solar energy system should be developed to meet the needs of the seasonal sun resource. A PV system for an off-grid residence may be designed for the winter season, when there is less sunshine. Water pumping requirements often decrease during the chilly or cold winter months and rise during the bright and sunny summer months. There is a natural link that bodes well for PV water pumping when systems can be constructed for optimal tilt to optimise utilisation for when the water is required.

Irradiance varies during the day and under stable air conditions, with lowest values at dawn and twilight and greatest values at midday. On a clear day, for example, the irradiance number at 9:00 a.m. will be lower than the irradiance value at noon. This is explained by the Earth's rotation on its axis, which enables sunlight to travel the shortest distance through the Earth's atmosphere at solar noon. During this time of day, the Sun's rays strike a surface perpendicularly and through the thinnest atmosphere (exactly 1 atm). We evaluate the average energy available throughout a day for practical solar energy system design and size; this is the insolation and corresponds to the cumulative irradiance over time. Insolation is usually measured in kiloWatt-hours per square metre. This statistic is often given as an accumulation of energy over the course of a day. Peak sun-hours are often used to indicate insolation. A maximum sun-hour is 1,000 W/m2. The quantity of energy generated by a PV array is proportional to the amount of insolation received.

Solar Trajectory

Apart from meteorological circumstances, another factor influences incoming solar radiation and system sizing: the apparent movement of the Sun during the day and year. The tilted axis of the Earth causes a day-to-day shift in the angle between the Earth-Sun line and the Earth's equatorial plane, known as solar decline (angle varies with the date). The major cause of the changing seasons is the daily change in declination, which causes variations in the distribution of solar energy across the Earth's surface and the number of hours of daylight and darkness. Solar energy systems must always be sized for the important season in which they will be used (Figure 7.1).

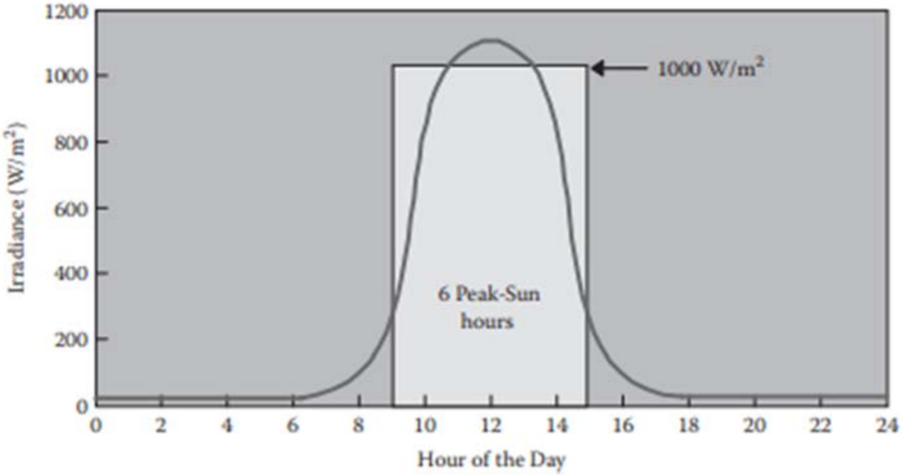


Figure 7.1 Represent the Irradiance and insolation expressed as peak solar hours (i.e., 6 sun-hours = 6 kWh/m2.

The Sun's location may be characterised by its height above the horizon and its azimuth, which is measured as an angles in the horizontal plane. Since the Earth's daily rotation and yearly orbit around the Sun are regular and predictable, the solar altitude and azimuth may be computed at any time of day using known latitude, longitude, and date (declination). The apparent rate of motion of the Sun is 4′ per degree of longitude because it seems to travel 360° in 24 hours. The Sun lies precisely on the meridian, which encompasses the south-north line, during solar noon. As a result, the sun azimuth, f, is 0°. The incidence angle is the angle formed by the line normal to the irradiated surface and the Earth-Sun line. It is significant in solar technology because it influences the intensity of direct solar radiation impacting a surface. It is only essential to consider the total daily tropics for calculating daily energy output for practical reasons linked to PV system design; nevertheless, it is crucial to recognise season fluctuations owing to the Sun's apparent movement over the sky dome.

When a PV array is maintained oriented directly normal (perpendicular) to the Sun, it obtains the most insolation. To do this, the Sun must be tracked throughout the day and year, necessitating the continual adjustment of two angles: the azimuth, which tracks the daily movement of the Sun from the east to the west, and the angle of elevation, which tracks the Sun's north-south course through the seasons. Tracking structural mounts built for this purpose (either single or multiple axis) are required for a Pv system to follow the Sun in this way.

Solar Energy System Sizing Considerations

Insolation is the most important factor to consider when designing a solar energy system. The most important elements influencing the quantity of insolation incident on a sun's surface are orientation, mounting angle with regard to the horizontal, and environmental conditions. Average insolation is lower in places where overcast days are common. Winter days are much shorter than summer days in latitudes higher than the tropics (i.e., >20°). As a consequence, average insolation is higher throughout the summer. For example, in wet tropics near the equator, such as southern Mexico's rainforests, insolation upon the horizontal plane reaches Four kWh/m2 per day in the winter, 5.2 kWh/m2 per day in the summer, and 4.5 kWh/m2 per day on a yearly basis. In the arid parts of northern California, insolation on the horizontal plane averages 5 kWh/m2 per day in winter, 8 kWh/m2 per day in summer, and 6.5 kWh/m2 per day year round. This difference is due to a combination of longer summer days in northern Mexico's higher latitudes and generally fewer overcast circumstances. A one-size-fits-all solar energy system does not exist, and it is highly dependent on latitude and associated sun resource.

Since the quantity of insolation generated by a solar surface varies with orientation and inclination with regard to the Sun's apparent location, the solar resource of a given site is described as the amount of insolation measured on the horizontal plane. Insolation values for surfaces placed at specified azimuths and angles of elevation may be determined using data for insolation on the horizontal plane. Charts and tables with horizontal-plane insolation values for different places and times of the year are available from a variety of sources. Appendix A includes insolation values for several cities.

Solar Energy System Sizing

The quantity of energy supplied by a PV array or module is determined by the amount of sunlight and the temperature. The electrical energy (in kiloWatt-hours/day) anticipated of an array with known nominal power may be estimated using the following approximations:

During the summer, PV modules put on buildings attached to the ground operate at about 55°C; certain desert regions may be much hotter. This is 30°C higher than the typical test circumstances (25°C). This indicates that the array's true capacity is around 15% less than its nominal power rating. Hence, the effective capacity is 85% of the nominal capacity. Estimated electrical energy (kiloWatt-hours) is the product of the array's actual capacity (kiloWatt-hours) and insolation (peak sun hours) at the array's angle of elevation.

The amount of PV energy generated changes seasonally, as do the degrees of insolation. Using an azimuth-adjusting tracker may enhance yearly energy output by up to 25% in temperate climes. There are several PV-sizing approaches, spreadsheets, and computer applications available. The most difficult component of scaling a system, however, is forecasting the predicted end user loads; this drives solar energy system design. Some users seem energy conscious, whilst others (for example, teens) have no understanding of, and are unconcerned about, energy use.

Examining solar energy system efficiencies is one of the easiest and most successful ways for assessing solar energy systems Hence, for off-grid systems with battery storage, the energy needed from a solar energy system is around half that of the array nameplate rating, and it lowers by one-quarter for grid-tied systems. Grid-connected systems are more lenient in that the user will never realise if the solar energy system is inadequate since the grid will provide any power shortage. Off-grid systems require the user to live inside the boundaries of the energy provided by his solar power system.

Sizing Inverters

The inverter for a PV lighting system provides a significant advantage in powering specialised AC equipment. Modern inverters are incredibly dependable, and there are hundreds of different sorts, sizes, brands, and models to choose from. Selecting the finest inverter from such a vast list might be difficult, and there is no such thing as a "best" inverter for all uses. Typically, power production is the most important component. An inverter must fulfil two requirements: peak (or surge) power and continuous power:

Surge is the highest power that an inverter can provide, generally for a brief period of time. Certain appliances, especially those with electric motors, use much more electricity upon beginning than they do when operating. Pumps and refrigerators are two additional popular examples (compressors).

Constant power is the electricity that the inverter must deliver on a consistent basis. Surge power is often significantly lower. This is what a refrigerator draws after the first few seconds of the motor starting, or what it takes to operate the microwave, or the total of all combined loads.

Continuous wattage output is used to rate inverters. The bigger they are, the more expensive they are. Assume sizing for a 19-inch TV (80 W), a blender (350 W), one fluorescent light at 20 W, and two fluorescent lights at 11 W each, for a total of 472 W. An inverter capable of supplying at least 472 W constantly will be selected. The only thing to be concerned about here is the blender's initial surge need. Typically, a tiny motor like the one in the blender would surge for a fraction of a second at twice the power it regularly uses—in this example, 350 multiplied by two equals around a 700 W surge. If the inverter is already continually loaded, some existing loads may need to be shut down to assist meet the surge.

Assume a 500 W inverter with a surge capacity ratings of 1,000 W is used, which is more than enough to handle the blender surge. The following factors were evaluated while choosing an inverter for the previously described PV lighting application example.

Array Estimation

The size of a PV array for a PV light system is determined by delivering enough energy to fulfil the demand during the time with the greatest average daily load and the lowest solar insolation on the surface.

1. The month of design is December at 5.4 h. (Oaxaca).
2. Suppose the PV array temperature derate is 15% of the daily need.
3. Assume inverter losses of 10% of daily demand.
4. Assume 1% fuses/disconnect losses.
5. Assume 3% wiring losses.
6. Assume 25% battery loss.
7. Therefore the total system losses are 0.85 * 0.90 *0.99 * 0.97 * 0.75 = 55%.

8. System load requirement adjusted = 63 Ah/day/0.55 = 114 Ah/day.

The PV module used for design (the panel derating factor is typically 80-90%) has a rated peak current of 3.55 A and a maximum peak voltage of 16.9 V at 60 W. The modified load Ampere-hour requirement/module peak current output * peak sun-hours = the number of parallel modules. The load demand has already been adjusted for module derate: = 114 Ah/day/(3.55A * 5.4 h) = 5.95, rounded to six modules in parallel. The number of series modules is calculated as 12 V/(16.9 V * 85%) = 0.84, rounded to one module in series. As a result, the entire PV array is 1s 6p, totalling 360 W.

Generic Water Pump Sizing Methodology

Spreadsheets may also be used to estimate the size of a PV array for solar pumping. While not as precise as utilising pump curves, this approach may be used to obtain early technical parameters for the a generic pump assuming a given efficiency. The boxes in the following three spreadsheets should be completed in the order they are provided They are structured as follows:

1. Required water volume (litres per day): Make a note of the user's intended daily water need. Select the month of the year with the highest water-pumping flow rate. sxample computations based on data from a specific place. To get to the key month, just swap the numbers from the suggested location. To calculate the flow rate, take the daily demand and divide it by the number of hours of peak solar insolation. The appendix has insolation data. Utilize solar data that is projected or accessible near the project location.

2. Site insolation (kWh/m2/day): Record the peak insolation hours per day that coincide to the critical-pumping month.

3. Pumping regime (l/day): Using the prior data, calculate this number. This number should not be more than the well's recharge capacity. Consider lowering daily consumption, employing battery storage for 24-hour pumping, or digging more wells if this is the case.

4. Static level (m): The vertical distance measured from ground level to water level when the pump is turned off.

5. Drawdown (m): This is the vertical separation between two while the pump is running from the static level to the water level.

6. Discharge height (m): This is the vertical distance measured from ground level to the point where the water is dumped.

7. Static head (metres): Using the numbers in list items 4, 5, and 6, calculate the vertical distance travelled by the water from the point of drawdown to the point of discharge.

8. Extra pipe length (m): The length of pipe that was not included in the static head calculation. Consider the vertical distance from the drawdown to the pump's location, as well as any horizontal distance covered by the tubing.

After the completion of list item 10, it was discovered that the total dynamic head was close to 40 m. This data was utilised to choose the pump. All manufacturers provide available tables and graphs to aid in the selection of a suitable pump. Some give advice on the estimated size of the PV array required to power your pump.

Pump graphs from solar pump manufacturers that link daily water volume, TDH, insolation, or PV-array size are available. These graphs depict pump production curves, which are critical when choosing a pump. The manufacturer's technical specification documents are the best way to size a particular pump.

Electrical Codes for PV System Design

There is a global absence of standards for PV system safety and quality. The National Electrical Code (NEC) has been in use in the United States for almost a century, whereas IEC regulations are commonly used in Europe. Japan, which has some of the best PV systems in the world, has its own set of basic electric rules The electrical rules apply to all building electrical systems, including the PV power systems that are increasingly being built across the globe. PV power systems, like all other electrical systems, should be designed, specified, and installed in accordance with applicable regulations and standards, such as the NEC. (Wiles, 2003). PV systems use current-limited producing PV arrays that are activated when they are exposed to light.

They may use electrochemical devices storage, which may be dangerous. However, many PV systems all around the world continue to have issues due to poor design and installation, which raises safety concerns and reduces system dependability. Some frequent PV system issues are: incorrect conductors; dangerous wiring; improper overcurrent protection; unsafe batteries; absence of grounding; use of nonlisted components; and improper usage of listed components. It is important to note that "listed components" relate to equipment and materials on a list issued by an institution acceptable to the body having jurisdiction and involved with evaluating goods or services that satisfy suitable stated standards (e.g., Underwriter's Laboratories). Listings include Japan Electrical Safety and Environment Technology, the Canadian Standards Association, and Environmental Testing Labs.

Given the millions of Third World PV systems installed by poorly trained personnel (often with little or no overcurrent protection), it is surprising that very few fires, injuries, or deaths have indeed been reported from PV; the very few reported cases are usually associated with large utility interactive systems or someone falling off a roof. The National Electrical Code (NEC) was created in the United States in 1897 as a fire-safety code and has been overseen by the National Fire Protection Association (NFPA) since 1911. NFPA 70 governs the installation of electrical systems and should be followed when designing and installing electrical systems. In 48 states, the NEC is recognised as a legal standard for residential electrical design and installation. Compliance with the NEC regulations may assist to reduce fire and accident dangers in any designing.

Article 690 ("Solar Photovoltaic Systems"), which was introduced to the code in 1984, concerns safety regulations for solar PV electrical energy systems such as array circuits, power conditioning devices, and controllers. Similarly, many other parts of the code include portions relevant to PV systems, such as wiring, grounding, overcurrent protection, and so on. These standards and criteria apply to the majority of PV installations in the United States. The NFPA updates the NEC every three years; the most recent edition is the 2008 NEC. NEC-compliant PV systems outperform noncompliant systems in terms of performance and reliability. Similarly, NEC-compliant installations are safer; even tiny PV systems may cause fires since a single deep-cycle storage battery (12 V, 100 Ah) can discharge over 6,000 A into a short circuit. Batteries provide extra dangers owing to the explosive potential of hydrogen gas and the possibility of acid or caustic burns. Shock dangers are also evident in larger PV systems with voltages higher than 50 V. Of course, even NEC-compliant equipment may fail, and there is no replacement for an ongoing maintenance programme.

The local inspector is ultimately responsible for interpreting the NEC and approving electrical installations. Regional electrical codes are occasionally used by local inspection bodies, however the NEC is used by the vast majority of jurisdictions. With over 65,000 electrical inspectors working in 42,000 local authorities, the United States has a complex electrical inspection system (county, city, etc.). Foreign nations that have adopted the NEC often have just a few electrical inspectors working in the most populous cities. Sadly, even in the United States, where the NEC has been in place for more than a century, the vast majority of PV systems deployed are not NEC compliant. Many inspectors in the United States are unfamiliar with PV systems and seldom encounter them in their job. Similarly, many PV installers are unregistered and may be unfamiliar with the law.

While several nations have embraced the NEC, they do not update it every three years and are often dealing with old versions. This is a greater worry for newer NEC technologies like as PV, because significant changes continue to occur over each code update cycle as the technology quickly progresses. The NEC, IEC, and UL are gradually collaborating to coordinate standards. A significant amount of effort is required to educate the worldwide PV sector on how to design and install code-compliant systems. PV developers should be encouraged to enforce code compliance until particular nations have a formal inspection process in place. In general, project developers seek high-quality, safe PV systems and are prepared to define codes if they are made aware of them.

Similarly, the Global Approval Program for Photovoltaics (PV GAP) was established in Geneva, Switzerland, as a non-profit organisation dedicated to the development of worldwide PV markets, especially in the rural sector. PV GAP was first sponsored and organised by the World Bank and the United Nations Development Program (UNDP). PV GAP is comprised of a number of PV manufacturers, including BP, Isofoton, Photowatt, and Schott). PV GAP is managed by the International Electrotechnical Commission's System for Conformity Testing and Certification of Electrical Equipment (IECEE), which is also in charge of the certification programme. PV GAP created a reference handbook for PV producers, which was initially published in 1998.

CHAPTER 8

PHOTOVOLTAIC (PV) APPLICATIONS

Ramachandran T, Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- t.ramachandran@jainuniversity.ac.in

PV systems have a broad range of uses, ranging from tiny stand-alone systems to massive utility grid-tied installations of a few megaWatts. PV is suited for dispersed applications because to its modular and small-scale nature. Almost a quarter of the world's population did not have access to electricity at the start of the twenty-first century, and here is where PV may have the largest effect. PV electricity is already filling this vacuum in rural areas, with literally millions of modest residential PV systems placed on houses throughout the globe, most typically as small stand-alone PV systems, but increasingly as bigger on-grid systems in certain industrialised countries (notably Japan, Germany, and California). Unfortunately, the bulk of PV users are affluent people who want to be seen as "green," or underprivileged rural power users who need energy and have few choices.

Grid-Tied PV

Decentralized photovoltaic power generation has the potential to be a broadly applicable renewable energy source for future clean energy production. Since the majority of electric power in developed nations is supplied by a centralised electric grid, the extensive usage of PV in developed countries will be in the shape of distributed power production integrated with the grid. Furthermore, the grid-connected sector has been the fastest expanding market segment for PV since 2000. Utility-interactive PV power systems put on houses and businesses are quickly becoming a common source of electricity. This phenomenal increase has resulted from government incentives and laws supporting clean energy in response to concerns about the environmental implications of traditional power production technologies, particularly global warming (especially coal). Europe, Japan, and California have seen especially rapid growth.

Grid-connected PV is a transition from large-scale central generating to small-scale distributed generation. The on-grid Photovoltaic system is the most basic PV system. There is no need for energy storage, as the system simply flows back into the current electrical grid. This expansion has also had unforeseen effects for the off-grid sector, as many module makers have stopped producing smaller, lithium ion PV modules in favour of bigger, higher voltage modules designed for on-grid inverters.

Utility-interactive PV systems are simple yet elegant, consisting of a PV array (which provides direct current power), an inverter, other balance of systems (such as wiring, fuses, and mounting structure), and a means of connecting to the electric grid (via back-feeding through the main electric service distribution panel). During the day, the inverter converts DC energy from the PV modules to AC and feeds it into the building power distribution system, where it powers building loads.

Excess solar energy is exported to the utility power grid. When solar electricity is unavailable, building loads are provided by the traditional utility grid. Grid-connected PV systems provide the following benefits over off-grid systems. When erected, utility-interactive PV systems cost between $6 and $8 per watt peak (Wp). Existing roofs are the least expensive alternative for siting since both the real estate and the mounting infrastructure are free. The system costs between $3 and $4 per Wp for PV modules, $0.60 per Wp for power conditioning, and $2 to $3 per Wp for mounting and labour. As a result, a turn-key 2 kWp PV home system will cost between $12,000 and $16,000.

