Solar Photovoltaic System Design

Pooja Sharma
Assistant Professor, Dept. of Electrical Engineering, New Era College of Science & Technology
Uttar Pradesh, India
e-mail: poojasharma114@gmail.com

Vaibhav Gupta
Assistant Professor, Dept. of Electrical Engineering, New Era College of Science & Technology
Uttar Pradesh, India
e-mail: vaibhavgupta786@hotmail.com

Abstract*— The history of solar cell development is briefly outlined, and the properties of the sun and solar radiation are reviewed. Properties of semiconductor materials that are important in the design and operation of solar cells are reviewed. The physical mechanisms involved in the generation and recombination of excess carriers are discussed and the basic equations of device physics are given. Both the dark and illuminated properties of p-n junctions are analyzed. Energy conversion efficiency limits are discussed for the photovoltaic process as well as the effects of various nonidealities on efficiency. Techniques for measuring the efficiency of photovoltaic devices are also described. The standard technology for making silicon solar cells is reviewed, and improved silicon cell technology is discussed. Considerations relevant to the detailed design of silicon cells are discussed. Several alternative device concepts are outlined and the structure and properties of solar cells made on some of the more developed alternatives to single-crystal silicon are discussed. Concentrating systems and photovoltaic systems components and applications are described. The design of stand-alone, residential, and centralized photovoltaic power systems is discussed. Solar photovoltaic modules are where the electricity gets generated but are only one of the many parts in a complete photovoltaic (PV) system. In order for the generated electricity to be useful in a home or business, a number of other technologies must be in place [1].*

I. Introduction

Photovoltaics offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from " photo," meaning light, and " voltaic," which refers to producing electricity. Therefore, the photovoltaic process is " producing electricity directly from sunlight." Photovoltaics are often referred to as PV. PV systems are being installed by Texans who already have grid-supplied electricity but want to begin to live more independently or who are concerned about the environment. For some applications where, small amounts of electricity are required, like emergency call boxes, PV systems are often cost justified even when grid electricity is not very far away. When applications require larger amounts of electricity and are located away from existing power lines, photovoltaic systems can in many cases offer the least expensive, most viable option. In use today on street lights, gate openers and other low power tasks, photovoltaics are gaining popularity in Texas and around the world as their price declines and efficiency increases.

1.Availability of Solar Radiation:

II. Availability of Solar Radiation

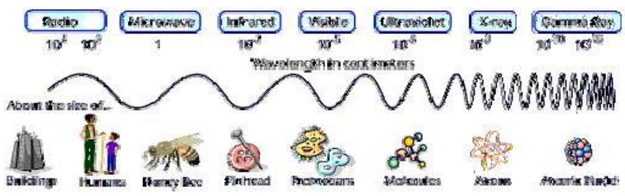
A. The Sun

- Medium sized, yellow star
- Distance: (149.7 million km) 149,680,000 km or 1 Astronomical Unit (AU)
- Rotates on its axis once in 4 weeks (27-30 days)
- Radius: 0.7 million km
- Mass: 2 x 1030 kg
- Density: 100 times of water
- temperature 8-40 million °C
- Equivalent Blackbody Temperature: 5777 K
- Energy radiated from sun's surface = 3.8 x 1023 kW
- Thermal radiation with wavelength from zero to infinity
- Visible spectrum 0.38 – 0.78 microns
- Solar radiation spectrum of our interest 0.3 – 3.0 microns

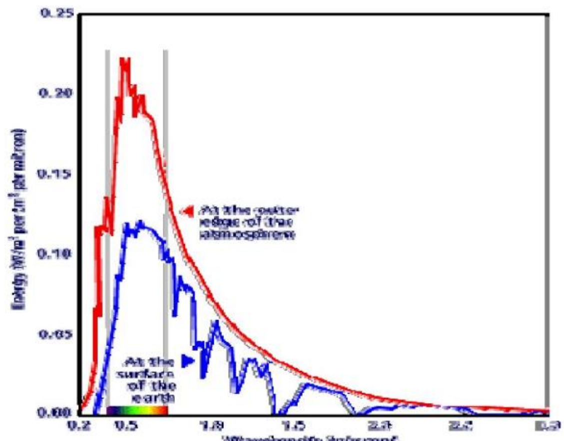
B. Structure of the Sun

Energy produced at the interior of the sun is transferred to outer surface by convection and radiation processes. Core is in the x-ray and gamma ray spectrum, with the wavelengths of the radiation increasing as the temperature drops at large radial distances.

C. Electromagnetic Spectrum



D. Solar Radiation Spectrum

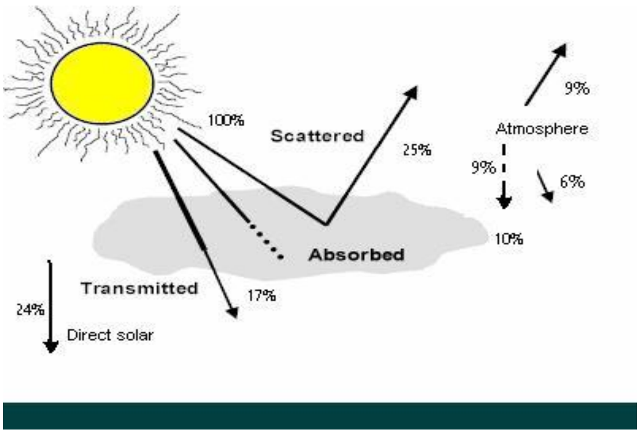


E. Spectral distribution of Solar Radiation

	UV	*Visible*	*IR*
Wavelength	*0 – 0.38*	*0.38 – 0.78*	*0.78 – ∞*
Fraction in range	*0.07*	*0.4729*	*0.4571*
Energy (W/m2)	*95*	*640*	*618*
Energy (%)	*7*	*47*	*46*

.

III. MEASUREMENT OF SOLAR RADIATION



The visible channel is in the region of the electromagnetic spectrum where the sun emits most of its energy. The radiation received outside the atmosphere of earth is called extra-terrestrial radiation. The extra-terrestrial radiation on top of the earth's surface depends on many factors such as the distance, orientation, etc. As the earth makes an elliptical orbit round the sun, there is approximately a 3% variation in the amount of solar radiation received on top of the earth's atmosphere throughout the year. Not entire extra-terrestrial radiation reaches the surface of the earth. The earth's atmosphere attenuates the radiation. That incoming energy is attenuated by molecules, clouds, and aerosols. Therefore, the extra-terrestrial radiation on top of the earth's atmosphere could be used as a reference for various calculations. About 53% of the incoming energy is either reflected or absorbed by the atmosphere and re-emitted to space. The remaining energy (about 47%) reaches the earth' s surface where it is either absorbed or reflected.

Various solar radiation instruments listed below:

- Campbell-Stokes Sunshine Recorder:
- Pyranometer:
- Shaded Pyranometer:
- Pyrheliometer:
- Pyrgeometer:
- Albedometer

A. Estimation of Solar Radiation

Extra-terrestrial solar radiation (ETR) falling on a surface normal to the sun's rays at 1 AU (mean sun earth distance) is given by solar constant (Gsc). For other times when the sun earth distance is not equal to 1 AU, the intensity of sun's radiation on top of the earth's surface depends on the day and the intensity of the extra-terrestrial solar radiation on a surface normal to the sun's rays on any day is given by the following equation [2]:

$$G_n = G_{sc} \{1 + 0.033 \cos (360n/365)\} (\text{in W/m2})$$

To calculate the ETR falling on a horizontal surface, the zenith angle has to be considered as:

$$G_h = G_n \cos(\theta z) \ (\text{in W/m2})$$

The above two equations give the instantaneous values (W/m2) of the radiation. However, these values are not always sufficient, and we usually require values on different time scales. The calculation of the ETR falling on a horizontal surface at different time scales, hourly, daily and any time scale.