After system losses, a 2 kWp system will generate around 2,700 kWh/year in an area getting an average of 5 sun-hours each day (for example, Atlanta, Oklahoma City, or Orlando). At $0.10/kWh, this energy is worth little more than $270 per year. Considering a $12,000 installation cost, the basic payback period for a grid-connected PV system is over 40 years. The life-cycle cost of grid-tied PV is often more than $0.20/kWh, assuming a somewhat decent solar resource and amortising over a couple of decades. While PV system costs are likely to fall progressively, it will be many decades before they are competitive with the grid in the United States. Nevertheless, in countries such as Japan and Germany, where grid electricity is already more than twice as expensive as in the United States, PV has reached basic equality with grid-tied power on a life-cycle cost basis,

In addition, there are no significant concerns about PV systems threatening line workers; in fact, many smart utilities no longer demand an outside disconnect. A PV inverter operates quite differently from a traditional rotating-type generator used to power the grid. A revolving generator is a power source that may produce independently of and synchronise with the grid. A PV inverter functions as a sinusoidal current source that can only feed the utility line by synchronising with it when the voltage and frequency are within specified limitations. Hence, islanding (independent functioning of the PV inverter) is practically impossible since PV inverters do not maintain line voltage. A rotating generator may also transfer the majority of its spinning energy into a fault under fault circumstances. Being a controlled-current device, a PV inverter will automatically restrict the current into a fault to no more than normal operating current. PV cells function as current-limited devices (because output current is proportional to sunlight).

Current PV inverters create high-quality sinusoidal currents using pulse-width modulation (PWM), therefore harmonic distortion is not an issue. Power is also generated at unity power factor by modern PWM inverters (i.e., the output current is exactly in phase with the utility voltage). Grid-connected PV inverters are built with inbuilt current-limiting circuitry, which protects output circuit wires from overcurrent from the PV system. Overcurrent protection between the inverter and the grid is intended to shield the AC and DC wire from grid currents during failures in the PV system wiring. PV inverters come in a variety of capacities, generally 1-6 kW with single phase voltage outputs of 120, 208, 240, and 277 V. The inverter is normally connected to the grid by back-feeding an adequately sized circuit breaker on the distribution panel. Bigger inverters, often exceeding 20 kW, are normally built to feed a 480 V three-phase supply.

Japanese PV Development and Application

Japan has one of the most sophisticated and successful PV sectors in the world, thus it is worth investigating more. In 2004, Japan became the first nation to install a cumulative gigatonne of PV. Japan has become a worldwide PV production and industry leader via strong government initiatives, starting with the SunShine Program in 1974 and continuing with more recent subsidies supporting installations. PV-powered residences are becoming commonplace in Japan. Japan used to contribute half of worldwide PV output, but now supplies one-fifth as the rest of the globe speeds up. Sharp was the second biggest worldwide manufacturer in 2007 with 370 MW (although it had previously produced more than that and was supply restricted), while Kyocera was fourth with 200 MW. Other important producers in 2007 were Germany's biggest producer (QCells with 400 MW) and China's Suntech, which placed third with 300 MW (Renewable Energy World 2008).

The Japanese government is incorporating solar energy into its total energy mix, with an aim of producing 10% of its power from PV by 2030. It aims to bring PV costs in line with conventionally produced power. Similarly, Japan is a party to the Kyoto Protocol and regards solar power as an important aspect of attaining CO2 reduction objectives. Japan rose to the top of the global PV market for three reasons:

Active government policies supporting PV to help achieve Kyoto Protocol targets; close cooperation among industry, government, and academia in R&D; and majority offshore exports driving down PV in-country production costs.

Private homeowners account for roughly 90% of the PV market in Japan. PV is purchased for two reasons in Japan. Secondly, the Japanese believe it "desirable to be green" and have culturally rooted links to environment. Second, at 23/kWh (US$0.21/kWh), the retail price of household energy in Japan is the highest in the world. Consequently, grid-connected PV electricity is truly cost efficient over a 20-year lifespan. Originally, the government provided significant incentives on PV installations (50% in the mid-1990s), but these rebates were drastically cut and phased out as PV costs fell. At its peak in 2002, Japan's funding for PV system research and marketing has been more than halved. This has been made feasible as PV costs have plummeted, and homeowners without incentives now pay about the same amount they did with rebates a decade ago. Several municipal and county governments continue to provide incentives for PV installation.

PV system prices in Japan are among the lowest in the world, with residential installations costing about 660/Wp (or about US$6/Wp) in 2004. Japan is able to achieve reduced costs by simplifying system balancing, incorporating transformerless inverters. All of the equipment utilised is made in the nation. Japan also has a tailored mass manufacturing approach, and some house builders provide PV alternatives. Similarly, rules for PV installations are straightforward and nonprescriptive. There are no specialised PV installers; rather, industry trains electricians to install PV systems. Self-inspection is performed on installations. The Japanese PV electric code is straightforward (one page) and non-prescriptive. Because of a cultural honour heritage, the Japanese depend on industry to self-police and perform a good job. If an issue arises, the homeowner may file a claim against the warranty and the firm. Most Japanese firms are highly responsive if there is a problem since doing a good job is a matter of dignity and pride for them. Actually, Japan boasts some of the greatest PV systems in the world.

PV systems are also designed to be simple to operate and comprehend for homeowners. Straightforward graphical displays are utilised to allow homeowners to readily monitor how their PV systems are performing in real-time and over time. This piques the homeowner's interest and engagement, and he then shows off his system to his friends while learning to save power. The systems are metered, and the homeowner saves money on his power bill by installing a PV system.

In general, PV technology implementation in Japan is mature, with few known failures. The majority of the government's financing has gone into deployment and discovering how to optimise electricity from clustered PV systems. Fundamental research is turning towards thin film technologies, and the Japanese are setting the standard for recycling PV modules across the globe.

Japan is a worldwide leader in PV production and boasts the world's most mature PV industry. The Japanese market accounts for almost one-twentieth of worldwide PV sales, and the nation exports more than 60% of its PV module output. The fast evolving Japanese market and experience have taught a number of lessons that are relevant for other nations interested in large-scale PV deployment. The Japanese experience may provide several technological and policy lessons.

The Japanese government has been working to create a self-sustaining residential PV market free of subsidies. Government subsidies have been decreasing year after year since they were phased out in 2006. This is due to the fact that PV prices have dropped by more than 30% in the previous decade, and PV is now competitive in Japan, particularly given that domestic grid electricity costs roughly US$0.21/kWh. PV is currently an appealing and cost-effective power solution for many houses.

In the Japanese market, there are few non-domestic enterprises. While there are no specific trade obstacles for foreign firms to sell their products in Japan, the national Japanese market is very competitive. Most international firms find it difficult to join since the market is so competitive. In the future, Japanese PV producers should continue to dominate global PV manufacturing. Through widespread commercialization, they have discovered how to make it cheaper and better.

The Japanese culture has long had deep links to environment, as seen by the country's famed gardens, poetry, and so on. Similarly, Japanese culture has long had a special bond with the sun, which is represented in the country's national flag as the "Land of the Rising Sun." As a result, many Japanese see the usage of solar energy as consistent with their cultural values. Following the signing of the Kyoto Protocol on Global Warming, the Japanese consider meeting Japan's portion of the protocol's CO2 emission-reduction targets as a matter of national pride. As a result, solar energy is seen as a key component of the answer to reaching these goals. This mindset pervades society at all levels, from households to schools, government, and business. Most people wish to utilise solar energy on their properties and contribute to the nation being "solarized."

The mitigation of the impacts of global warming is a cornerstone of Japanese government policy. In comparison to national aims of achieving the Kyoto Protocol, economics for PV play a minor role. The prime minister's home, the Japanese Parliament, and numerous significant government buildings all have rooftop PV arrays ranging from 30- to 50-kW. (Figure 8.2). Almost a megaWatt of power is placed on major government buildings in central Tokyo. Government officials and planners, business leaders, and the general public are all fully committed to making Japan a solar country. Japan has an integrated solar development strategy. There is also a strong desire for energy independence. Since grid power prices in Japan are among the highest in the world, there is an economic return for home PV. The Japanese believe that expanding PV power production systems in Japan will help to create new employment and businesses in the next decades. This is consistent with the Japanese government's energy and industrial plans.

The majority of Japanese PV systems are placed on single-family homes owned by regular people. They are generally Japanese parents in their forties with a couple of children. In Japan, the average annual family income is 6.02 million yen (MHLW 2002). The majority of Japanese PV systems (about three-quarters) are retrofits on existing residences. The average monthly home power usage in Japan is 290 kWh (JAERO 2004), which is more than half that of the United States. In Japan, a 1 kWp PV system produces around 1,050 kWh/kWp on average per year.

While the bulk of PV systems are retrofitted into existing houses, some prefabricated residences have PV as part of the package deal. There are no set specifications, and manufacturers are allowed to collaborate with the PV businesses who provide the best pricing. In the future, more and more prefabricated houses will have a PV option. Close collaboration among government, industry, and academia has elevated Japan to the world's leading producer of solar cells, accounting for approximately 16% of global production (previously, Japan had over 40% of global production, as did the United States before that, but other countries such as China and Germany have greatly increased production). In Japan, about 92% of the deployed systems are for grid-connected dispersed applications like as houses and public buildings. In 2006, total PV output in Japan was 927 Megawatt. Sharp is the leading PV module manufacturer, producing over 370 MW in 2007. (Renewable Energy World 2008).

In terms of scale and cost, Japan sets the worldwide standard for residential PV installations. Nowadays, the nation constructs 50,000-60,000 PV houses each year in collaboration with big cell producers and home builders. Japan has the most PV residences of any nation; the overall number of household PV systems will exceed 500,000 by 2010. Because of Japan's substantial PV manufacturing base, PV systems are less costly there than elsewhere in the globe. Because of simpler electrical code requirements, the balance of systems (BOS) is also less expensive. The typical cost of a home PV system is about 650/Wp.

Japanese PV Utilitie

Japan's electricity industry is unregulated. In Japan, there are five electric utilities, all of which are investor-owned. Vertical integration exists between generation, transmission, and distribution. Several independent power producers create electricity as well. METI's Agency for Natural Energy and Resources (ANRE) regulates the power generating business. Japan's power distribution network is single-phase, three-line, and 100/200 V AC. The western section of the nation (for example, Osaka) utilises 60 Hz electricity, whereas the eastern part (for example, Tokyo) uses 50 Hz power. This is particularly advantageous for the Japanese inverter sector, which builds inverters for both 60 and 50 Hz for its domestic market and so has ready-made items for the European and American markets.

30-minute interval readings are typical metering setups and price structures for power users. There is a time-of-use fee available. Utilities are in charge of their part of the grid. Photovoltaic installation is handled by the PV and contracting industries. There are some large utility PV installations, but more than 90% of PV is put on residential properties. Generally, a separate metre checks the operation of the PV system. There are around 500,000 PV-powered households in Japan.

Japanese Marketing

PV is an essential component of Japan's overall energy plan. The government has enhanced public understanding about climate and energy issues, as well as how solar PV may assist both the global and personal levels. Continuing government public relations programmes, both national and local, emphasise the environmental advantages of PV. PV technology is advocated via a variety of media, including newspapers and television.

The Japanese PV industry engages in marketing for its own PV goods. In Japan, solar energy is a popular notion among the general public, thus industry sales must differentiate themselves from their rivals rather than selling the public on the concept of solar energy systems. Most are marketed to homeowners who are well aware of the environmental consequences of their purchases and are unconcerned about the system's long-term payback.

PV advertisements are seen on television. In one famous Kyocera solar ad in Japan, a young Japanese woman homeowner joyfully views the energy output of her Kyocera PV system with the Kyocera graphical display metre inside her house. Suddenly there is a thunderclap and rain, and she is disappointed that her system is not generating electricity. The camera pans away from the PV system and explanation. Shortly, the sun will shine again, the birds will sing, and the owner of the PV system will be glad to produce electricity once again. Similarly, Sharp has an ad that promotes the environmental benefits of solar energy and encourages viewers to "convert all of Japan's rooftops into PV plants." The Japanese PV sector has also made it simple for customers to understand the effectiveness of their PV systems, which is widely included in ads. Industrial equipment is used on installations. Graphical metres are easy to read, allowing homeowners to readily monitor the functioning of their system.

Japanese PV Electrical Cod

The Japanese Industrial Standards (JIS) define the standards utilised in Japan's industrial activity. The Japanese Industrial Standards Committee (JISC) coordinates the standardisation process, and the Japanese Standards Association publishes the results (JSA). The JSA's mission is to "inform the public about the standardisation and unification of industrial norms, and thereby contribute to the advancement of technology and the development of production efficiency" (JSA, 2007). The Japanese have a well-established electric code known as the Technical Standard for Electric Facilities, which was formed after 1945. In Japan, this basic, scientific method to building high-quality PV systems has shown to be highly successful and safe. Engineers do not get bogged down in intricate nonsense arguments about "how many angels can fit on the head of a pin," as in some other developed nations with prescriptive electric standards that stifle development and innovation in PV system design.

Japan boasts some of the finest quality PV systems in the world while adhering to some of the most basic standards. Section 50 of the Japanese code is the equivalent of the US NEC Article 690 for PV. It is just a one-page checklist. Unlike the US NEC, the Japanese code is more of a guidebook than a prescription. Each manufactures are responsible for ensuring that the code is followed on their installations. Companies in Japan take pleasure in their work and strive to provide high-quality installations. While the code does not necessitate the use of listed modules, inverters, and so on, manufacturers take pleasure in having their equipment listed with JET, and installers will prefer to utilise listed equipment. The major features of the Japanese electric code concerning PV installations are easy and uncomplicated.

Japanese PV Design

PV arrays are often installed directly on reinforced corrugated metal roofs (no roof penetrations). For high-end roofing, most roofs in Japan are made of metal or a traditional style ceramic. In Japan, there is tremendous worry that PV systems will be able to survive typhoon (hurricane) strong winds, which are typical during the late summer months. Commercial PV systems in Japan are often not ideally slanted for solar energy generation, but rather for greater wind survival (typhoons). To lessen wind loads, system profiles are mounted low to the roof. Local standards often require PV systems to resist winds of 36 metres per second in Tokyo, 8 metres per second in Okinawa, and even 60 metres per second in certain regions, such as Kanazawa City.

One distinguishing feature of certain Japanese PV installations is that many systems include PV arrays facing south, east, and west on the same roof. This is because smaller Japanese dwellings have little roof space. West and east arrays generally provide around 80% of the energy produced by a south-facing array. For this reason, certain inverters (e.g., Sharp) are built to monitor three separate subarrays individually. On the DC side, Japanese PV systems are not grounded (although they all have a chassis ground). Only the alternating current side is grounded. The operating voltage is 200/100 V alternating current. Japan's electrical distribution network is single-phase 100/200 V AC. The western section of the nation utilises 60 Hz electricity (for example, Osaka), whereas the eastern part uses 50 Hz power (e.g., Tokyo).

Crystalline PV modules are by far the most common in Japan, accounting for more than 80% of all PV modules manufactured and installed in the nation. Performance guarantees are often included with modules. depending on the manufacturer, from 10 to 25 years (those active in U.S. markets will have a superior warranty). Thin film modules are gradually gaining popularity, however sales of crystalline modules continue to trail far behind. Cadmium telluride (CdTe) modules will never be found in Japan since the culture despises the use of harmful elements. Toxic materials are swiftly excluded from consideration for use in PV modules in Japan since much attention has been devoted to how to recycle a PV module.

There are over two dozen household PV inverter manufacturers in Japan. Transformers are not used in the majority of Japanese inverters. In Japan, there are over 100 listed household PV inverters. Single-phase, three-wire inverters (100 and 200 V). Manufacturer warranties for inverters differ (typically 1–3 years). Some Japanese PV manufacturers, including Kyocera, Sanyo, and Sharp, also manufacture their own inverters.

Sharp and Daihen are working together to create inverters for large-scale PV systems deployed by business customers and power utilities. Daihen is in charge of producing solar inverters, whereas Sharp concentrates on PV modules aimed at power utilities. Japanese inverters are likely to become as common as Japanese PV modules across the world in the future. Sharp/Daihen, Siemens, Toshiba, Mitsubishi, Sanyo, GS, Matsushita, and Kyocera are some of the main inverter manufacturers Inverters are an established technology in Japan. In Japan, the industry is looking at how huge clusters of inverters function together and how to increase performance, such as the Ohta City project with over 500 PV residences

PV installations in Japan are of high quality and are completed by professional electricians. There are no independent qualified installers (e.g., no comparable to the North American Board of Certified Energy Practitioners (NABCEP). It is the responsibility of the industry to educate its installers and maintain quality standards. Some module manufacturers, like as Kyocera, will also install PV systems, while others may hire electrical contractors to do so. Often, the same electricians who install a home's electrical system also install the PV system in new houses.

Total PV system installation costs in Japan are lower than in the United States because systems have less BOS requirements and more simplified installation methods (e.g., no roof penetrations). Installations of 3 or 4 kWp may be effectively erected in a matter of days. Electrical teams are typically made up of two or three electricians or helpers. PV installations are typically done in two or three days. There are no on-site QA records kept, and it is up to the installation to perform a decent job. If anything goes wrong, the installer will be held accountable. In general, in Japanese culture, installers and manufacturers desire to remedy any flaws with their goods. Having pleased clients is a matter of cultural dignity for them.

Japanese PV Development

Japan is a worldwide leader in PV manufacture and innovation. Residential system requirements have aided in the development of better cell efficiencies and lower cell sizes. Bigger commercial systems have prompted advancements in PV for building integration, which necessitates flexible, inexpensive, light-transmitting, or bifacial solutions for facades and large-area installations. Some office buildings now have see-through PV installed on their south-facing windows. PV is used in certain prefabricated dwellings.

only 25% of residential systems installed are on new buildings. The research and development of increasing the usage of PV on prefabricated structures is ongoing. The manufacturer will provide PV system delivery bundles. The majority of assembly is still done on the job. Japan is likewise leaning towards "mass customisation" in house development. A prospective homeowner is presented with a plethora of standardised alternatives for customising his or her prefab house design (e.g., a dozen different stairway designs, windows, etc.). Customized alterations may be substantial on properties and include the homeowner in the planning process. PV manufacturers do provide standardised systems, however they differ from one another.

The Japanese PV industry is the worldwide PV industry's backbone. The government's research initiative has been closely coordinated with Japanese business and academics. In Japan, there are 13 major PV module producers, including some of the world's top PV businesses, including Sharp, Sanyo, Kyocera, Mitsubishi, and Kaneka. Japanese industry continues to seek for cost reductions in PV manufacture while retaining a strong profit margin, particularly for established players in the field. Home PV installations are the primary application for Japan's domestic PV market.

PV expansion in Japan has also boosted the production of silicon feedstock, ingots and wafers, inverters, and reinforced aluminium frames. Sharp is the market leader in photovoltaics, followed by Kyocera and Sanyo. Japan surpassed the United States in manufacturing in 1999, and their current market share of total global PV output is at 15%.

Japanese PV Module Certification

Japan Electrical Safety and Environment Technologies (JET) delivers product certifications to manufacturers and importers, as well as consumers, as a METI-designated testing organisation and independent and impartial certification institution with an established track record. JET gets a variety of requests from government organisations, including requests to perform market testing on electrical goods, reconcile domestic standards with IEC standards, and undertake research and development on technology for evaluating solar power electric production systems (Figure 8.1).