B. PV Stand-alone System Design

- Load estimation
- Radiation Estimation
- Module sizing
- Battery sizing

C. Load estimation

The AC and DC loads are estimated separately. They may vary from day-to-day and hence in such cases, weekly averaged load estimated are prepared.

- DC load Demand= DC load current (amps) x Hours of operation
- AC load demand= AC load Power (watts) x Hours of operation
- Daily load (Ah)= DC load + (AC total / efficiency / input DC voltage)

IV. INVERTER SELECTION

The inverter should meet all continuous loads at a given time and meet surge demands also. To avoid unreasonably high surge demands, assume 4-6 times of inductive load currents. The other features need to be considered during inverter selection include – efficiency, output waveform, voltage or frequency regulation, etc. An inverter with a higher DC input voltage is preferred since this reduces the size of other components like wires, etc. Hence, DC Amp Hours input to inverter is calculated as follows

AC Load (Ah)= AC subtotal (Wh) / (Efficiency * Input DC voltage)

DC Watt Hours into inverter = AC subtotal (Wh) / efficiency

DC Amp Hours into inverter = DC Watt Hours into inverter / DC Input Voltage of Inverter

A. Battery Sizing

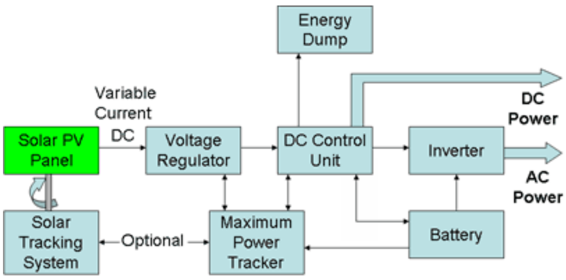
Use an average of 5 and 10 days for non-critical and critical applications as an autonomy. 50% and 80% loads can be discharged from a shallow and deep discharge battery. Correct the battery capacity for temperature and rate of discharge.

B. Array Sizing

Since the effect of temperature is offset by using Imp values rather than values in sizing, de-rate the modules by 10% to account for dust. Further an increase in capacity of 5-10% is needed to accommodate the battery Coulombic efficiency.

C. HOW IT WORKS

PV cells convert sunlight directly into electricity without creating any air or water pollution. PV cells are made of at least two layers of semiconductor material. One layer has a positive charge, the other negative. When light enters the cell, some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell’ s negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current. To increase their utility, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs, no matter how large or small.



Photovoltaic Electric Power Generation

Efficiency Improvements

Charge Controller

Basic functions of a controller:

Block reverse current

Prevent battery over-charge

Prevent battery over-discharge

Protect from electrical overload

Display battery status and the flow of power

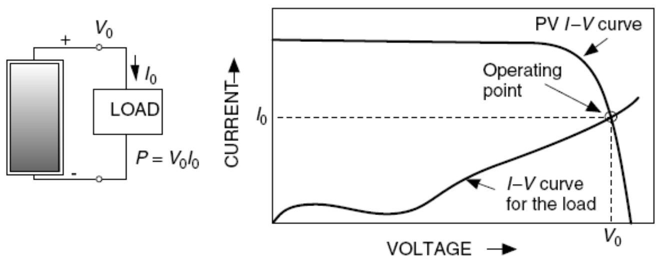
Generally small arrays do not need a C/c

Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called on/off control. Others reduce the current gradually, called pulse width modulation (PWM)

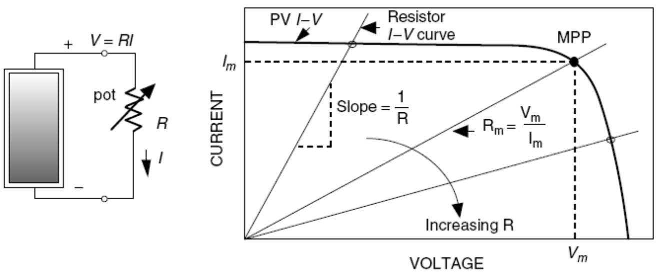
- PWM controller holds the voltage more constant
- If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then it will drop the voltage lower to sustain a “ finish” or “ trickle” charge
- Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy). It maintains a full charge but minimizes water loss and stress
- The voltages at which the controller changes the charge rate are called set points
- Ideal set points for charge control vary with battery temperature. Some controllers have a temperature sensor built in.
- Control set points vary with battery type also
- Has low voltage disconnects (LVD) to make sure that the DoD is maintained – disconnects the load
- Reconnect voltage – connects the load only when the battery voltage has recovered due to some substantial charging (say 13V)
- A circuit is overloaded when the current flowing in it is higher than it can safely handle. This can cause overheating and can even be a fire hazard. Overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance (like a frozen water pump). Some charge controllers have overload protection built in, usually with a push-button reset.

D. Operating point

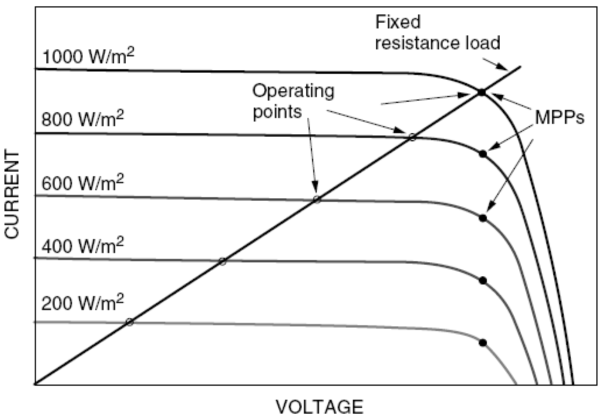
The operating point is the intersection of the current– voltage curves for the load and the PV



E. Module supplying power to a Resistive load

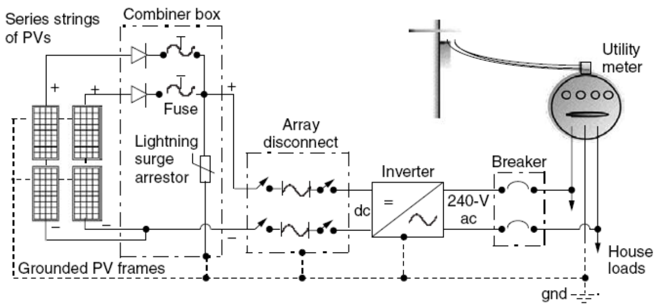


- As resistance changes, the operating point moves around on the I – V curve



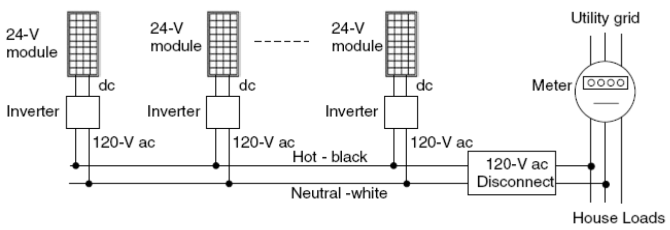
- The efficiency of a PV module with a fixed resistance load designed for 1-sun conditions will decline with changing insolation
- The solid maximum power point (MPP) dots show the operating points that would result in maximum PV efficiency.