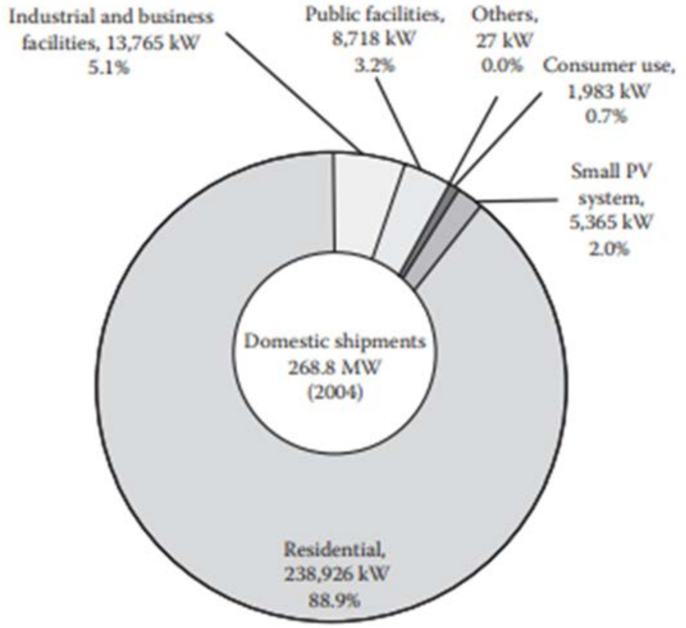


Figure 8.1 Represent the Japanese installations by sector type in 2004, dominated by residential (OITDA).

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CHAPTER 9

STAND-ALONE PHOTOVOLTAIC (PV)

Ramachandran T, Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- t.ramachandran@jainuniversity.ac.in

During the last quarter-century, the developing world has aggressively embraced stand-alone PV technology for social and economic growth. PV is a possible replacement for large-scale rural grid systems. With the introduction of PV as a trustworthy contemporary technology alternative and more private involvement and options made accessible to the general population, PV systems have grown appealing across the world's less developed regions. The difficulty is to create financing options that prospective customers can afford. Off-grid markets are the natural market for PV technology since they do not need government subsidies to compete or succeed. The device serves a real-world need and is particularly beneficial in poorer nations where the national power infrastructure is often underutilised. From an original idea pioneered by a few visionaries over 25 years ago to numerous successful enterprises across the developing world today, the usage of PV systems in rural areas of the developing world has expanded rapidly.

PV is a possible replacement for vast agricultural grid systems. With the introduction of PV as a trustworthy contemporary technology alternative and more private involvement and options made accessible to the general people, PV systems have grown appealing all over the world, with literally millions of rural families powered by PVs. Actually, the most prevalent PV system on the globe is the tiny 50 Wp solar home system, which provides enough power for a few lights, a radio, and maybe a small TV. Even smaller solar lamps and torches with LCDs are becoming increasingly popular. The problem is to provide financing options that are accessible to prospective rural consumers, whose earnings are often based on agriculture harvest cycles.

PV Solar Home Lighting Systems

PV first serviced space and distant communication demands, but it swiftly gained popularity for basic home energy needs in rural areas of the United States, and later across South America, Africa, and Asia. Solar energy pioneers started to promote PV technology in rural Latin America in the mid-1980s as a solution for delivering basic electrical services to communities without electricity. Nongovernmental organisations (NGOs) such as Enersol Associates in the Dominican Republic began some of the world's first pilot projects in 1984. (Figure 8.15). Little solar enterprises started to emerge gradually across the developing globe as prominent module manufacturers of the period, like as Solarex and Arco, sought for distributors for off-grid rural markets. These operations were followed by large-scale solar electrification activities supported by government agencies in Mexico, Brazil, South Africa, and other countries by the mid-1990s.

Since planners sought to push large-scale rural solar electricity projects on unknowledgeable rural customers, many of the early large-scale PV government electrification attempts encountered sustainability challenges. Inappropriate battery technology, subpar charge controllers, dishonest salespeople, and poor-quality and unmanaged installations were all common issues. Since they were generally giveaway programmes, users had no feeling of ownership, which may sometimes lead to a lack of obligation to care for systems. Notwithstanding these obstacles, PV modules themselves relatively seldom failed; in fact, they remained the most dependable component of any deployed system.

After early system failures, implementing agencies progressively started to adopt fundamental technical requirements that adhered to international standards, therefore improving the quality and reliability of PV systems. Rural consumers mostly seek a PV system that can supply basic electric lighting as well as entertainment through radio and television. PV users aren't concerned with the intricacies of technical operation and maintenance. They want a basic, functional, and easy-to-maintain solution. Consider the concept of sustainability. All roads should lead here, and organisations using solar energy systems must demonstrate a genuine commitment to long-term sustainability. Government organisations have especially challenging tasks since political parties often change. The end objective is to have a well-designed and installed solar energy system that will give many years of dependable and acceptable service. The last quarter-century has laid the groundwork for future solar growth, which is expanding at an exponential rate.

Sandia Labs/NMSU built a PV lighting system (PVLS) for the residence in Chihuahua, Mexico, under the USAID/DOE Mexico Renewable Energy Initiative in the late 1990s with the state of Chihuahua. The programme installed a Sunwize Technologies Solisto PVLS to fulfil Mexico electric code standards (i.e., NEC). This is a pre-assembled control device designed for small-scale rural electrification and extended life. The positive and negative legs of this system were fused (it was an ungrounded 12 V system), and suitable disconnects were employed. The system included a sealed maintenance-free leadacid battery and a UL-listed solid-state charge controller with fuzzy logic to assist assess battery state of charge.

In the municipality of Moris, some 250 kilometres west of Chihuahua City, 145 systems were built. The environment is made up of high mountains and 1,000-meter-deep valleys surrounded by pine trees. The steep terrain makes access to the electric grid difficult, and there is no connectivity with the national power system or paved roads. More than three-quarters of Moris people lack access to electricity, and those who have are largely on diesel-powered minigrids.

Moris PV systems are made up of one 50 W Siemens SR50 module, which was the first to be deployed exclusively for the rural lighting market. The PV modules are installed on a 4 m galvanised steel pole that can resist strong winds. Figure 8.16 shows how the module charges a nominal 12 V sealed gel VRLA battery (Concorde Sun-Xtender, 105 Ah @ C/20 rate at 25°C). These are sealed, absorbed glass mat (AGM) plants that never need to be watered. The immobilised electrolyte wicks around in the absorbed glass mat, allowing hydrogen and oxygen to recombine inside the enclosed cells when the battery is charged.

The thick calcium plates are crushed inside a microfibrous silica glass mat envelope, which allows better electrolyte absorption and retention while providing a larger contact area to the plates than gel batteries. Being a certified system component, Concorde batteries meet UL924 and UL1989 requirements. These batteries fulfil the US Navy standard MIL-B-8565J for restricted hydrogen generation below 3.5% during overcharging (less than 1% in the case of the Sun-Xtender), making them suitable for use in residential environments. All batteries were fitted within a sturdy plastic battery container that was secured tight and was spill-proof and childproof.

Control is maintained via a UL-listed Stecca charge controller with a 10 A fuse through the Solisto power centre. The system includes a DC disconnect and six additional DC fuses to safeguard other circuits. The Stecca controller monitors battery charging utilising fuzzy logic to minimise under- or overcharging the battery, and it has an LED lit display to show the status of charge. The Solisto power centre is still available on the commercial market; Chihuahua was the world's first application of these power centres.

Three small fluorescent bulbs with electronic ballasts are powered by the PV system (20 W each). It also has a SOLSUM DC-DC voltage converter (3, 4.5, 6, 7.5, and 9 V choices) and connector for usage with various appliances like as radios and televisions. End-users may also choose to install a Tumbler Technologies Genius 200 W inverter for an additional US$200; although few decided to do so, many customers did install satellite TV service, which comfortably gave them roughly 3 hours of colour TV watching in the evenings. The Solisto SHS was designed with the assumption that a family utilising the entire set of three fluorescent lights for an average of 2 hours per day would require around 120 Wh/day. Given that Chihuahua receives approximately 6 sun-hours per day, and assuming an overall PV system efficiency of 60% for this reasonably well-designed system (i.e., including battery efficiency losses, module temperature derate, line losses, and so on), the user could expect to have approximately 180 Wh/day of available power.

Of course, there are seasonal differences, and the battery might draw double or more power on any one day, but this could not be maintained over time. Mexican consumers soon learned, as is normal for solar energy users, to live within limited energy system constraints and to restrict energy usage during lengthy overcast periods, which are rather infrequent in Chihuahua.

An extra novel finance component that represented the first financing of PV systems in Mexico was also of significant interest. The State Trust Fund for Productive Activities in Chihuahua was in charge of the program's finance (FIDEAPECH). This state trust fund mainly offers direct loans and guarantees based on direct lending (e.g., to farmers for tractors). FIDEAPECH established and executed a revolving fund in which the municipality paid 33% of the entire cost of PV home-lighting systems up front, end users contributed 33%, and FIDEAPECH subsidised the remaining 34% for a year. The city government guaranteed the debt and eventually repaid it to FIDEAPECH. Each quality-code-compliant PV house lighting system cost about $1,200 to install.

Other 50 Wp PV systems have been installed in this location for the same price, but with much worse quality and performance (e.g., with some breakdowns recorded in less than a month). Since October 1999, the operation of a Solisto PV lighting system has been continually monitored at New Mexico State University's (NMSU) Southwest Area Solar Experiment Station in Las Cruces, New Mexico, mimicking use of around 171 Wh/day. Long-term monitoring offers a reliable baseline against which deployed devices may be compared. In 2008, the monitoring system was still operational. During protracted overcast periods, the Stecca charge controller effectively protected the battery from severe damage caused by overcharging and deep draining. For sealed batteries, charge control employing pulse-width modulation charging and fuzzy logic to assess the state of charge has done extremely well, offering a long lifespan. The nominally controlled voltage on the battery averaged 12.9 VDC per day, with the lowest battery voltages reported following overcast periods being 11.9 VDC. The daily depth of discharge (DOD) averaged at 13.5%.

According to the Sun-Xtender battery manufacturer, the 105 Ah battery should have a cycle life of around 1,600 cycles at 40% DOD at 25°C and 5,200 cycles at 10% DOD. After 5 years, NMSU had the chance to monitor the systems in the field. Electrical measurements, visual examination, and an end-user survey were used to analyse performance and establish user satisfaction. A total of 35 assessments were carried out. Around 80% of the installed systems were running properly and as specified, 11% were in fair condition (most typically, one of three bulbs had failed), 6% were nonoperational, and 3% had been disassembled (e.g., user moved). After 5 years, the high proportion of functional PV lighting systems indicates the potential dependability of PV house lighting systems. According to the results of the home study, 94% of customers were completely satisfied with their PV lighting systems, 86% felt PV was superior to their former gas lighting source, and 62% considered the PV systems were competitively priced for the service offered (Foster, 2004). The sealed battery lives were satisfactory. PV modules proved to be one of the most dependable components; all modules were operational, and no module issues were noted. Sewing, watching TV, reading, and studying were among the new and increased nighttime activities described.

PV Battery Charging Stations

During the mid- to late-2000s, the Nicaraguan National Energy Commission (CNE) collaborated with the World Bank to launch the Renewable Energy for Rural Zones Program (PERZA—Proyecto de Electrificación Rural para Zonas Aisladas). Over 80% of Nicaragua's rural population lacks access to electricity. PV is a viable option for supplying electricity to rural regions, whether through individual PVLS for the house or centralised PV battery charging stations (PVBCSs). The project installed centralised PVBCSs in the Miskito area of northeast Nicaragua, one of the Latin American nations with the lowest energy coverage.

Both systems use charge controllers to charge batteries. A few energy-efficient light bulbs, a radio, and maybe a black-and-white TV are typical gadgets powered by one battery per family. The primary distinction is that the PVBCS charges the batteries centrally (and then transported by the users). Each residence has its own little PV module, battery, and charge controller for PVLS. PVBCS benefits include possible economies of scale in administration and battery charging, as well as the ability to tailor payment schedules to local requirements. The key benefits of PVLS over PVBCS are enhanced convenience and home charge controllers, which prevent deep discharge and extend battery lifespan.

These indigenous Miskito settlements may be found in Nicaragua's North Atlantic Autonomous Area (RAAN), north of Puerto Cabezas, in the Waspam region. The initiative funded seven PV battery charging stations, which power around 300 households, accounting for almost three-quarters of the entire population of the settlements of Francia Sirpi, Butku, Sagnilaya, and Ilbara. These battery charging stations were erected in November 2005 at places chosen by the communities to enable population access. Each house is outfitted with a full "kit" that comprises a battery, two fluorescent bulbs, and a voltage regulator. The design and assembly of all PV systems and kits are comparable.

Because of the acute poverty of the Miskito indigenous populations, the Nicaraguan government funded the whole project. To recharge their batteries, consumers paid a nominal price dependent on their payment capacity. In the village of Francia Sirpi, a typical PV battery charging station consists of a 2,400 W PV array with three subarrays that can charge up to 24 lead-acid batteries at the same time.The PV modules are Shell SQ80 80 Wp. The whole system is made up of three PV 800 Wp substations, each with its own Stecca PL2085 controller capable of charging eight PV batteries per station at the same time

The intelligent control unit, in which a microprocessor performs the adjustment, operation, and display tasks, acts as the brains of the battery charging station. The batteries are charged as rapidly and effectively as possible, in the sequence in which they were attached. Moreover, an MPP-tracking system allows for the most efficient use of available energy even when not all battery stations are completely employed. Even if all eight stations in a subarray are not occupied, no energy is lost

At the Francia Sirpi neighbourhood, around 150 individual home lighting kits were installed. Homeowners received a PV lighting household kit that included two or three 15 W fluorescent bulbs. Each house's lighting package included a tiny 6 A Morningstar SHS-6 charge controller that served as a low-voltage disconnect for the 12 V, 105 Ah maintenance-free AGM battery.

On the individual dwellings, no PV modules were placed. Instead, when the battery ran out of power, it was unplugged from the house lighting system and transferred to a charging station to be replenished. After the battery had been completely charged, it was returned to the house and reconnected to the home lighting system.

The key worry with PVBCS is that if users over-discharge their batteries (e.g., circumvent the LVD), battery lives may be prematurely cut short. There were some early controller failures with the Stecca controller because if the operator switched the polarity on the battery leads, the controller may fail since it was not polarity protected. These failed controllers were eventually replaced with Phocos controllers, which could only charge a battery one at a time. Several of the installed installations were also severely damaged by a storm in October 2007, which struck the Miskito community very hard. The PERZA project is basically a "supply push" rather than a "demand pull" for off-grid PV applications. Off-grid rural energy services may be structured to be franchised and distributed via standardised distribution networks. The benefits of PVBCS include possible economies of scale in administration and battery charging, as well as the ability to tailor payment schedules to local requirements. The key benefits of PVLS over PVBCS are enhanced convenience and home charge controllers, which minimise deep discharge and extend battery lifespan. PVLS is a more successful application, as shown by this project and others in Brazil and Bangladesh.

PVLS Human Motivation: the Final Driver of System Success

The village of Xenimajuyu is situated in Guatemala's highlands, in the department of Chimaltenango. While the electric system terminates quite close, a combination of issues, including the hilly terrain and the political ramifications from the town's separation from another bigger community, have made it exceedingly unlikely that the energy infrastructure will be extended to Xenimajuyu in the near future. One home in the neighbourhood has decided to produce its own power. To fulfil his electrical requirement for lights and entertainment, the homeowner employs solar PV panels in addition to a modest generator. The system has been running for over a decade, despite the fact that the panels are of low quality, the system lacks a charge controller, and the car battery is insufficient.

This system exemplifies the need of human motivation in the long-term viability of rural solar PV systems: Individual homeowner choices to keep the system operating proved more powerful than the system's technological flaws. Guatemala has an overall illumination rate of 83.1% (CEPAL 2007a), although over 40% of the rural population is still without power (Palma and Foster 2001). This equates to around 2.2 million individuals or over 440,000 dwellings without connection to the national electricity network (CEPAL 2007b). The so-called Franja Trasveral Norte, which includes the Departments of Huehuetenango, Quiché, Alta Verapaz, Baja Verapaz, and Izabal, as well as Petén, is one of Guatemala's poorest departments, with the highest number of people without power. According to 2000 figures, this group without electricity is mostly made up of the 32% of the population living in severe poverty (Hammill 2007). According to the same figures, 56% of the population was poor in 2000. (Hammill 2007). In addition to high rates of poverty and severe poverty, these departments are distinguished by neighbourhoods with very difficult access and a large dispersion rate of dwellings (Arriaza 2005)—characteristics that make grid extension economically unfeasible. As a result, renewable energy is often the greatest electrification choice. This is particularly true for Guatemala, which has abundant solar resources.

The minimum solar source that should exist before a project may be deemed practicable, according to several PV design guidebooks, is 300 W/m2/day. The Solar and Wind Energy Resource Assessment (SWERA), cofinanced by the Global Environmental Facility (GEF) and the United Nations Environment Program (UNEP), identifies good to excellent solar resources (400-600 W/m2) in Guatemalan areas that correspond to the country's most marginalised population. Since the early 1990s, rural Guatemalan communities have used isolated PV systems in applications ranging from residential and communal lights to productive uses and community services.

While there is no full list of installed Photovoltaic system in the nation, the government has installed PV panels in roughly 80 towns, supplying over 3,435 homes with 50 W systems, via the Ministry of Energy and Mines. Some of these systems have been removed, while others have been relocated. Other organisations built over 5,000 residential systems in the eight years running up to 2001. These systems generally include a 50 W PV module, a 12 V deep-cycle battery, a charge controller, and three CF light bulbs, which provide around 3 hours of lighting every night. This translates to about 220 kW of home PV installation, producing over 400,000 kWh per year (Palma and Foster 2001).

Several lessons have been learnt throughout the years, some of which have influenced more current installations. Early PV initiatives prioritised technological considerations above human and societal concerns (Palma and Foster 2001). While technological flaws may be a cause of PV project failure, the case study in the next section shows that, despite these flaws, human motivations and convictions may lead to long-term sustainability practices.

PV in Xenimajuyu: the Xocoy Family

Candles, kerosene, and ocote (a sort of fuel wood) are often used in Guatemalan rural unelectrified dwellings. Richer households may be able to acquire a vehicle battery or a diesel generator to power light bulbs, radios, and TVs; but, most families do not have this choice and, depending on the number of close relatives, burn three to five candles every night. With each candle costing 1.5 quetzales, households may spend up to US$1 per day on lighting energy, a larger proportion of their income than lighting takes in metropolitan areas (UNDP 2005).

The Xocoy family resides in the Xenimajuyu village. The terrain around the village is exceedingly hilly, making even short-distance power grid extensions prohibitively costly (Palma and Foster 2001; CEPAL 2007a). According to a local Peace Corps volunteer, Xenimajuyu separated from Chuisac, a bigger adjacent hamlet, to become its own independent village. Xenimajuyu was not included in the plan when the parent village received grid power in 2000. The neighbourhood does not expect grid expansion in the near future since it is tiny and especially difficult to reach. The Peace Corps suggested a community-wide photovoltaics power project, albeit it is still in its early phases and there is no realistic deadline for completion.

Estanislado Xocoy and his family now fulfil their energy demands with three distinct sources: conventional fuels often used in rural Guatemala, a gasoline-powered generator, and a tiny photovoltaic (PV) system. The family seems to favour their little gas generator above more standard illumination sources. While the generator provides sufficient energy for the family's requirements, it is not an ideal alternative due to the high and variable price of fuel, as well as the difficulties of transferring gasoline from the gas station to the house.