V. GRID-CONNECTED SYSTEMS

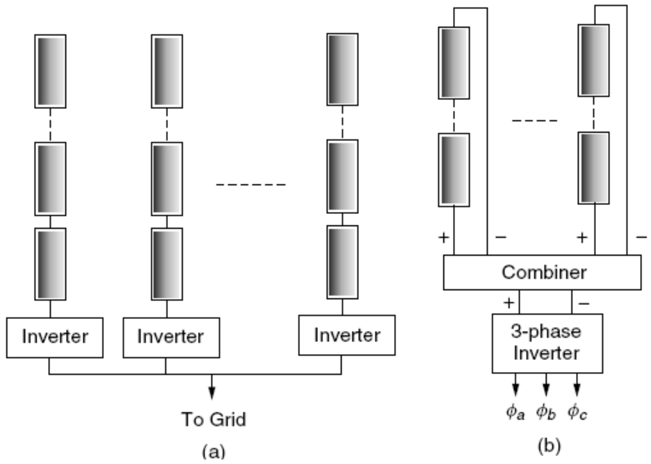


- Principal components in a grid-connected PV system using a single inverter

A. AC Modules

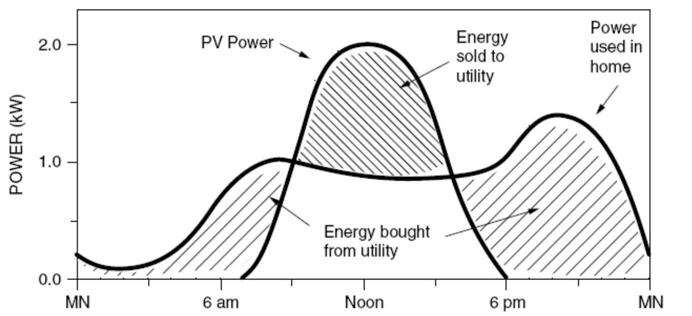


- AC modules each have their own inverters mounted on the backside of the collector, allowing simple system expansion at any time



- Large grid-connected systems may use an individual inverter for each string (a) or may incorporate a large, central inverter system to provide three-phase power (b)

Net Metering

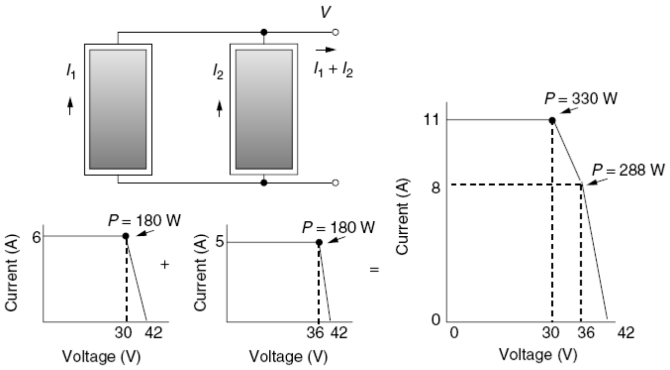


- During the day, excess power from the array is sold to the utility; at night, the deficit is purchased from the utility - a single electric meter runs in both directions.

B. Islanding

- The power conditioning unit (PCU) absolutely must be designed to quickly and automatically drop the PV system from the grid in the event of a utility power outage
- When there is an outage, breakers automatically isolate a section of the utility lines in which the fault has occurred, creating what is referred to as an " island."
- A number of very serious problems may occur if, during such an outage, a self-generator, such as a grid-connected PV system, supplies power to that island.

C. Module Mismatch

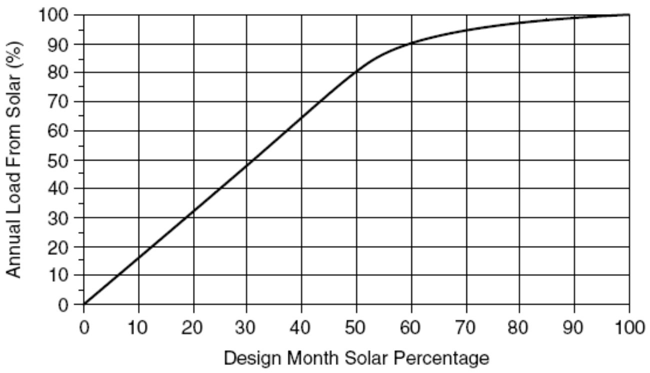


Each module is rated at 180 W, but the parallel combination yields only 330 W at the maximum power point.