The family asserts that their solar PV system is their preferred lighting energy source. Solar panels, a battery, three tiny fluorescent bulbs, and a small black-and-white television comprise the system. The owner has two PV panels that are similar, but none has a module plate. The first was bought new about 11 years ago, while the second was bought secondhand three years ago. When the previous owner obtained grid power, he stopped using it. The first PV panel is installed on the top of the home. It's a notional 50 W amorphous thin-film silicon panel. The darkening on the panel surface and the rust in the wires indicate that the panel has degraded significantly. This deterioration is not surprising given that the homeowner has kept the panel for longer than the predicted 10-year life of an amorphous panel. The degree of deterioration could not be exactly quantified since the ambient circumstances did not allow for reliable assessment. It is built on an eastward-facing roof slope rather than the suggested south-facing slope, and it is mounted directly on the metal roof rather than on a mounting frame that would enable air circulation to cool the panel and increase performance. It is also erected with an angle of less than 10°; an inclination about equivalent to the location's latitude (around 15° in this example) will yield best yearly power production. The dirt on the panel lowers the quantity of sunlight that strikes it and hence its output.

The second panel, which is even more seriously damaged than the first, had been attached in parallel to the first panel for around 6 months before being disconnected since the owner decided it was no longer useful. Measurements of this second panel's output revealed that it was capable of providing some power, however the modest amount may or may not warrant its reinstallation to augment the presently installed panel. A charge controller may considerably enhance system performance by preventing the battery from being overcharged or overdischarged. Since this home system lacks a charge controller, the frequency with which the battery must be changed, as well as the system's cost, are increased.

Solar applications are best served by a deep-cycle battery built for PV or maritime usage. This system used an automobile battery, which degrades fast when subjected to the severe drain cycles required by this sort of device. Nonetheless, the battery is in good condition, with no signs of corrosion, overheating, or loose connections, which may be issues with batteries in solar house applications. When the terminals "become humid," as the owner puts it, he changes the automobile batteries every 2-3 years. The system can only light one bulb for one hour instead of three lamps for three hours, together with three hours of television, or five hours of illumination with no television.

The Xocoy family's system falls well short of the norms and requirements anticipated of a well-designed quality system: The panel is improperly mounted and in poor condition; the wiring is in poor condition; the battery is unsuitable for the application; critical system components such as the charge controller are missing; and the system is installed without basic safety considerations such as electrical grounding or a compartment to protect family members from battery accidents. This family, on the other hand, has successfully maintained this system functioning for over a decade and even want to extend the system by replacing the second problematic panel with a new one. The owner believes that renewable radiation works: Photovoltaics is a more appealing alternative for his family and community than fossil fuels or conventional energy sources, and it is also a more feasible option than waiting for grid expansion. Estanislado Xocoy is a technical resource and an opinion leader who will be a major facilitator of the effort to electrify the town using solar energy.

PV for Schools

Many of rural schools in underdeveloped countries lack access to electricity. It is critical to close this gap so that rural student populations that do not have access to power grid services may have the same chances as other students. A better level of education lays the groundwork for increasing production, which leads to higher living standards. Solar power provides a feasible solution to such power requirements. Renewable energy technologies may be utilised to deliver services such as distant education and computer Internet connectivity to remote and isolated populations when such applications are feasible and suitable. The high expenses of fuel purchases, transportation, and engine maintenance, along with difficult-to-quantify environmental impacts, make renewable energy an appealing option to traditional fuel-burning motor generators. PV systems are utilised to power TVs, DVD players, and computers, modernising rural schoolchildren's educational experiences

Numerous initiatives in Mexico and Central America are using renewable energy to provide high-quality distant education to their rural communities. The Mexican Secretariat of Public Education is well-known for its satellite-based distant learning programmes. The majority of the schools in the programmes are on the grid, but there is a growing desire to expand the academic network to off-grid communities.

A comprehensive grasp of what renewable energy technologies are, what equipment is available, and how they might best be employed to satisfy energy demands is often absent in many initiatives. The technical competence necessary to develop renewable energy projects is often ignored and does not exist within implementing agencies. To build and maintain long-lasting, high-quality systems, in-country partners need knowledge, experience, and technical competence.

PV systems are presently installed in over 500 off-grid schools in Mexico, as well as over 300 in Honduras and Guatemala. Several of the PV systems in use have been poorly designed and developed, resulting in inefficient operation.

1. inadequate battery cables, restricting battery recharge;
2. inappropriate panel orientation and position;
3. incorrect battery types employed for the application; and
4. lack of end-user information on proper operation and maintenance.

In some ways, public education agencies in Mexico and Central America have lost faith in the utilisation of renewable energy sources and technologies, reducing their desire to repair or replace current systems and/or acquire new systems for further remote offgrid schools. The bulk of the issues, however, are straightforward and treatable with sufficient knowledge and institutional ability. PV school installations in various countries of South America started to improve dramatically around the year 2000, as the sector developed and implementing agencies received significant knowledge and expertise. Rural school PV electrification schemes have been executed successfully on a wide scale in Mexico, Guatemala, Cuba, Honduras, Peru, and Brazil. PV systems are utilised to power TVs and laptops, modernising rural schoolchildren's educational experiences.

PV for Protected Areas

Renewable energy technologies have been extensively used in Latin America to sustain protected areas, particularly in Guatemala, Mexico, and Ecuador (Galapagos). PV technology have been used by major environmental organisations including as the Nature Conservancy, World Wildlife Fund, and Conservation International.

Solar energy in protected regions improves the living circumstances of researchers, technicians, and rangers while also powering environmental training facilities. Solar energy systems also offer the benefit of producing electricity without the noise nor pollution associated with traditional fossil-fueled generators, as well as lowering the danger of fuel leaks in these fragile biosphere reserves. As is usually the case, upfront design choices, user operation, and long-term maintenance difficulties are critical to total system stability.

Solar energy is an ecologically relevant model for nearby buffer settlements (sometimes without power) around biosphere reserves, which may also benefit from imitating the example of protected areas. Solar energy systems are also a good example for visitors and tourists to follow.

Moreover, solar panels aid distant protected-area institutions economically by lowering operating and maintenance expenses associated with fossil fuel generators. The actual life-cycle costs of any given solar or wind electricity grid vary depending on design, consumption, application, and maintenance. With good system operation and maintenance, the estimated lifespan of a solar energy system should be 25 years or more (with necessary battery replacements, etc.).

The PV-wind hybrid system application in Isla Contoy in Quintana Roo, Mexico (PNIC—Parque Nacional Isla Contoy) is one example).

It is colloquially known as Bird Island because of the 1bird species present on the island, which is surrounded by approximately 5,000 frigates. It is also vital for the conservation of sea turtles, crocodiles, 31 coral species, and 98 indigenous plant species. The park was using gasoline supplied by boat from neighbouring Cancun to power a 3.5 kW generator, resulting in substantial noise pollution that upset birds and the continual fear of fuel spillage.

Finally, $35,000 in USAID financing was obtained to enable the construction of a hybrid renewable energy system. The possible effect of wind turbines on the big bird refuge was of special concern (i.e., threat of bird kills). A bird is unlikely to fly into the whirling blades of a tiny wind turbine because they spin so quickly and are so conspicuous. It was decided that no wind turbines would be placed in any of the island's important bird transit routes (usually, directly along the shore) or in vital nesting regions (which are off limits to all visitors as well). During the first five years, the wind turbine had killed just two birds.

Sandia Laboratories found that a hybrid solar-wind energy system would be the best choice for PNIC throughout the system design phase. The average yearly wind speed was 6.5 metres per second. Loads were designed for an average daily demand of 5,000 Wh/day, with the majority of the energy going to lights, communications, radio, fans, and TV/VCR, as well as an LCD projector (for workshops), shop equipment, kitchen appliances, and a water pump.

The initial hybrid system's design included two 500 W wind turbines, a 256 Wp amorphous PV array, a 4,500 W Trace sine-wave inverter, and a 19.2 kWh battery bank. The wind turbines were initially built atop a towering dune on the little island's east side. A three-day training session on renewable energy system design, operation, and maintenance was then held for 23 people from local institutions, including PNIC. Individual instruction on suitable RE system operation and maintenance was also offered to the three essential PNIC maintenance workers (Figure 9.1).

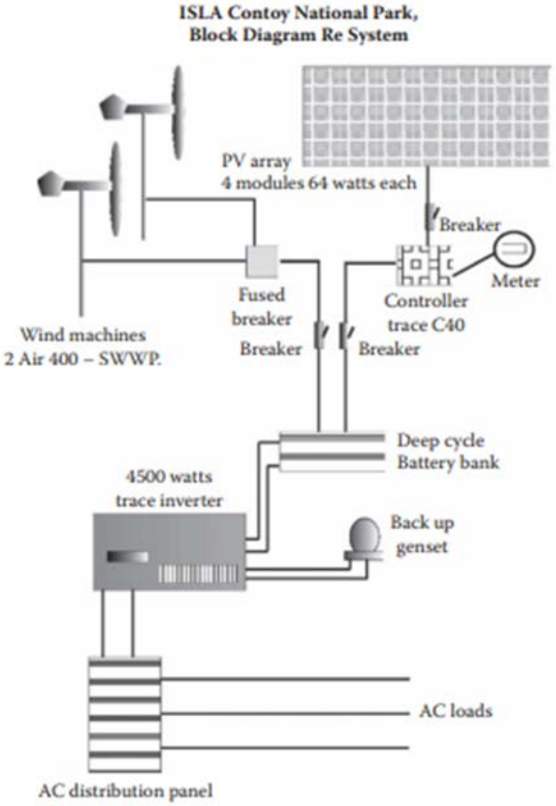

Figure 9.1 Represent the Isla Contoy National Park (Quintana Roo, Mexico) solar-wind hybrid system designed by Ecoturismo y Nuevas Technologias and funded by USAID with Sandia National Laboratories.

CHAPTER 10

PV ICE-MAKING AND REFRIGERATION

Beemkumar N, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- n.beemkumar@jainuniversity.ac.in

Another important business category for PV technology is remote refrigeration or ice production. This may be accomplished with or without the use of electrochemical battery storage. Since DC compressors, batteries, and charge controllers have been in mass production for years, battery-based PV refrigeration technology is rather established, resulting in reduced cost manufacture. Since battery-free technology is younger and has a lower degree of production, manufacturing costs remain relatively expensive. Thermal storage is used in a PV direct-drive or "PV-direct" solar refrigerator, where a direct connection is formed between the vapour compression cooling system and the PV panel. This is achieved by incorporating a phase-change material into a well-insulated refrigerator cabinet and inventing a microprocessor-based control system that enables direct connection of a PV panel to a variable-speed DC compressor. This enables peak power-point monitoring and battery removal. This novel direct-drive technique to ice storage might transform refrigeration in far-flung parts of the planet.

The use of solar PV power systems is growing due to both technological and economic considerations. Built-in energy storage is beneficial to some of the most successful solar energy applications, such as water heaters and PV waterpumping. This is now true for solar freezers that store thermal energy in the form of ice. Formerly, solar PV refrigerators needed batteries to store electricity; however, recent research has focused on the "PV-direct" idea and thermal storage to remove the need for electrical energy storage. While PV-direct technology may be used to freezers, air conditioners, and larger-scale refrigeration systems, early attempts have concentrated on small-scale refrigerators, which are best suited for off-grid personal or small-scale business usage. Instead of storing electrical energy in a battery, the battery-free solar refrigerator stores thermal energy in a phase transition material. A well-insulated cabinet and a phase transition material with a high latent heat of fusion are needed to produce a workable thermal storage device that successfully substitutes batteries. A chest-style cabinet with typical insulation is employed for the commercial application. A nontoxic, low-cost, water-based solution with excellent freezing capabilities is chosen as the phase change material. A amount of thermal storage material is determined based on the heat-leak rate of the cabinet to provide 7 days of reserve cold storage at an expected average ambient temperature of 29.5°C (85°F). Its thermal storage reserve is meant to mimic the electrical energy reserve of solar refrigeration system batteries. Good thermal contact between the thermal storage material and the refrigeration system evaporator is also required for efficiency. Inadequate contact lowers the efficiency of the refrigeration system as well as the cooling capacity of the compressor. The phase change material is placed in containers against the refrigerator cabinet's cold inner wall, behind a polyethylene liner that keeps the containers in place and conceals the thermal storage containers.

A variable-speed DC compressor is employed to power the refrigeration system directly (and effectively) from solar panels. The variable-speed function enables the compressor to run for extended periods of time throughout the day, making greater use of the changeable solar resource. A fixed-speed compressor could not start cooling as early in the morning or as late in the afternoon, wasting electricity during solar noon (when the available power is more than the compressor needs to operate). A fixed-speed compressor can only use around half of the available solar energy. On a bright day, a variable-speed compressor consumes around 75% of the available solar resource since its speed may change to match the available solar input. A microcontroller controls the speed, attempting to optimise the compressor speed for the available solar power. When the compressor is running, the control algorithm effectively keeps the PV array at its highest power point. The computer also does array load testing before starting the compressor, cabinet temperature management, and extra speed control as needed to maintain the compressor power within the manufacturer's restrictions. Beginning capacitors are also utilised to provide a brief burst of power to the compressor at startup. A tiny DC cooling fan is utilised to increase heat evacuation from the condenser and compressor.

Thermal storage is used in the SunDanzer direct-drive prototype refrigerator, and a direct link is formed between the cooling system and the PV panel This is done by the incorporation of a water-glycol combination as a phase-change material into a well-insulated refrigerator cabinet and the development of a microprocessor-based control system that permits direct connection of a PV panel to a variable-speed DC compressor. A more efficient variable-speed DC compressor is used in the refrigerator. The machine is intended to operate on 90-150 W of PV electricity (required for compressor start-up), but only requires around 55 W while cycling. Even in a tropical region, inbuilt thermal storage keeps items cold for a week during gloomy weather. Using a variable-speed compressor and peak power tracking, the battery-free machine is meant to perform best in regions with at least four hours of sunlight every day. For rural residents, the unit is the most cost-effective type of on-site refrigeration. 6SunDanzer is an American success story that has sold thousands of solar freezers (most of which need batteries) all over the world.

PV Ice-Making

PV ice production is not extensively used yet, however there have been several efforts. In March 1999, the world's first automated commercial PV ice-making system was constructed in Chihuahua, Mexico, to service the inland fishing hamlet of Chorreras. SunWize developed and implemented the system, which was funded by the New York State Energy Research and Development Authority, which collaborated with USAID, Sandia, the state of Chihuahua, and New Mexico State University. The $38,000 hybrid system generated an average of 8.9 kWh/day to the ice machine at 240 V.

The system coefficient of performance (COP) was 0.65, and the PV array provided 97% of the energy; the backup propane generator contributed just 3%. Ice production fluctuated from month to month owing to fluctuations in insolation and ambient temperatures, but averaged about 75 kilogramme of ice each day (11.5 kg/sun-hour). The ice-maker water pipes would need to be cleaned every 9 months to eliminate calcium buildup. The ice machine was programmed to run for 3 hours each day, with a dozen 15-minute cycles at night to manufacture ice, except on Sundays when there is no fishing (Foster, 2001).

The ice machine worked well for the first few years but finally went out of service after roughly four years. The Mexico project partners' long-term dedication and follow-up were essential for the project's sustained success. However, state political upheavals occurred, and the region experienced severe drought. By 2003, the lake had retreated nearly 2 kilometres from the ice house, and the fisherman had transported their catch to the opposite end of the reservoir. The ice-making system was decommissioned and has not been used in some years.

PV Water-Pumping

PV water-pumping is very cost-effective when compared to conventional energy solutions. PV electricity is often the least cost option as compared to expanding the power supply grid for applications in distant locations or with minor loads. PV is best suited for distant site applications with low to moderate power needs. In addition to water pumping, common cost-effective uses include household electrification, lighting, small-scale irrigation, refrigeration, and electric fencing. Pumping water is an ubiquitous necessity in agriculture, and using PV electricity for this application is a perfect fit. Agricultural watering requirements are often highest during the hotter summer months, when more water may be pumped using a solar energy system. Arid locations, which have the most water demands, also have the most sunshine accessible. PV-powered pumping systems may cover a wide variety of irrigation demands, from tiny hand pumps to big generator-driven irrigation pumps, including drip/trickle, hose/basin, and even open channel irrigation, while flood or sprinkler irrigation are seldom employed with photovoltaics. PV water-pumping systems are simple, dependable, and need little maintenance. Tens of thousands of agricultural PV water-pumping systems are now in use across the globe. The key benefits of PV pumping systems are that they are dependable and durable, do not need fuel, and require minimal maintenance. The primary downside of a PV system is its high initial capital cost.

A PV-powered water-pumping system is comparable to any other pumping system, except that it is driven by solar energy. These systems must have a PV array, a motor, and a pump. PV water-pumping arrays are often installed on passive trackers (no motors) that follow the sun throughout the day, increasing pumping duration and volume. PV pumping systems generally employ AC and DC motors with centrifugal, displacement, or helical rotor pumps. A battery bank may be utilised to store energy if absolutely necessary (e.g., certain home systems often employ this strategy), although water is normally much more cheaply and efficiently stored in a tank. The benefits of PV water pumping include cheaper long-term expenditures as compared to alternatives such as diesel or gasoline-powered water pumps. If a location is already connected to the traditional electric grid, PV pumping is never the most cost-effective choice. PV water pumps have a minimal environmental effect and do not need an on-site operator (no water, air, or noise pollution). Another benefit is system modularity, which allows the owner to satisfy particular demands at any time and expand system size as water-pumping requirements develop. Systems that have been well designed and built are relatively easy to run and maintain. To ensure the success of a PV waterpumping project, it is essential to grasp fundamental principles such as solar energy, PV, water hydraulics, pumps, motors, and other system needs. Solar water pumping is among the more basic but attractive solar applications available today, with many years of dependable service.

Hydraulic Workload

The daily amount of water needed is insufficient to calculate the size and cost of a water-pumping system. Total dynamic head (TDH) should also be included (pumping depth + discharge height plus drawdown plus friction losses throughout the pipe's length). For example, a cubic metre of water requires more energy to extract with a TDH of 10 m than with a TDH of 5 m. The hydraulic load or duty is a handy measure for rapidly analysing if a particular project is a viable candidate for solar power pumping. Multiply the expected total dynamic head for the pumping system by the daily amount of water needed (in cubic metres) (expressed in metres of height). This is the hydraulic workload, and it offers a great idea of the power necessary to satisfy the project's requirements. If the result is less than 1,500 m4, the project is most likely PV-capable. If it is between 1,500 and 2,000 m4, solar pumping may or may not be viable. If it is more than 2,000 m4, a technology other than solar should be investigated.

While developing a water programme plan with a PV emphasis, keep in mind that PV occupies a niche, and that this niche is limited to a certain community size, well depth, & service level. It is significantly preferable to incorporate PV in a mix of implementation alternatives as one of the instruments for satisfying a rural demand than than requiring PV for a certain number of projects. PV may be an excellent alternative in certain really challenging situations when other solutions are not feasible, but it may not be suitable for widespread adoption within an area.

a flow chart that covers the major technical elements to examine when PV is a probable practical option for a water-pumping system. The selection procedure takes into account criteria such as grid distance, hydraulic workload, as well as the solar energy resource available at the location. Every project, regardless of technology, needs a slightly personalised and specialised strategy, as is frequently the case with water-pumping. The Sun provides the energy required to run the pump in PV power systems. Solar cells, the building parts of a PV module, collect and convert solar radiation into electrical energy. Typically, solar energy is connected directly to power a pump motor.

Dynamic Systems

A dynamic system is one in which there is movement of water. The water pressure in a dynamic system is affected not only by the height of the water "column," but also by the friction caused by the flow of water in a pipe and any decrease in the static water level caused by pumping. The following factors must be considered in the dynamic system:

1. The pipe's length. The higher the pressure loss due to friction, the longer the pipe.
2. The pipe's diameter. The higher the pressure drop, the smaller the pipe. The flow of water. The pressure drop increases as the flow increases.
3. Roughness of the pipe's inside. The higher the pressure drop, the rougher the internal surface. PVC pipe has a smoother surface than galvanised iron pipe.

4. Joints and fittings. Each union or elbow creates an extra pressure decrease.
5. Variation in the static water level. The water level may decline when water is pumped.

The length of the pipe, the speed of the water, the decrease in static water level, and other factors all increase resistance, resulting in a bigger pressure drop and higher pumping power needs. The static head (SH) is the height from the well's static water level to the discharge level. As indicated in the formula that follows this paragraph, this is often separated into two components. TDH is the sum of all the components that contribute to total pumping height, given in feet or metres. The dynamic head comprises all frictional and pressure losses.

Frictional losses are affected by pipe size, flow (quantity), number of elbows, and other factors. There are two methods to manage the friction factor: using pipe friction tables or with an approximated number. To utilise the friction table, the pipe length (vertical and horizontal distance), pipe type (PVC, GI), flow rate, and pipe diameter must all be specified. The overall friction loss will be provided by the tables in Appendix B. While friction losses are generally a minor component of the total, their value may be adequately estimated for the TDH equation as well. For a well-designed distribution system, a typical default is to account for 2-5% friction loss. This number may need to be increased if there are extensive pipe runs.

To begin using the friction tables in Appendix B, calculate the system's pumping flow rate (in litres per second) by dividing the total daily water pumped by the number of seconds in the solar pumping cycle (Figure 10.1).

A normal solar pumping cycle lasts around 6 hours, between 9 a.m. and 3 p.m. There are 21,600 seconds (6 hours, 60 minutes, and 60 seconds) in the span. If the daily water pumped volume is 25,000 l, the average flow rate is 25,000 L/21,600 s = 1.16 l/s. This flow rate, together with the kind of pipe material and pipe size, is entered into the tables (see Appendix B). The friction factor for a flow of 1.16 l/s in a 2 in. PVC pipe is 0.71, or 0.71 m of friction for every 100 m of pipe distance (horizontal or vertical). If the pipe is 300 metres long, the total friction factor is around 2 metres (0.71 3 = 2.13 m).

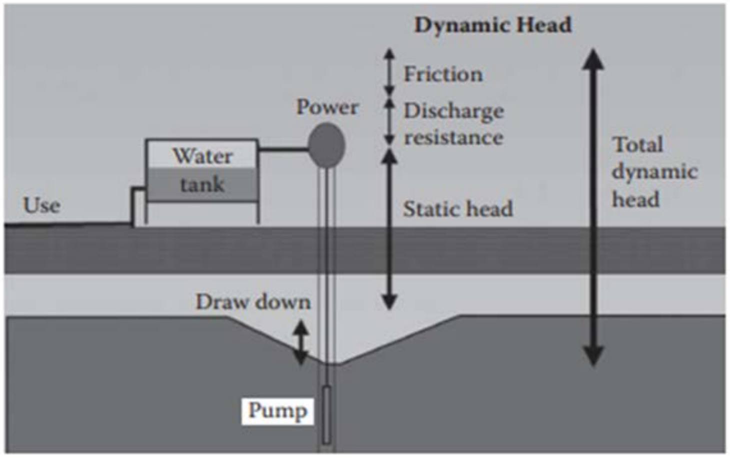

Figure 10.1 Represent the Total dynamic head includes all components.

Water Demand

The average daily demand (cubic meters/day) during the month of high demand and/or the solar design month is estimated (month with lowest average solar insolation). Moreover, the demand must account for any increase throughout the design period, which should be at least ten years. Water consumption for cattle may reach 90 litres per day   Evaporation will demand much more water, particularly in windy and arid places. Also, since animals will only move a certain distance from a water source, water supplies should be separated roughly one every 250 hectares of rangeland. If the water supply and grassland are shared, there is a strong probability that herd increase may result in overgrazing, particularly near the water source.

Domestic water demand is determined by the number of persons, the amount of water used, and the kind of service provided. What is deemed essential in one country or area may be considered a luxury in another. Nevertheless, during hot, dry spells, individuals will drink more water. Local water use is the best indication; nevertheless, keep in mind that if water supply increases, usage per person will likely rise. Water supply in the village comprises clinics, businesses, schools, and other organisations. Water availability, herd or flock size expansion, and population growth in communities will all influence demand growth. Likewise, population growth should be evaluated using current local patterns rather than national ones. Irrigation water demand (low or high volume) will be determined by local circumstances, season, crops, and evapotranspiration. Often, these statistics are obtained via regional or national government agriculture agencies.

Water Resources

The capacity of surface water resources (rivers, streams, reservoirs, etc.) must be assessed by season or month. It is critical to estimate the capacity and drawdown for various pumping rates for wells. The dynamic head must be established in both circumstances. The dynamic head comprises all frictional and pressure losses. Frictional losses are affected by pipe size, flow (volume/time), number of elbows, and other factors. If drawdown and frictional losses are not known, they may be predicted but should be validated, particularly for larger pumping operations.

Lower capacity sources may need a larger storage tank, or possibly numerous wells, for residential, livestock, or communal usage. Hundreds of solar pumping systems are in use across the globe. They provide a variety of purposes, including cattle water and small-scale irrigation, as well as human needs, aquaculture, and industrial uses. When correctly constructed and implemented, they are dependable and low-maintenance. Solar pump quality has improved dramatically during the 1990s, while prices have decreased. Solar pumps are sometimes less expensive to install than engine-driven pump systems.

a typical solar pumping system. An array of PV modules, a controller, a motor, and a pump are the primary components. The array may be installed atop a solar tracker to enhance the daily water volume and prolong the daily pumping duration. The motor may be either conventional (with brushes) or electronic (brushless). The pump's mechanism might be centrifugal or positive displacement (volumetric). Water is often held in tanks rather than electricity in batteries. A system that does not need batteries is known as "PV-direct" or "solar array direct." This section describes the pump, motor, and controller in detail.

Storage of Water versus Storage of Energy in Batteries

Some type of storage is essential to ensure that water is accessible at all times. Water storage in a tank is less expensive than energy storage in batteries. Batteries are costly and must be changed every few years, but a storage tank may last for decades. A battery system needs protection from temperature extremes as well as controls to avoid battery overcharge and overdischarge. Since battery round-trip efficiency are often only about 70%, they waste a significant amount of the energy that passes through them. The addition of batteries to a PV pumping system reduces its dependability while increasing its cost and maintenance needs. In general, it is ideal to size a solar pumping system to deliver the desired water volume sans batteries, even if it involves putting two pumps in the same well or building an extra well and pump. A battery system may be utilised in situations where a water tank is impractical or when the water must be pressured beyond the natural height of a tank.

Centrifugal Pumps

These pumps feature one or more impellers that spin the water, causing it to experience centrifugal force. A centrifugal pump may have many stages, each consisting of an impeller, to achieve high lift. Each level increases the lift capability of the pump. This is how conventional electric well pumps are constructed. To achieve high elevations, centrifugal pumps may use up to 20 stages. Each level adds pressure but also friction, resulting in a 5% efficiency loss every stage. Centrifugal pumps with many stages may be inefficient and are not necessarily suitable for solar pumping.

Centrifugal pumps are most efficient when the flow exceeds 40 l/m and the lift is less than 40 m. The efficiency is weak at lower flow rates and greater elevations. Centrifugal pumps lose efficiency disproportionately at low speeds, such as those seen under low-sun situations. For these reasons, pumps with positive displacement are employed in the majority of systems that need significant lift, even at low volumes.

Positive Displacement Pumps

A positive displacement pump sucks water into a sealed chamber and then mechanically pushes it out. A famous example is a piston pump. Instead, a diaphragm or a helical rotor with traps water in chambers that advance upward as it spins may be used in a solar pump. These pumps feature a large lift capacity as well as a great energy efficiency. They perform well at lower flow rates (e.g., 50 l/m), particularly when the lift surpasses 15 m (Figure 10.2).

Figure 10.2 Represent the Positive Displacement Pumps.

Most solar pumps with a power rating of 500 W (0.5 hp) or less employ positive displacement pumps. Even at low rotational speeds, such as those experienced by a solar-direct pump in low-light situations, the efficiency and lift capacity of these pumps remain high. This is not the case with centrifugal pumps.

Surface Pumps versus Submersible Pumps

A surface pump is one that does not need to be immersed in water It can be put above the water source, but the height to which water may be extracted by suction is strictly limited by nature. The pump should be no higher than 3-6 vertical metres above the water source. Otherwise, it will draw bubbles from the water and stop pumping. A surface pump may take water from a river, irrigation canal, pond, or water tank, but it cannot pull water from a deep well. It may be less costly and more efficient than a submersible pump for high-volume pumping. A submersible pump, on the other hand, is frequently easier to install, better shielded from the environment, and far less likely to be harmed by running dry (Figure 10.3).

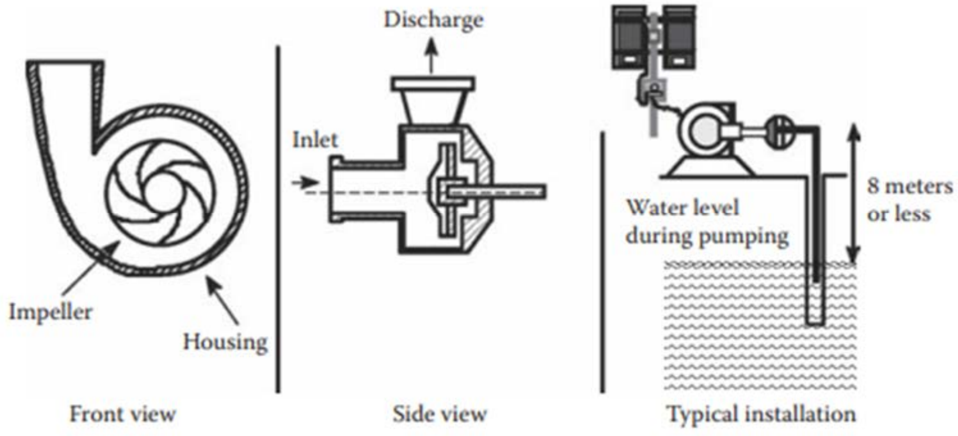

Figure 10.3 Represent the a surface centrifugal pump.

Types of Motors Used with Solar Pumps

A PV array creates direct current electricity at varying levels depending on the amount of sunlight that strikes it. Running a pump directly from this one-of-a-kind source of energy necessitates the use of a specialised motor or motor/control system. Solar pump motors are classified into two types: brush-type motors and brushless motors. Brush-type motors are a form of classic DC motor that has been utilised in battery-powered applications for many decades. The "brushes" are little chunks of carbon-graphite that are electrically conducting. They brush against the motor's rotating portion (commutator) and conduct electricity into it. This causes the current to alternate (becoming alternating current) inside the motor. This straightforward method has two significant drawbacks: (1) the brushes wear out and must be changed on a regular basis, and (2) the motor must be filled with air (not liquid) and completely sealed against water leakage.

These are significant drawbacks for submersible pumps. Brush-type motors are often utilised in surface pumps where they are maintained dry and have simple access. Brushless DC motors are a form of AC motor that is controlled by an electronic controller that converts DC power into variable AC power. With a brush-type motor, the controller replaces the brushes and commutator. The brushless motor has two significant advantages: (1) No brushes to wear, and (2) the engine may be loaded with either oil or water. The most secure solar submersible pumps employ water as a lubricant inside, reducing the possibility of oil contamination.

Solar Pump Controllers

Brush-type motor controllers (linear current boosters). A positive displacement pump needs a surge of current to start and must accelerate against the continuous pressure exerted by the water in the pipe. A PV array might not have been designed big enough to provide the requisite initial surge, particularly in low-light circumstances when current is limited. A linear current booster (LCB) may be used to lower PV array voltage while increasing current. This turns on the pump motor and keeps it from stalling in low-light situations. Since it starts readily and its current demand decreases with speed, a brush-type centrifugal pump is often provided without an LCB. During low-sun times, an LCB controller's efficiency increases, although the performance improvement is quite tiny. Brushless solar pump motor controllers. A brushless motor controller includes a sort of inverter (a device that converts DC to AC). It performs the LCB function and adjusts the motor speed in accordance with the available power. Three-phase alternating current electricity is ideal for starting and operating the motor efficiently. The controller changes the motor speed by adjusting the frequency of the alternating current source. Brushless pumps are often offered with a controller designed expressly for them.

Additional Features of Pump Controllers

Further control capabilities are included into solar pump controllers to make solar pumping feasible and efficient. A typical controller has float switch connections to prevent the sump from overflowing. When the tank is full, the switch instructs the controller to turn off the pump. The float switch resets as the water level falls. This avoids floods, excessive pump wear, and water waste. Since most solar pumps may be damaged if left running dry, most pump controllers include a dry-run protection device. This might be accomplished by mounting a sensor above the pump's intake. If the water level falls below the probe, an electric current is opened, and the pump is turned off by the controller. After the water level returns to normal, the controller will wait for the level to raise (usually after 20 minutes) before restarting the pump. Some pumps employ a thermal switch to cut off the pump if the temperature starts to increase due to dry operating.

Overload protection is also included in a controller to avoid harm if the pump is halted by dirt, ice, crushed pipe, or a closed valve. A controller with suitable overload and surge protection should also be fitted. The controller should also have indication lights so that an observer can quickly detect when the pump is working, when the reservoir is full, and when the system is malfunctioning. Maximum power point tracking (MPPT) is a feature found on the majority of solar pump controllers. This is an advancement above the standard linear current booster. It enables the pump to extract the greatest amount of power from the solar array, despite the fact that solar cell properties fluctuate with temperature and sun intensity. The pump controller's location. The controller of a brushless submersible solar pump might be incorporated inside the motor (Grundfos SQFlex), located aboveground (ETA pump), or put partially above and partly inside the motor

(Sun Pumps). A submersible controller is immune to both weather and human intervention. If the electronics in the motor fail, the complete pump and pipe system must be removed from the well and the entire motor assembly replaced.

CHAPTER 11

SOLAR PUMP

Beemkumar N, Associate Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- n.beemkumar@jainuniversity.ac.in

The procedure of choosing a pump is important to project success. Since the PV array that powers it is the most costly component of the system, a solar pump must utilise energy effectively. Centrifugal and volumetric pumps have distinct properties for different applications. Because of the many technologies and models available, the pump selection process may look confusing. for assistance in determining the optimal kind of pump for a specific application. Manufacturers of both helical rotor and centrifugal subsea (Grundfos SQFlex, ETA) have integrated their product lines. The manufacturer's selection guide, which is typically automated, will recommend the best pumps for a certain application.

Installation, Operation, and Maintenance

A PV water-pumping system's long-term dependability is dependent on good operating and maintenance methods. While a well-designed and installed PV pumping system is safe, dependable, and needs minimal care, basic maintenance, particularly for the pump, may be necessary at times. The operator must understand is to operate the system and execute normal maintenance and operating procedures such as system shut-off/start-up. All of this information should be included in the original system provider's operation and maintenance handbook. The operator should be aware of the estimated signal level in cubic metres per day, the flow rate on a bright day, the meaning of indicator lights, and the fundamental array, wiring, and pump characteristics.

System Installation

Every component of a water-pumping system might fail if it is not properly installed and maintained. Since solar pumping systems are built on-site, skilled professionals are required for a safe and professional installation. The installer is responsible for ensuring that all supplies and equipment are available during installation and for adhering to local electrical safety requirements. The installation instructions provided by the pump manufacturer should be followed. Depending on the region and local circumstances, further specific steps may be necessary (freezing, flooding, lightning, vandalism, theft, etc.) For a successful installation, follow these steps:

Verify the water source (seasonal production); inspect civil works (foundations, piping, and storage system); test mechanical and electrical field connections; cycle through system operational modes; quantify component and system performance (acceptance test); and provide an operational and upkeep manual to the system owner/operator.

Experience has shown that paying attention to detail during installation is critical to avoiding subsequent unanticipated system problems, which are often caused by inadequate initial electrical or mechanical connections. Thermal cycling of inadequate electrical connections, for example, may cause a system to degrade or malfunction over time. The system controller box may not even be adequately sealed, allowing moisture to infiltrate and ultimately damage circuit boards or connections. These first modest faults might result in a stop in functioning and subsequent substantial maintenance expenditures.

The designer must appropriately identify the gauge and type of conductor to be utilised for the current, voltage, and system operating conditions. All exposed wires should be outdoor-rated (e.g., USE or SE wire) or placed in electrical conduit. Cables should be appropriately covered and secured. In certain circumstances, burying conductors may be essential; underground cable or conductor certified for direct burial should be utilised (e.g., USE or SE). All connections should be established in easily accessible junction boxes that may be examined, repaired, and mechanically fastened. All electronic equipment and electrical wiring should be water, dust, and bug proof. It is critical to safeguard cables from physical damage, particularly when a pump cable enters a well. To reduce increasing voltage losses, excessively lengthy wire lengths should be avoided. Strain relief should be used on all connections. All cable ties used should be UV resistant (i.e., black nylon).

Submersible pump wires should be installed with extreme care. Since this cable may be buried in water for decades, it must be completely waterproof and have appropriate strain relief to prevent failure. Cylindrical butt connectors sized for the wire are often used for pump cable splices. If the wire gauge of the submersible cable is bigger than the wire gauge of the original manufacturer's pump cable, a connector designed for the submersible cable should be used, and the pump cable should be doubled up to ensure a tight connection. For maximum force, ratcheted crimping tools should be utilised. Pump splice connections should be insulated with epoxy and rubber-sealed thermal shrink tubing. To prevent short circuits, each splice connection should be individually insulated. The manufacturer's installation instructions should be properly followed. The weight of the pump should never be held by the electrical pump line, and a separate inorganic rope, corrosion-proof cable, or rigid pipe should always be used to support and hoist the pump into and out of a well.

Piping

The system's pipes and fittings should be corrosion resistant. The plumbing utilised from ground level to the well should be able to resist the pressure created by the water column. The fittings must be able to endure these stresses without leaking over time. Leaks diminish production and, in the terms of surface pumps, induce suction loss. Friction losses greatly add to the total head and, as a consequence, reduce system productivity. Long pipeline lines and small pipe sizes should be avoided to reduce friction losses. Elbows and valves should also be avoided wherever feasible. Always utilise corrosion-resistant mounting structures and fasteners.

It is recommended that the PV array be protected against physical damage by animals. A fence may be built around the array. During the hours of 9:00 a.m. and 4:00 p.m., avoid shading the array by trees, fences, or buildings.

Surface-Pump Installation

Ground-level pumps should be attached to a structure (usually concrete) that is erected over the water source's surface. The construction and mounting fasteners should be strong enough to resist pump vibration as well as the weight of the water column in the pipe that travels from ground level to the well. The highest suction capacity of surface-mounted centrifugal pumps is around 7 or 8 m. Suction limits also apply to surface-mounted piston and diaphragm pumps. As a result, the vertical distance between the pump and the water level in the well should be kept as short as possible. Wide diameter pipes with valves and an outlet water flow metre should be placed to avoid friction losses.

Positive displacement pumps should include a check valve. Water must be present in the suction line for the pump to function. After priming the pump, the check valve should maintain the suction pipe full with water even if the pump is turned off for an extended length of time. If no check valve is provided, the system will need manual priming (filling the suction line with water) every time the pump is turned on. If the water-distribution line is lengthy, it is essential to install a check valve on the discharge side of the pump to prevent "ram" damage (water hammer). Any pump intake should be set far enough away from the bottom and sides of the well to prevent pumping mud, sand, and debris, which may all damage pump seals and components. If the water level is likely to dip below the intake, a switch (a floating or electrode) must be installed to prevent the pump from running dry.