D. Hybrid PV Systems

PV system designed to supply the entire load in the worst month (the “ design month”) usually delivers much more energy than is needed during the rest of the year

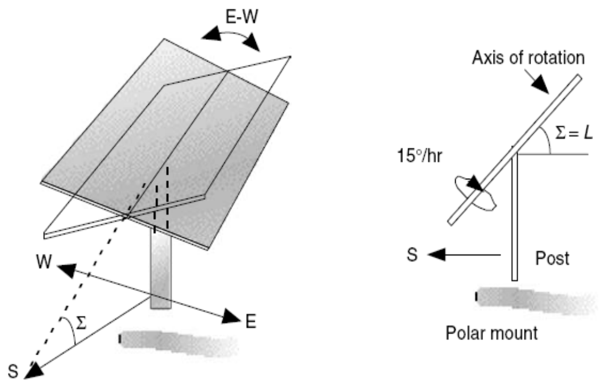
Outside of the tropics, it is not at all unusual for the energy supplied during the best month to be nearly double that of the design month



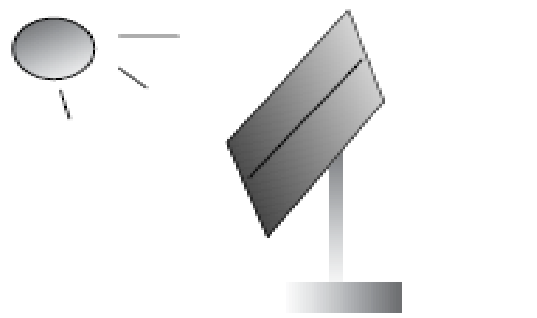
- Significant reductions in the size of the solar system may still cover a high fraction of the annual load
- PV system designed to deliver only 50% of the load in the design month will still cover about 80% of the annual load
- When a generator is included in the system, the most versatile inverter is an inverter-charger capable of converting dc from the batteries into ac for the load, as well as converting ac from the generator into dc to charge the batteries
- Switching from one mode to the other can be done manually or with an automatic transfer switch in the unit itself
- The generator can be sized just to charge the batteries, which is the usual case, or it can be sized large enough to charge batteries and simultaneously run the entire household.
- The battery storage bank can be smaller since the generator can charge the batteries during prolonged periods of poor weather
- One constraint on how small storage can be is to check to be sure that the load can’ t discharge the batteries at too fast a rate—certainly no faster than C/5
- The generator should be sized so that it doesn’ t charge the batteries too rapidly—again, certainly no faster than C/5
- A nominal 3-day storage system (autonomy) is often recommended since it will avoid discharging too rapidly, while at the same time keeping the number of times the generator has to be fired up to a reasonable level.

E. Tracking Systems

- Two-axis trackers, which track the sun both in azimuth and altitude angles so the collectors are always pointing directly at the sun
- Single-axis trackers, which track only one angle or the other



- Single-axis tracking for photovoltaics is almost always done with a mount having a manually adjustable tilt angle along a north-south axis, and a tracking mechanism that rotates the collector array from east-to-west
- Polar mount: When the tilt angle of the mount is set equal to the local latitude



Polar mount, 1-axis tracker

Acknowledgment

Solar power is an immense source of directly useable energy and ultimately creates other energy resources: biomass, wind, hydropower and wave energy. Most of the Earth's surface receives sufficient solar energy to permit low-grade heating of water and buildings, although there are large variations with latitude and season. At low latitudes, simple mirror devices can concentrate solar energy sufficiently for cooking and even for driving steam turbines. The energy of light shifts electrons in some semiconducting materials. This photovoltaic effect is capable of large-scale electricity generation. However, the present low efficiency of solar PV cells demands very large areas to supply electricity demands. Direct use of solar energy is the only renewable means capable of ultimately supplanting current global energy supply from non-renewable sources, but at the expense of a land area of at least half a million km.

REFERENCES

[1] *MA Green - 1982 - osti.gov.*

[2] *ME2005 Solar Photovoltaic System Design R. Nicole,*