It is a major cause of pump failure since it degrades seals, fills impellers, and so on. A sand filter should be built if the well is in an area where sand or dirt may get into the pump. Most pump manufacturers that provide this type of filter may provide advice on how to decrease the danger of damage.

Surface Water Pumps: Preventing Cavitation and Noise

Cavitation is the development and collapse of bubbles caused by excessive suction. Water vapour and/or dissolved gases are produced when water pressure is lowered below a critical threshold, much as when a fizzy beverage is opened. As a bubble enters the pressure side of the pump, the gas is converted to liquid. With a quick implosion, bubbles collapse. This causes water to contact the pump's working surfaces fiercely, like small hammer strikes. Cavitation produces high pump wear and loud noise. That is not the pump's issue, but rather the installation. Take the following steps to avoid cavitation:

1. Read the pump's specification page and instructions carefully, and keep in mind the vertical suction lift restrictions.
2. Water should flow freely via input lines. Employ a big intake pipe (one that is larger than the intake opening on the pump). This is particularly important in the case of lengthy input pipework (see pipe sizing chart.)
3. Avoid 90-degree elbows. To decrease friction losses, use pairs of 45° elbows.
4. Choose intake screens or input filters with care to ensure minimal friction and ease of cleaning.
5. Take care to reduce the potential of air leaks.

6. Keep high places in the intake pipe to a minimum. They may catch bubbles, causing the flow to be restricted (as in a syphon). If a high point is inevitable, place a pipe tee with a cap or a ball valve above it.

Grounding and Lightning Protection for Solar Water Pumps

One of the most prevalent reasons of electronic controller failures in solar water pumps is surges caused by lightning. Lightning that hits a considerable distance away from the system might cause damaging surges. The following actions may considerably decrease the chance of damage:

1. Installation of PV array wiring. Minimum lengths of wire should be used for array wiring, which should be tucked into the metal structure and then routed via metal conduit. Where feasible, positive and negative wires should be of identical length and run together. This will reduce the induction of high voltage between the conductors. If greatest protection is desired, long outside wire lines should be buried rather than routed above and put in grounded metal conduit. To fulfil electrical code requirements, the negative conductor should be grounded.
2. The location of the pump controller. In general, a pump controller's input circuit is more sensitive than its output circuit. As a result, when a lengthy wire run between the PV array and the water supply is necessary, it is typically ideal to install the controller near the array to reduce the length of the input cables.
3. Provide a discharge channel to the earth. Static energy that builds in the aboveground construction will be discharged through a correctly constructed discharge conduit to ground (earth). This reduces the attraction of lightning. When a nearby lightning strike occurs, it is believed that a well-grounded building would redirect the surge around the power circuitry, considerably minimising the likelihood or severity of damage. Most solar pump controls have built-in surge protectors that only work if they are properly grounded.

Solar Tracking for Solar Water Pumps

A solar tracker is a photovoltaic (PV) rack that revolves on an axis to face the sun as it moves across the sky. Depending on latitude, two-axes monitoring may enhance energy generation by roughly 25% each year. Tracking may increase performance while lowering total system costs in solar pumps. Tracking allows for more water to be extracted from a smaller, less costly PV array by enhancing performance.

When the sun is at a low angle, certain solar pumps (especially centrifugal pumps) see a disproportionate decline in performance (early morning and late afternoon). When the output of the PV array is less than 50%, a centrifugal compressor may not create enough centrifugal force to accomplish the needed lift. Tracking may significantly boost daily water output (30% or more) by forcing the pump to operate at maximum power for an entire sunny day. The benefit from tracking is more precisely related to the actual energy collection in the case of positive displacement pumps.

In the design process, the tracking choice is a variable. Typically, a suggested system generates somewhat less than is required, while the next bigger system costs far more. A tracker seems to be a low-cost method of increasing the yield of a smaller system to meet demand. Tracking is least effective during shorter winter days and when the sky is overcast. If the requirement for water is stable throughout the year or is highest during the winter, or if the climate is significantly overcast, it may be more cost effective to construct the system with more solar Watts and no tracker.

Operation and Maintenance of the Systems

Photovoltaic water-pumping systems that have been properly planned and built are relatively easy to run and maintain. Generally, the system must start and stop in response to the demand for and availability of water and sunlight. The majority of systems may be automated at a minimal extra cost by using switches (float or electrode). Manual shutdown is required for water distribution system and electrical system repairs, as well as when the pump is pulled from the well for inspection, maintenance, and repair.

The installer should train those who will be in charge of operating and maintaining the PV water-pumping system. The system installer should provide an operation and maintenance handbook that outlines the system's operating principles, a regular maintenance schedule, and servicing needs. The handbook should also provide information on safety and frequent issues that may arise.

Preventive maintenance is the most effective way to maximise the advantages of PV water-pumping systems. A preventative maintenance programme should be developed to extend the system's usable life. Obviously, each system has distinct maintenance needs; some pumps may run for 10-20 years without any maintenance, while others require repair within the first year. The frequency will be determined by operational and water conditions.In general, PV water-pumping system maintenance includes the following:

Standard maintenance and minor repairs. Monitoring system performance, water level, and water quality are all included. On-site inspections may discover minor issues before they become major ones. Look for strange sounds, vibrations, corrosion, loose electrical connections, water leaks, algae, and so forth. Routine maintenance and minor repairs should be performed by the system operator (usually the owner). Regular maintenance will assist in detecting and correcting the majority of minor issues that arise from time to time before they become big issues

Preventative and remedial maintenance. This may need the replacement or repair of components such as diaphragms and impellers, as well as the replacement or repair of damaged parts. This form of maintenance may need the use of specialised tools and skills beyond that of the system owner. The bulk of the time, trained professionals are required to do the repairs. Pump failures are the most prevalent issue with PV water-pumping systems; PV modules seldom fail.

The PV Array

The avoidance of shadow is one of the most significant aspects of the PV array. Weeds and trees nearby might develop and cast shadow on the pump over time, so they must be kept under control. Cleaning PV modules is not essential; a substantial accumulation of dust will impair efficiency by about 2-4% and will wash away with the next good downpour. If the mounting structure allows it, the array tilt may be altered twice a year to maximise production between the summer and winter pumping seasons. Field care of controllers consists of ensuring a good seal to prevent dust, water, and insects from entering.

Pumps and Motors

From an operational standpoint, it is critical to prevent dry pumping, which causes a motor to overheat and fail. Water is required in the pump for lubrication and heat dissipation.Since surface-mounted centrifugal pumps need regular priming, an examination should be performed to verify that there are no leaks in the suction pipe or the check valve. Pumping against a clogged discharge should never be permitted, since this might cause the engine to overheat. Maintenance is minimal for both surface-mounted and submerged centrifugal pumps. The bulk of issues are caused by excessive sand and caustic water with a high mineral concentration.

These substances have the potential to degrade impellers and pump seals. In other circumstances, the pump may not entirely collapse, but its productivity may suffer as the impellers fill with muck. A thorough cleaning of the impellers may be all that is necessary to restore a pump to full function. Some pumps may be rebuilt by installing new impellers and water seals. Algae and other organic debris may clog the pump's intake, which can be mitigated by using input screens. Submersible pumps are comprised of stainless steel, which is resistant to corrosion.

Positive displacement pumps have higher wear-prone components. Diaphragms should be changed every 2 or 3 years under normal working circumstances (more often in sandy water). Seals on piston pumps normally last 3-5 years, but may be destroyed sooner if exposed to cold temperatures. Diaphragms and seals all fail early in the presence of sand, which accelerates the wear of the components. Many positive displacement pumps may be refurbished in the field numerous times by changing diaphragms. Brushless AC and DC motors need no field maintenance and may last between 10 and 25 years under perfect working circumstances. Brushes on brush-type motors must be changed on a regular basis. In most designs, this is an easy process. To ensure proper equipment functioning, the brushes should be replaced with components provided by the manufacturer. Miniature motors with brushes have a lifespan of 4-8 years, depending on use.

Pv Water-Pumping Results

Where there is no electrical grid service, PV systems have shown to be an outstanding solution for addressing water-pumping demands. First as part of the USAID/DOE MREP-Fideicomiso de Riesgo Compartido (FIRCO) initiative, and subsequently as part of the GEF/World Bank renewable energy for agriculture programme, water-pumping systems were erected across Mexico. Before to 1994, PV water pumping was practically unknown in Mexico, and MREP cleared the door for wider adoption; the nation today leads Central America in this use.

In 2004, FIRCO, NMSU, and Sandia reviewed 46 of the originally installed PV-pumping systems. A PV array (500 Wp on average), pump, controller, inverter, and overcurrent protection were typical system designs. After up to ten years, more than three-fifths of the systems assessed were still operational. The surveys were carried out in the states of Baja California Sur, Chihuahua, Quintana Roo, and Sonora. 85% of consumers said PV systems were outstanding to good in terms of dependability. Water production was rated excellent or satisfactory by 94% of consumers, with just 2% dissatisfied. According to the poll, more than four-fifths of rural Mexico consumers were pleased with the dependability and performance of their PV water-pumping equipment. When system faults occurred, they were mostly related to the pump technology and the installation. When issues have arisen, it has been due to the failure of pump controls and inverters, well collapses, or drying out due to drought. There were no failed PV modules. PV water-pumping system investment payback has averaged approximately 5 or 6 years, with some systems reporting payoffs in half that time.

Economic Feasibility

The most important elements in calculating the value of renewable energy systems are (1) the initial cost of the hardware and installation, and (2) the quantity of energy produced yearly. Renewable energy must compete with the unit value of energy available from competing technologies when considering economic feasibility. If the system generates electrical energy for the grid, the price at which the energy may be sold is also important. For renewable energy to be widely used, the return on energy produced must surpass all expenditures within an acceptable time frame. Renewable energy systems and applications range from watts for a lamp and radio to megawatts for large-scale solar farms and solar electric systems that provide electricity for the grid. Since economics is entangled with incentives and punishments, determining true life cycle costs is difficult, particularly when externalities like as environmental effect and government funding for research and development are not included. The majority of the energy should be consumed on-site for quicker investment return on residential or small systems linked to the grid. Such energy is worth the retail rate, however selling to the utility is often worth less since most utilities do not wish to buy energy at the retail level from their consumers willingly. Nevertheless, net energy billing (also known as net metering) enables larger-scale installations since the system may be built to produce all of the energy required on-site. Net metering is often forced by the government in order for utilities, who are frequently reluctant, to embrace it.

Nevertheless, before contemplating active solar energy systems, passive solar and energy efficiency might be applied. First and foremost, a solar house must be energy-efficient. Conservation and energy efficiency measures are the cheapest to implement and often pay for themselves within 2-4 years. Every house is a solar home, either working with or against the sun. The first and most important solar use is designing and positioning homes and structures with the sun in mind.

PV Costs

PV electricity is the most cost-effective alternative for many applications, particularly remote-site and low-power applications. The ability to generate clean electric power on-site without the use of fossil fuels is an additional bonus. PV has significant capital expenses, but there are no fuel expenditures. PV module prices have plummeted by orders of magnitude during the last two decades. Depending on the quantity ordered, new PV modules typically cost about $3 per Watt. Depending on system size and location, off-grid Photovoltaic systems with battery storage generally cost between $12 and $15 per peak Watt installed. Grid-connected PV systems cost an average of $6-$8 per Watt installed, depending on system size and region. Bigger PV water pumping systems, including all balance-of-system components, may be installed for less than $10 per Watt. A well-designed PV system will run unattended and need minimum maintenance, saving you money on personnel and travel. PV modules on the market now are guaranteed for up to 25 years, with premium crystalline PV modules lasting up to 50 years. While developing PV systems, it is critical to be realistic and adaptable, rather than overdesigning the system or overestimating energy needs. PV conversion efficiency and manufacturing processes will improve more, leading costs to fall steadily. It takes several years to transition PV cells from the laboratory to commercial manufacturing.

Economic Analysis

Economic analysis may be both simple and complex. First, simple calculations should be performed. The following values are often calculated: (1) simple payback, (2) cost of energy (COE), and (3) cash flow. More complex analysis, including payback period, discount rates, and so on, may be performed later. A renewable energy system is economically viable only if its total revenues surpass its total expenditures during a time period up to the system's lifespan. The period when earnings equal expense is referred to as the payback time. Because of the relatively high initial cost, this phase is sometimes many years long, and in certain circumstances, profits will never equal expenditures. Of course, a quick return is preferable, but 5-7 years is frequently acceptable. Extended payback periods should be approached with utmost care.

How is the total revenue or worth of energy calculated? If there is no other source of energy for lights and a radio, a cost of $0.50-$1/kWh may be reasonable considering the advantages acquired. If a solar hot-water system is purchased, the costs of such system must be compared to the expenses of a standard gas or electric hot-water system. Many consumers are ready to pay a higher price for renewable energy since it causes less pollution. Ultimately, a few individuals wish to be entirely self-sufficient from the electric grid, regardless of expense.

Externalities

Externalities are increasingly being included in integrated resource planning (IRP), as future expenses for pollution, carbon dioxide, and other pollutants are added to life cycle costs. Externality values vary from zero (past and present value ascribed by many utilities) to as much as $0.10/kWh for filthy coal-fired steam facilities. Legislation and regulation, once again, assign values (public utility commissions). A social value for employing clean PV technology may be assigned and included in a life cycle cost study. Understanding the social worth of clean-energy technologies such as PV requires an understanding of the environmental and political ramifications of contemporary energy infrastructure. The mining, production, distribution, and use of fossil fuels degrade the natural environment severely while escalating geopolitical rivalry for finite fuel supplies. These issues have an impact on the quality of our air and water, ecosystems, land and material resources, human health, and global stability, as well as the aesthetic, cultural, and recreational qualities of impacted areas. Energy production and consumption, notably via the use of fossil fuels, has emerged as a prominent driver in environmental damage and climate change. Carbon dioxide (CO_2), methane, and nitrogen oxide emissions caused by humans are the primary contributors to global climate change. The major contribution to emissions is energy consumption, which encompasses all elements of electricity generation and utilisation. The energy industry and the widespread use of fossil fuels are directly responsible for around three-quarters of all anthropogenic emissions linked to global warming.

Anthropogenic CO_2 emissions now account for roughly 5% of total world CO2 emissions, with the remainder coming from natural sources (Easterbrook 1995). But, since the natural carbon cycle is at a near equilibrium condition, artificial emissions are not justified. Even minor and continual contributions to an equilibrium system may have significant long-term repercussions. CO2 is the greenhouse gas responsible for 64% of all human-caused climate change (Dunn 1998). Externality is a side effect that occurs when an economic actor's economically productive acts (production or consumption) directly impact the opportunities of another agent, rather than via pricing. Externality is designed to remedy market failure since prices do not always accurately represent the impact of all economic agents' activity. External influences may be classified as either good or negative. Externalities are a flaw in conventional economic theory since behaviours that influence environmental well-being are only considered as external.

It is impossible for PV technologies to compete properly with other conventional energy technologies without taking into consideration the externalities and environmental costs of various power production systems. Positive externalities or side effects often benefit economic actors who are not directly engaged in the production or consumption process by extending their economic activity or lowering expenses. Positive externalities for PV applications include no pollution emissions (CO2, SO4, NOx, etc.), no danger of fuel spills and contamination, no noise pollution, and no reliance on imported energy sources. Production or technology externalities are often related with negative externalities. Pollution or other undesirable byproducts of a company's manufacturing activities may have an impact on the wellbeing of others (e.g., a polluted water supply).

To account for externalities that traditional markets have failed to notice, a social approach to establishing the most effective resource allocation for every community is required. The social costs and advantages of any energy resource must be considered in addition to the private costs and benefits.

CHAPTER 12

EXTERNALITY EVALUATION METHOD

Ramachandran T, Professor,
Department of Mechaical Engineering, Jain (Deemed to be University) Bangalore, India
Email Id- t.ramachandran@jainuniversity.ac.in

Externality costs and benefits may be assessed using two basic methodologies. These techniques may be based on market pricing, which attempt to identify some form of proxy measure, such as land value, to calculate the societal value put on averting environmental harm. The alternative, more often used technique is based on nonmarket valuation methods, which attempt to predict what the market clearing price would be if an item or service were exchanged in the market. The hedonic pricing, journey cost, and contingent value approaches are common nonmarket methodologies for evaluating externalities. They mostly depend on survey approaches to get information from resource users about how they value a given degree of product and how much they are ready to pay for it. Individual preferences for the protection of environmental "commodities," according to conventional economic theory, may assess the worth of all environmental assets. To offer a "genuine" value of environmental welfare measures, the contingent valuation approach is applied. A customer's "willingness to pay" is a compensated variation in how much a consumer is willing to pay for a welfare benefit owing to changes in nonmarket environmental commodity provisions.

Comparison of Pumping Alternative

PV systems are often not competitive in regions with access to conventional power because to their high initial costs. When there is no connection to the electrical grid, solar and internal combustion systems are definitely the most practical choices. Solar energy systems may be more cost-effective in the long term than internal-combustion systems if the solar resource at the project site is excellent (at least three peak hours per day) and a hydraulic workload of less than 1,500 m4/day is needed. Although while internal-combustion systems are often less expensive in the beginning, the long-term expenses of fuel, maintenance, and repairs are significant Depending on how distant the location is, a diesel system may cost $0.40/kWh or more to run.

Calculate the yearly operating and maintenance costs. Internal-combustion systems must include the cost of components (lubricants, filters, tuning, and so on) as well as labour. The remuneration of the operator must also be considered. If the system requires regular trips for operation and maintenance, the cost of gasoline consumed for transportation to the site might be substantial and should be included into the operation and maintenance budget. The pump is the sole mechanically wearable component of a solar energy system. Centrifugal pumps do not need maintenance under typical working circumstances. The majority of small diaphragm pumps need diaphragm and brush replacement every 3-5 years of continuous operation.

Calculate the usable life and replacement cost of the system's main components (pump, motor, generator, etc.) throughout the analysis period. The useful life is determined by the quality of the components as well as the working circumstances. The usable life of major components and the maintenance required are calculated based on prior experience or information contained in owners' manuals or other manufacturer material. If this data is unavailable, the approximate values in Table may be utilised.

Calculate the yearly cost of the system's fuel use. The yearly fuel cost of an internal-combustion system is determined by the characteristics of the motor used and the number of hours required to pump water. The most typical size of pump-generator systems is 3 horsepower. The yearly operating hours may be calculated using the following formula:

It should be noted that pump efficiency is proportional to total dynamic head. According to field experience, pump-generator systems of 3-15 hp burn around 0.25 litres of fuel per hour per unit of horsepower. As a result, Formula 9.2 may be used to calculate the yearly fuel usage (in litres):

Yearly fuel consumption (litres) = 0.25 L/h/hp motor power (hp) annual operating hours The same method is used to estimate the yearly hours of operation for systems that employ a generator and a submersible pump, bearing in mind that motor power (hp) refers to the power of the electric motor that powers the pump. These systems require more fuel since the generator's internal-combustion engine is bigger than the electric motor that powers the pump.

Institutional Issues

The key to every successful solar energy project is to establish a long-term institutional structure. Renewable energy sources are now commercially accessible to satisfy a broad variety of urban and rural uses, from small to big scale, on a cost-effective basis. But, without appropriate institutional and commercial frameworks to manage and sustain renewable energy systems over time, they will fail. Future operation and maintenance are often planned ahead of time for bigger utility-scale projects. In contrast, future follow-up and maintenance are often disregarded for smaller size individual applications. In many respects, this is the most essential chapter of the book since it examines the lessons learned linked to fundamental institutional concerns that ultimately determine the success or failure of long-term solar energy projects.

Smaller, rural-scale solar energy projects often face more institutional hurdles than larger, utility-scale systems. Smaller installations are often the most distant and easily neglected, and solar was typically selected since extending the existing power infrastructure was too costly to begin with. These kind of projects are often organised by office bureaucrats with no field or sun application expertise. Smaller rural solar energy systems are the most basic, cost-effective, and acceptable uses for solar energy technology; nonetheless, institutional concerns must be considered for long-term success.

Not only is the technology utilised in every renewable energy project vital, but so are the implementing and follow-up agencies or organisations, as well as the infrastructure necessary to support it. Technological considerations are vital in ensuring the quality and effective execution of renewable energy projects, but they are not sufficient to assure a project's future success. Technically sound designs and exhibits often fail owing to a lack of attention to institutional difficulties and follow-up. This is particularly true in development initiatives that bring new and poorly understood technology into rural areas, such as solar energy. But, much like any other mechanical and electrical system, the implementation agency and user must be prepared to do future maintenance on the system to guarantee its long-term performance. To achieve long-term sustainability, a sustainable renewable energy project must include not just maintenance difficulties, but also social and political issues such as capacity building, technical support, education and training, and local infrastructure development.

Sustainability

Sustainable development, often known as sustainability, is the attainment of long-term economic and social progress while minimising long-term adverse effects on the environment, culture, and natural resources. For example, in the utilisation of solar energy technology for rural water pumping, sustainability offers users (consumers) with local access to competent suppliers, high-quality equipment, and maintenance skills at a fair cost and payment schedule. Since solar energy systems have a larger initial capital cost than conventional technologies, access to appropriate finance is often a crucial aspect in the sustainability of rural renewable energy technology. Long-term sustainability is a natural byproduct of local market expansion.

Market forces ultimately develop the infrastructure necessary for the formation of a local market when demand for a product or service is strong enough to allow for profit generation and competition. Renewable energy development initiatives should aim to offer required services like water supply, refrigeration, or communication while also contributing to local market growth and sustainability. Development initiatives are often implemented in economically poor areas where consumer capacity to pay is low and supply infrastructure is insufficient or nonexistent. Rural programme implementation is often done in the context of social programmes that entail different types of government or other organisation funding. Subsidized programmes are not intrinsically sustainable; yet, they are reasonable and may make major social benefits, as well as serve as a spur for carefully developing local markets for renewable energy technology and exporting or promoting local goods. Large government incentive schemes (e.g., California, Germany, Spain) have supported the majority of worldwide expansion in on-grid photovoltaics. Many decision makers have largely neglected the more sustainable and expense off-grid PV sectors because they are less visible and often help distant populations with little political influence.

Policy Issue

Renewable energy project implementation is most effective when favourable international, national, state, or local policies are in place. Recognizing the social, environmental, and health advantages of solar energy systems may lead to appropriate policies on importation restrictions, tariffs, fossil fuel subsidies, and other government impediments that artificially raise the cost of installed renewable energy systems. Existing government initiatives in adjacent fields such as farming, cattle ranching, and drinkable water might justify direct government engagement in the execution of renewable energy schemes. The majority of states in the United States currently have renewable energy portfolio requirements mandating a proportion of electricity generating to come from clean energy sources; Texas and California are leading the way. Feed-in tariffs are in place in Germany to stimulate investment in PV generating. Such initiatives may help to promote solar technology and educate prospective end users. Favorable policies promote entrepreneurship and extensive market expansion.

Strong collaborations should be fostered. Solar energy programmes should foster strong collaborations among government, business, and development organisations to solve the varied cultural, technical, social, and institutional difficulties that arise while working to fulfil programme objectives. Collaboration with in-country organisations and business is critical to the success of a solar energy initiative. Moreover, members of the programme team, which is made up of people from several organisations, must work effectively together. It is critical to carefully choose partners and to maintain honest and open communication.

Capacity Building

Substantial effort is needed to help partners in developing the local capability required to effectively create and independently assess solar projects. Technical support, formal training seminars, concentrated field activities, and in-depth analyses of supplier quotations and designs for proposed systems are all examples of capacity development. Local assistance and training are critical for the success of solar energy schemes. In-depth training is essential for developing the desire and expertise needed to comprehend and effectively utilise renewable energy technology. A framework is required to help partners establish the capacity required to guarantee the long-term operation and maintenance of solar energy projects. Technical support and training are ongoing procedures that are best delivered incrementally over time. It is critical to teach not just project developers, but also to update local industries (supply side).

System vendors must also be able to return to existing installations on a regular basis and correct any issues that arise. This allows them to observe what works and what does not over time. The technical skill of local technicians and administration who continue to run a solar energy system long after the system's inauguration is critical to success. Increased technical competence of local suppliers increases consumer and development agency trust in quality projects.

Technical Assistance

Working with local partners and project developers to offering technical help to local system vendors are all examples of technical assistance. Working with local partners (project developers) is essential for developing workable technical specifications for solar energy systems that take into account local norms and hardware limits. This provides a fundamental overview of what is necessary for a professional and safe system installation that will last for years. It is also critical to collaborate with local suppliers to ensure that they understand what is necessary to achieve the technical criteria. It is impossible to overstate the significance of including business in all phases of a renewable energy programme. On a local level, market sustainability and development can be ensured only if a solid supply-chain infrastructure exists and deployed systems perform consistently over time. To improve their capacity to produce high-quality solutions at affordable rates, project developers must collaborate closely with local suppliers. Suppliers should be encouraged to attend training courses, understand proper electrical regulations, implement prototype systems, and create their own in-house capacity-building initiatives. Renewable energy resource maps for project areas may help choose where to deploy certain technologies. These maps are useful resources for partner organisations and system vendors as they seek to identify the most viable places for renewable energy technology. These and other types of technical support are part of the capacity-building process, and they help programme partners make educated choices about how to deploy solar and other renewable energy technology.

Involving the Community

The message must be clear: solar technology requires a larger social component to be effective than conventional technologies. It is not only a matter of technical maintenance or system management; rather, the system's operational survival is dependent on broader community participation and dedication. The essential need of greater community participation with solar projects necessitates inclusionary policies: women, the elderly, children, and men must all be involved and buy in to solar energy project development its responsibilities. If not, youngsters may carelessly toss pebbles that shatter panels, and no one will take responsibility to replace them if the programme is entirely funded by the government. To create a feeling of ownership and responsibility in each stakeholder group, specific and concentrated activities are required. Beneficiaries might be asked to pay a fair amount of system expenses within their means or to give sweat equity to help with system installation to foster ownership emotion. When individuals are unwilling to offer in-kind gifts, it is advisable to walk away and continue down the road since views will undoubtedly vary in various communities. Solar technology requirements are ideally adapted to widening project engagement to include youngsters and the elderly in comprehending the difficulties and giving extra monitoring for the system with that knowledge. The scenario is similar to PV house lighting projects, where it has long been recognised that children were effective agents for ensuring that lights were switched off—something crucial in these PV systems. Water projects of all kinds are particularly good venues to press for increased female participation, since they are the ones most impacted by water scarcity—as consumers and, historically, as procurers.

Community Reduction of Theft Risks

Tiny solar energy systems are prone to theft, and engineering-based antitheft methods may be ineffective. Thieves may cut support elements beneath the panels if antitheft nuts or rivets are used. Alarms may be an option, but they would increase system costs and may be ineffectual if the array are isolated. Several communities (for example, Honduras, Mexico, and the Dominican Republic) have come up with a spontaneous and autonomous societal solution to the issue. The members of the community take turns guarding the solar array. This is not a perfect answer, particularly for industrialised nations that put a high value on labour. If outside thievery is a danger in a remote community, it may be a fair remedy. Local inhabitants are unlikely to steal from their own common system. The most vulnerable system to theft is the isolated system beside a well-traveled road on a ranch with no one nearby.

Program Implementation

A renewable energy programme may be effectively implemented by the government, nongovernmental organisations (NGOs), or private sector. Each implementing organisation will have various aims and objectives; nonetheless, collaboration between these institutions is frequently the most effective. Governmental agencies may define a deployment agenda and impose procurement and quality control criteria. Moreover, they often have substantial human resources and infrastructure at their disposal to cover a large geographic region. They may also advocate the use of renewable energy as an alternative to traditional energy systems where it is a more realistic option for distant rural communities. Renewable energy must be integrated into current development plans as part of the answer to attaining programme goals (rather than the focus only on renewable energy). Remember that government workers sometimes lack the technical competence and experience required to build a renewable energy programme on their own, and they frequently have unreasonable expectations. They should seek the assistane of skilled outside specialists to assist them with realistic planning and objectives.

Organizations who concentrate their efforts on renewable energy have shown to be highly effective in the implementation of renewable energy schemes. In recent years, certain non-governmental organisations (NGOs) have been successful in acquiring funds to carry out rural development initiatives. The key for an NGO or government organisation to effectively implement renewable energy is to avoid becoming the system installer, but rather to collaborate with local system installers and offer supervision. Sadly, some non-governmental organisations (NGOs) get funds for renewable energy initiatives but have no practical understanding or dedication. As a result, they have deployed resources inefficiently and implemented inadequate equipment, giving the sector a bad reputation that may take years to overcome locally. This strategy has slowed the growth of renewable energy in several areas. The most common error for an Organization is to build a system while failing to offer long-term project support and maintenance.

CHAPTER 13

CONDUCT STRATEGIC PLANNING AND ENERGY STORAGE

G. Ezhilarasan, Professor,
Department of Electrical and Electronics Engineering, Jain (Deemed to be University)
Bangalore, India
Email Id- g.ezhilarasan@jainuniversity.ac.in

Strategic planning with collaborative partners aids in the development of realistic targets for incorporating renewable resources into established programmes. Early planning must be pragmatic and within the constraints of available resources; in other words, doing one thing well is preferable than doing several things badly. Plans should incorporate adequate promotional efforts, including training, to speed technology uptake. Local developers must learn to control the creation of a full programme from the project discovery stage through acceptance testing and operation, while keeping programme development as basic and clear as feasible. In general, there are far more prospects for collaborating and tapping into opportunities than resources can support; so, it is better to specialise, restrict, and succeed in a few regions rather than extend. Government-funded initiatives often enforce a one-year cycle for planning and budgeting. Renewable energy development initiatives benefit tremendously from multiyear financing, owing to the fact that meaningful benefits are often reached only after many years of devoted labour. Short-term, one-of-a-kind projects are generally not long-term successes.

Install Appropriate Hardware

Several renewable energy initiatives and systems have earned a bad reputation due to the use of subpar components and designs. Some development projects, particularly those aimed at impoverished rural populations, provide subpar answers to their problems. Even the poorest rural residents have a right to high-quality, safe components and designs in order to get the most out of renewable energy technology. Subpar systems merely reinforce the perception that solar energy systems are restricted, inefficient, and prone to failure. Quality components and designs that are safe, dependable, and long-lasting are required for good installations. The adoption of energy-efficient equipment is the first order of business for every solar energy project. Poorly planned out and performed systems must never be deployed.

Monitoring

A true dedication to project follow-up and monitoring distinguishes effective renewable energy development initiatives from less-than-stellar ones. Monitoring operations should be built into every programme from the start, and they should concentrate on a variety of concerns, including the technical, social, economic, and environment implications of proper technology and application usage. Monitoring data may be gathered from a number of sources, including interviews with partner agencies, suppliers, and end users, site inspections, and performance monitoring of deployed equipment. Long-term consequences cannot be assessed without monitoring activities. Receiving images and data from functioning systems in the field after many years is much more valuable than a gorgeous inauguration-day snapshot of dignitaries with a new technology that may be destined to fail due to a lack of a maintenance infrastructure.

Monitoring operations should aim to create a pool of projects and technology for long-term assessment. It is beneficial to have a database of relevant project and programme information gathered from field people. Keeping a database helps programme employees to perform analysis and make required changes when the programme is implemented. When a programme progresses from direct pilot project execution to wider replication and institutionalisation of partner organisations, these monitoring measures become more important.

Institutional Models for Solar Energy Dissemination

Project replication, or establishing sustainable markets, is the ultimate measure of a program's success or failure, and it may happen in a variety of ways. When partner institutions and end-users get more acquainted with solar energy technology, they begin to develop new projects on their own. This usually starts in a certain place and then spreads to other areas. Other associated institutions learn about the benefits of renewable energy technology and begin initiatives as a result of such actions.

The potential for this sort of replication is immense, considering that development organisations' budgets for development projects may be in the millions of dollars, yet only a small percentage of money are dedicated particularly for renewable energy. Successful pilot initiatives result in private-sector spin-off replication. Many variables must be handled sufficiently for replication to be significant: the local populace must be aware of the technology and what it can give, quality goods and services must be accessible locally, and the capacity to pay for the technology must exist. Access to appropriate finance sources is particularly beneficial for the latter reason.

Despite the fact that the levelized product lifecycle costs of renewable energy are frequently extremely competitive when compared to traditional fossil fuel expenses, particularly in rural areas, the initial cost of solar energy may be prohibitive for many prospective consumers, particularly in less developed countries. Occasionally development funds are available to buy down system costs in order to make system costs more affordable.

Table 10.2 summarises the project development models often used in renewable energy development. The effectiveness of a model is determined by the location of the project, local cultural norms, the degree and kind of political organisation, and other considerations. Program implementation by private industry is uncommon in rural renewable development, although certain projects have been highly effective, particularly in terms of funding. Private-sector-led programmes have the benefit of being in the greatest economic interests of the implementing agency or customer.

The following are four primary tactics used in the private sector to stimulate the acquisition of renewable energy systems: Market-based financing and leasing alternatives for renewable energy offer the greatest promise for increasing rural families' access to this technology. Solar energy has the ability to produce new and significant commercial activity in economically challenged rural regions by providing employment in local retail sales and services, as well as manufacturing (e.g., solar cookstoves).

Renewable energy technologies are yet to be acknowledged as a consumer commodity that can be funded in most industrialised as well as developing nations. Certain outliers, such as Soluz in the Dominican Republic and Honduras, are generating unique alternatives for renewable technology diffusion.

Sales of renewable energy technologies, particularly PV in developing nations, may be grouped into four stages, as shown by a conventional sales strategy pyramid in Figure 10.1. The few direct cash sales to very rich families who can afford the high initial capital expenses of a renewable energy system are at the top of the pyramid. After this, there are many more people who can afford to buy a renewable energy system if suitable loan conditions are offered. The approach also demonstrates that even more individuals might pay a service charge for electricity by leasing a renewable system. Finally, the poorest households, often traditional tribal groups living largely outside of any cash economy, live a subsistence lifestyle and would likely refuse to participate in any form of renewable electrification programme unless it was directly subsidised by development agencies; however, it is appropriate to seek in-kind sweat equity from even these tribal groups to help generate a sense of project ownership. The actual proportion of people who fit into any of these groups varies substantially from nation to country.

Consumer Financing

Consumer finance was one of the most significant breakthroughs of the twentieth century. Consumer finance is a prevalent method of expanding consumer goods sales all around the globe. This has enabled inhabitants of industrialised countries to acquire houses, vehicles, and gadgets that the typical person could not afford to buy outright. However, commercial banks and vendors seldom finance the purchase of consumer items by individuals living in developing nations' rural regions, and if they do, only at exorbitant interest rates. Much more renewable energy systems could be deployed if customers had easy access to funding. This would allow for more rural economic growth. Sadly, most nations have essentially no finance options for renewable energy systems.

To make finance a sustainable company, financing should be produced at competitive interest rates and prevent a mismatch of loan and subloan maturities. When working with rural people who are unfamiliar with finance principles, procedures should be as easy as feasible and allow for speedy distribution. Parallel compliance monitoring, which allows for end-user audits, performance audits, product and installation standards, after-service sales, warranties, and customer satisfaction surveys, is essential. This manner, the success of a funding programme may be followed in real time and modifications made as required before the programme runs into problems.

The leased systems concept is another strategy that has been used for solar energy systems in rural areas. Leasing is intended to make solar-powered home systems more accessible for rural residents by removing the need for a down payment, cutting monthly rates, and reducing the customer's financial commitment to a simple month-to-month lease agreement for energy service. This strategy has had mixed results in locations like the Dominican Republic and Honduras. Since administrative expenses are significant, it is a challenging approach to adopt for modest solar energy residential systems.

Subsidie

Subsidies are often misapplied and poorly constructed by planners. Incentives for renewable energy technologies that do not establish any local infrastructure for system maintenance or infrastructure development sacrifice long-term market growth. Subsidies should be supplied with the goal of constructing a sustainable future in mind (i.e., "smart subsidies").

Subsidies must be able to maintain cost-cutting demands in technology, but they must not impede competition by giving subsidies to a single firm. Subsidies should be technology and supplier agnostic, with a modest cost share from users to foster a feeling of ownership. For example, Japan successfully utilised subsidies to assist drive down the cost of PV from the late 1990s to the mid-2000s; they were subsequently phased out by the late 2000s as PV became economically competitive with national electric pricing on a life cycle basis (electric rates of roughly US$0.25/kWh). As a consequence, PV installation growth in Japan has stopped out, but the sector has reached a sustainable steady-state.

Subsidies are more effective when they fund outcomes rather than investment costs. Capital cost subsidies encourage the installation of systems but not their long-term use. There is no reason why a subsidy for renewable energy water pumping could not be established in such a manner that a fee-for-service method could not be used. This would assist to ensure long-term system reliability while also developing a sustainable local supply and service base.

Subsidies should also be utilised to ensure that they are satisfying the requirements of the communities that have prioritised them. Participating homes should also be carefully chosen and have a real interest in the service supplied, whether it is water, power, ice, or anything else.

Energy Storage

Solar energy is a nondispatchable energy technique that absorbs energy exclusively during the day.

To make the energy accessible during non-sunny seasons, some kind of energy storage is necessary. Energy storage may take several forms, the most common of which is electrochemical energy storage using batteries. Nevertheless, energy may also be stored as compressed air, pumped hydrostorage, hydrogen, or thermal mass. With standalone PV systems, several kinds of batteries and charge controllers are employed to supply electricity when the sun is not shining.

Batteries in PV Systems

An electrochemical device is a storage battery. It stores chemical energy that may be released in the form of electrical energy. When the battery is linked to an external load, the chemical energy in the battery is transformed into electrical energy, and current flows across the circuit (Harrington 1992; Lasnier and Gan Ang 1990).

A PV system battery's three major roles are to: store electricity generated by the PV system; provide the power necessary to run the loads (e.g., lighting, pumps) for the end-use application;

and serve as a voltage stabiliser in the electrical system. The battery smoothes out or decreases transient high voltages that may occur in the PV electrical system.

In the electrical system, high transient voltages may be created (this could occur in making or breaking a circuit). The battery absorbs and considerably decreases these peak voltages, protecting solid-state components from harm caused by very high voltages.

PV systems do not charge batteries in the same way that battery makers are used to. Designers may encounter challenges while selecting and optimising batteries for PV systems. Better knowledge of the PV environment may assist extend battery life.

PV designers may not utilise batteries precisely as planned, but via improved design, they may use them more efficiently. Secondary, or rechargeable, batteries of various sorts are used in stand-alone PV systems. Because of its deep-cycle capabilities and extended life, the flooded (wet) traction or motive power battery is the best choice for PV applications among lead-acid battery types. Because to their restricted deep-cycle capabilities, starting, lights, and ignition (SLI) batteries, which are extensively used in vehicles, are not suggested for PV applications. VRLA sealed batteries are popular, however they have specific criteria that are difficult to achieve in a PV system. These batteries will need greater care in terms of how they are handled if they are to be effective.

If a lead-acid battery is not overcharged, overdischarged, or operated at temperatures over the manufacturer's suggested standards, its life is proportional to its average state of charge (SOC). A typical deep-cycle flooded lead-acid battery. Maintaining a battery over 90% SOC may offer two to three times the number of complete charge/discharge cycles as allowing the battery to approach 50% SOC before recharging.

Lead-Antimony Batteriey

The capacity of flooded lead-antimony open vent batteries vary from 80 Ah to over 1,000 Ah. Because of their deep drain capabilities and ability to withstand abuse, they are often the most readily accessible and acceptable kind of battery for PV applications. To keep electrolyte levels stable, these batteries need the injection of water. Evaporation and gassing cause electrolyte loss. The charge algorithm and set points determine the gassing rates. The insertion of catalytic recombiner caps may greatly minimise water loss (CRCs).

These batteries are the most resistant to charging algorithms and incorrectly selected set points. They are physically tough and can withstand temperature extremes, while temperature adjustment is advised when setting charge controller set points. For batteries under continuous temperature extremes, the electrolyte is readily adjustable. The specific gravity of the electrolyte may be used to determine the battery's health. This value, although not an exact measure of capacity, does show the health of each individual cell as well as the extent of sulfation or electrolyte stratification.

Lead-Calcium Batteries

Flooded lead-calcium open-vent batteries, often known as stationary batteries, generally have nominal 2 V cells with 1,000 Ah or larger capacity. They are not designed for deep cycling, but they have low self-discharge rates and reduced water losses. They will endure more than ten years in continuous standby usage if properly cared for. They often have a shorter lifespan owing to electrolyte sulfation and stratification. This risk may be mitigated by using charging procedures tailored to PV charging regimes.

Flooded lead-calcium sealed-vent batteries were first adopted for the PV sector from the automobile industry. These batteries are known as maintenance-free batteries. They are not designed for deep cycling, although they do have reduced self-discharge rates and water losses. They do not tolerate more than 20% depth of discharge well, resulting in a significantly reduced lifespan.

These batteries are typically 12 V and have a capacity of 80 to 100 Ah. They fare poorly in hot weather or when overcharged. Controlled charging and low gassing are required for these batteries. They must be blasted to mix the electrolyte since they are waterlogged. If the battery is over-gassed, the electrolyte is lost permanently via the vents, limiting battery life. Due of their sensitivity to overcharging, these batteries are more prone to undercharging than overcharging.

Lead-antimony/calcium hybrid batteries are often flooded and have high Ampere-hour ratings—300 Ah and higher. These batteries have lead-calcium tube positive electrodes and pasted plate negative electrodes, combining the benefits of both lead alloys. Since they are hybrids, they are expected to have lower electrolyte loss and a longer depth of discharge and lifespan in cyclic applications.

1. Benefits: Calcium strengthens lead.
2. Calcium lowers gassing and water loss (higher electrolysis threshold).
3. Minimal upkeep is needed.
4. Self-discharge rate is low.

Disadvantages:

1. Low charge acceptance after a deep discharge depth.
2. Repeated deep discharges (>15-20% depth of discharge [DOD]) significantly reduce battery life.

Captive Electrolyte Batteries

Captive electrolyte batteries are built in sealed packages. Typically, lead-calcium grids are used, however other grids utilise lead-antimony/calcium hybrids. The solution of sulfuric electrolyte is immobilised. Captive electrolyte batteries, often known as VRLA batteries, contain complex valve (pressure)-regulated systems for cell vents. There is no need to add water to these batteries since they are spill resistant.

Initially, sealed lead-acid gelled electrolyte (gel) electrodes were intended for use in electronic devices and regulated settings. Gel batteries have lead-calcium pasted plates. The technology behind batteries is very sensitive to charging techniques, set points, and temperature extremes.

With the same technology, charging voltage regulation (VR) set points differ from manufacturer to manufacturer. The charging strategy advised is constant voltage, with temperature correction necessary. The chemistry of the battery has an upper temperature limit. When this limit is surpassed, permanent harm occurs. Certain batteries perform better in cold conditions than flooded batteries because the electrolyte is suspended in a silicon gel rather than water, lowering freezing susceptibility. By adding alkaline solution to the electrolyte, new technology has been used to lessen the negative effects of deep discharge on these batteries. When a battery is depleted, the concentration of sulfuric acid decreases, raising resistance and decreasing the battery's capacity to recharge effectively. Phosphoric acid is utilised to reduce oxidation between the grid and paste during low charge states.

The charging methods, set points, and temperature extremes of sealed lead-acid, absorbed glass matte (AGM) technology are all sensitive. With the same technology, charging VR set points differ from manufacturer to manufacturer. The charging strategy advised is constant voltage, with temperature correction necessary. The chemistry of the battery has a fixed upper temperature limit of around 135°F; surpassing this limit causes catastrophic, permanent destruction. The lower maximum recharge rate of gel type electrolytes batteries applies here as well.

Separators

Separators are installed between the positive and negative plates to prevent a short circuit from releasing all of the plates' stored energy. A separator is a thin sheet of highly porous electrically insulating material that permits charged electrolyte ions to travel between the positive and negative plates. The separators' high porosity assures minimal resistance to current travelling between the plates. To avoid metallic conduction between plates of opposite polarity, the separators must offer enough insulation. Microporous rubber, plastics, and glass-wool mats are examples of suitable separator materials.

Lead-Acid Battery Operation

When two opposing metals, such as the positive and negative plates, are submerged in sulfuric acid (the electrolyte), the battery is formed, and a voltage is produced that is dependent on the metals and the electrolyte employed. A typical lead-acid battery has around 2.1 V per cell. The chemical reaction between the metals and the electrolyte generates electrical energy. When there is a circuit between positive and negative terminals (when a load such as the headlamps is connected to the battery), the chemical reactions begin and electrical energy flows from the battery. The electrical current travels as electrons via the outside circuit and as charged acid (ions) between the battery's plates (Figure 13.1).

Discharge Cycle

Current flows when a battery is linked to an external load. The positive plate's lead dioxide (PbO2) is a combination of lead (Pb) and oxygen (O2). Sulfuric acid (the electrolyte) is a hydrogen (H2) and sulphate radical combination (SO4). When the battery drains, the Pb in the positive plate's active material reacts with the SO4 in the sulfuric acid to generate lead sulphate (PbSO4) in the positive plate. The active element of the positive plate, oxygen (O), interacts with H2 from the sulfuric acid to generate water (H2O); the concentration of acid is lowered as SO4 is eliminated from solution (into the plate PbSO4). At the same time, a comparable reaction is taking place on the negative plate (Figure 13.2).

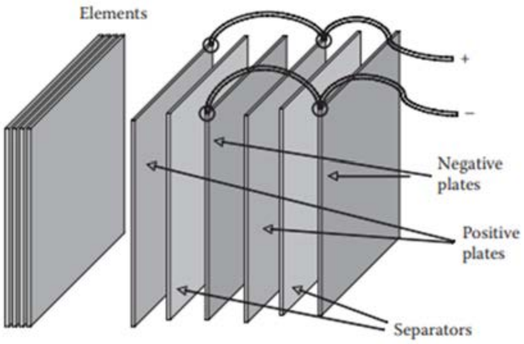

Figure 13.1 Represent the Lead-acid battery plate construction configuration.

In the negative plate, lead from the negative active material reacts with SO4 from the sulfuric acid to generate PbSO4 As the discharge advances, the sulfuric acid in the electrolyte is diluted, resulting in a decreased specific gravity. A hydrometer or refractometer may be used to measure specific gravity, providing an accurate and easy technique for detecting a battery's state of charge. The active material on both plates changes to PbSO4 during the discharge. The plates are getting increasingly similar, and the acid is weakening. As a result, the voltage falls as the difference between the two plate materials and the acid concentration decreases. The battery eventually loses its ability to provide power at an usable voltage and is said to be discharged.

When a battery is exposed to a high discharge rate, it drains fast. The acid circulation into the pores of the plates and the diffusion of electrolyte from the pores of the plates are too sluggish to support the discharge at high discharge rates. During the relatively short time of a high discharge rate, only a tiny fraction of the electrolyte and plate active materials near the plate surface of the cell participate in the chemical process. At lower discharge rates, acid circulation diffusion has less of an impact on battery performance. At modest discharge rates, almost all of the acid may be used, and the material in the centres of the plates has a better chance of participating in the chemical process.

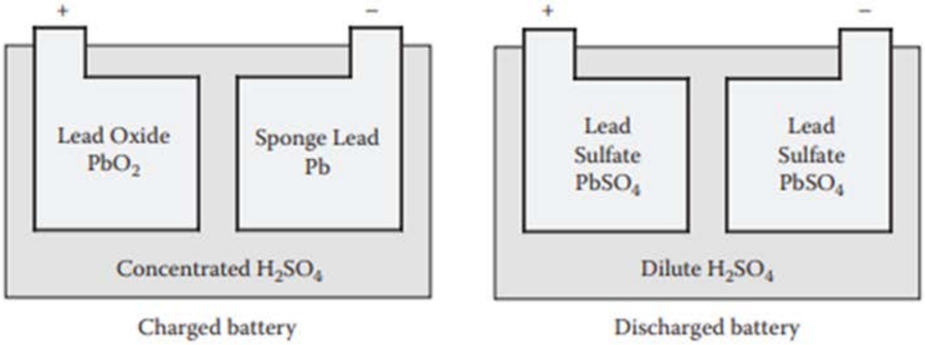

Figure 13.2 Represent the Lead-acid battery operation for charging and discharging modes.

Lead-acid batteries are chemically reversible. A discharged storage battery may be charged (by passing an electrical current through it in the opposite direction of discharge) and its active ions will be restored to a charged condition. The battery is now fully charged and ready to go. This discharge/charge cycle may be performed indefinitely until the plate or separator deteriorates or the battery fails due to another cause.

Charge Cycle

The chemical reactions that occur inside a battery during charge are almost identical to those that occur during discharge Both plates' sulphate ($PbSO_4$) is separated into its native forms of Pb and SO_4. Water is separated into H and O. Once the sulphate exits the plates, it reacts with the hydrogen to form sulfuric acid (H_2SO_4). At the same time, the oxygen reacts chemically with the positive plate's lead to generate lead dioxide (PbO_2). When sulfuric acid is generated and concentration rises during charge, the specific gravity of the electrolyte increases.

When a battery is charged, it produces gas. The negative plate emits hydrogen, whereas the positive plate emits oxygen. These gases are produced by the breakdown of H_2O. It employs water as a battery gas. In most cases, a battery will gas at the conclusion of a charge because the battery voltage is too fast for the almost charged battery. Much of this gassing is eliminated by a charger that automatically slows the state of charge as the battery near full charge. It is critical not to charge low-water-loss batteries at rates that cause them to gas for extended periods of time. A battery should never be overcharged for an extended length of time.

CHAPTER 14

BATTERY CYCLE LIFE

G. Ezhilarasan, Professor,
Department of Electrical and Electronics Engineering, Jain (Deemed to be University)
Bangalore, India
Email Id- g.ezhilarasan@jainuniversity.ac.in

The life of a battery is measured in cycles. A battery's cycle life is the number of lifetime cycles that may be anticipated from it at a given temperature, discharge rate, and depth of drain. Generally, the end of battery life occurs when the capacity of the battery falls 20% below its rated capacity. Battery lifespan increases with shallower depths of discharge and decreases with higher depths of discharge owing to increasing internal pressures caused by more full use of active components. As the temperature of the battery rises, so does its cycle life. Greater discharge rates improve available battery capacity but reduce battery life owing to deeper acid penetration into the plates—for example, 1,500 cycles at 40% DOD at 25°C for a 20 h discharge rate (C/20). show a life cycle curve for a battery.

Many reasons may contribute to decreased battery life: Exterior corrosion increases connection resistance, interior (grid) corrosion lowers the physical size of current-carrying grid wires (this occurs quicker in plate bottoms due to stratification), and excessive gassing causes electrolyte loss and plate breakage. The capacity of the battery may be lost if the electrolyte level dips below the top of the plates, preventing active components from interacting there. By washing out active compounds, violent gassing may physically harm the plates. With flooded lead-acid batteries, good system architects do not allow for more than 10-15% DOD.

Sulfation

When discharge, fine sulphate crystals develop. When huge lead sulphate crystals form on the plates instead of the tiny crystals that are typically present, this is referred to as sulfation. Larger crystals increase the cell's internal resistance, resulting in lower discharge and higher charge voltages, reducing voltage efficiency. A severely sulfated battery is difficult to recharge and might sustain irreversible damage owing to plate breakage caused by crystal development.

Sulfation happens when a totally or partly depleted battery is left unused for an extended length of time, when a battery functions at a partial state of charge for many days without receiving a finishing or equalising charge, or when battery temperature varies. Sulfation is driven in part by the increased solubility of lead sulphate at higher electrolyte temperatures. During high-temperature periods, little lead sulphate crystals melt and slowly recrystallize into massive crystals when the temperature is decreased. Changes in ambient temperature or heat produced during battery or discharge cause electrolyte temperature to cycle.

Battery Maintenance

Fill flooded lead-acid batteries with purified water (not to sealed batteries). Unless catalytic recombiner caps (e.g., Hydrocaps) are used to lessen the need for battery watering, the electrolyte level in flooded lead-acid batteries should be checked roughly once a month. If there is no level indication, only add water up to 0.5 inch (13 mm) over the separators. After the battery is completely charged, add water. If the battery is not totally charged, add less water (but evenly to all cells) and top up the water level when the battery is fully charged. The electrolyte level increases when a discharged battery charges. If too much water is given to a depleted battery, acid will bubble out of the top once completely charged (Lasnier and Gan Ang 1990).

The charge state of a battery may be assessed by measuring the specific gravity of the electrolyte using a hydrometer or refractometer. The state of charge of a sealed battery may be ascertained by monitoring the battery open-circuit voltage. Battery voltage should be measured at least an hour (preferably 24 hours) after the PV module has been unplugged (or after sundown). All loads should be turned off.

Charge equalisation should be performed on flooded lead-acid batteries on a regular basis (approximately once a month, depending on the battery) to bring all batteries up to 100% charge. An equalising charge is a protracted charge at the finishing rate or less (ended when specific gravity or voltage measurements remain consistent for around 3 hours). Overcharging the battery causes gassing, which avoids stratification of the electrolyte and consequent sulfation.

A thin layer of electrolyte may form on the battery's tops and neighbouring surfaces. This substance is conductive and may produce leakage currents to drain the battery, as well as a shock danger in high-voltage battery banks. The released sulfuric acid should be rinsed away on a regular basis using a neutralising solution. A weak solution of baking soda (sodium bicarbonate) and water works well for lead-acid batteries. With nickel-cadmium batteries, a moderate vinegar solution works nicely. Automotive and battery supply businesses provide anticorrosion sprays and greases that lessen the need to maintain the battery bank.

Hydrometer Description and Use

The specific gravity of the electrolyte determines the state of charge of a lead-acid battery (its weight compared to water). The specific gravity may be calculated using the stabilised voltage or measured directly using a hydrometer. A hydrometer is a syringe with a bulb that extracts electrolyte from the cell. In the hydrometer barrel, a glass float is calibrated to read in terms of specific gravity. The usual specific gravity range for these floats is 1.160-1.325. The lower the specific gravity, the lower the float sinks in the electrolyte. The barrel must be held vertically to avoid the float scraping against the side. A little quantity of acid is poured into the barrel so that, with the bulb completely blown, the float will be pulled free and not contact the barrel's side, top, or bottom stopper.

One's gaze should be level with the liquid's surface in the hydrometer barrel. The curvature of the liquid, where the surface rises against the float stem and the barrel owing to surface tension, may be ignored. typical specific gravity values for a lead-acid battery at different charge phases. A fully charged specific gravity of 1.265 is assumed, adjusted to 80°F (26.7°C) (Battery Council International 1987).

All of the sulphate in acid is present in a fully charged battery. Some of the sulphate starts to develop on the plates as the battery drains. When more water replaces sulfuric acid, the acid gets more dilute and its specific gravity falls. The plates of a completely depleted battery contain more sulphate than the electrolyte. Please keep in mind that when the specific gravity decreases, the hydrometer float falls deeper in the electrolyte. A hydrometer measurement should never be taken just after adding water to the cell. The water and underlying electrolyte must be well combined.

Battery Acid

While dealing with acid, such as filling batteries, a face shield, gloves, and protective clothes should be used. Spilling or splashing electrolyte (dilute sulfuric acid) is very dangerous since it may ruin garments and burn the skin. While handling a plastic-cased battery, excessive pressure on the end walls may cause electrolyte to spill from the vents. As a result, a battery carrier or hands located at opposing corners should be utilised to raise these batteries. If electrolyte is spilled or sprayed on clothes or the body, it should be quickly neutralised and washed with clean water. As a neutralizer, a baking soda and water solution may be employed.

Splashing electrolyte into the eyes is quite harmful. If this occurs, the eye should be pushed open and filled with clean water for around 15 minutes. When an accident happens, a doctor should be summoned promptly and, if feasible, emergency medical assistance should be provided. Unless prescribed by a doctor, no eye drops or other prescription should be used. If an acid (electrolyte) is taken orally, it should be followed by a substantial amount of water or milk, followed by milk of magnesia, beaten egg, or vegetable oil.

If a specific gravity electrolyte is required, the concentrated acid should always be placed gently into the water; water should never be thrown into acid. When acid and water combine, heat is produced. Little quantities of acid should be gradually added while stirring.If the mixture becomes noticeably hot, it should be allowed to cool. Nonmetallic receptacles and/or funnels should be used instead of lead or lead-lined containers. Acid should not be kept in places that are too hot or in direct sunlight.

Hydrogen Gas

During regular battery functioning, oxygen and hydrogen gases are created. When flooded, nonsealed lead-acid batteries are charged quickly or when the terminal voltage hits about 2.4 V per cell, the batteries emit hydrogen gas. These gases escape via the battery vents and, if ventilation is inadequate, may generate an explosive environment surrounding the battery. Explosive gases may be present in and around the battery for many hours after charging. Under some situations, even sealed batteries may leak hydrogen gas. This gas is explosive if it is trapped and not properly ventilated. The quantity of gas produced is determined by the battery temperature, voltage, charging current, and battery bank size. Compact battery banks (one to eight 220 Ah, 6 V batteries) in a big room or well-ventilated area offer no substantial risk. Venting manifolds may be fitted to each cell and directed to the outside.

While flame barrier vent caps are meant to prevent external ignition sources from igniting gases inside the battery, it is still preferable to keep sparks, flames, or other ignition sources far away from the battery. Anybody in the area of the battery when it bursts may get injuries, including eye injuries from flying case or cover parts or acid ejected from the battery.

Each cell may have a catalytic recombiner cap (e.g., Hydrocap) connected to it to recombine part of the hydrogen in the air with oxygen to make water. If these combiner caps are utilised, they will still need maintenance on a regular basis. If hydrogen gas is still an issue, the batteries may be housed in a battery box with exterior venting. Forced ventilation is almost never required.

Some charge controllers are intended to reduce hydrogen gas production by preventing the battery voltage from rising into the vigorous gassing area, where the large volume of gas causes electrolyte to bubble out of the cells. Lead-acid batteries, on the other hand, need frequent overcharging to equalise the cells. This causes gassing, which should be dissipated.

Charge controllers, switches, relays, or other equipment capable of creating an electric spark should never be installed in a battery enclosure or immediately above a battery bank. When running conduit from a sealed battery box to a disconnect, extreme caution is required. Hydrogen gas may pass via the conduit to the switch's arcing contacts.

Since batteries emit explosive gases, sparks, metallic objects, flames, burning cigarettes, and other sources of ignition should be maintained at a safe distance at all times. While dealing with batteries, safety goggles and a face shield should always be used.
