Solar Energy

Resource Assessment Handbook

Prepared for

APCTT

**Asian and Pacific Centre for Transfer of Technology
Of the United Nations – Economic and Social
Commission for Asia and the Pacific (ESCAP)**

By

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September 2009

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AC	Alternating Current
CPV	Concentrated Solar Photovoltaics
DC	Direct Current
KW	Kilo Watt
kWh	Kilo Watt hour
kWp	Kilo Watt peak
kV	Kilo Volt
MWh	Mega Watt hour
MWp	Mega Watt Peak
NASA	National Aeronautics and Space Administration
PCU	Power Conditioning Unit
PV	Photovoltaic
RE	Renewable Energy
RES	Renewable Energy Sources
RFQ	Request for Quotation
SPV	Solar Photovoltaic
Wp	Watt Peak

CHAPTER 1
INTRODUCTION

World population is expected to double by the middle of the 21st century (Global Energy, 1998). This will consequently result in a 3-5 fold increase in world economic output by the year 2050, and a 10-15 fold increase by the year 2100. Consequently, Primary energy requirements are expected to increase by approximately three folds by the year 2050 and five folds by the year 2100. This is expected to exert tremendous pressure on primary energy supplier.

Energy has an established positive correlation with economic growth. Providing adequate, affordable and clean energy is a prerequisite for eradicating poverty and improving productivity. The inevitable increase in the use of fossil fuels alongside a country's economic growth presents associated side effects of threat to the nation's energy security, as well as environmental degradation through climate change. A feasible alternative to the indiscriminate burning of fossil fuels lies in the accelerated use of renewable energy. In tropical countries, which have sunshine almost throughout the year in most parts, solar energy is one of the most viable options.

Energy from the sun has been used to provide electricity for many years. This form of renewable energy occupies less space compared to the space occupied by hydropower projects. Developing countries can cover all their demands for energy by solar systems with 0.1% of the land area.

Table 1 in the following page provides a comparison of various non-renewable and renewable energy sources in terms of consequences and damage to the environment.

Table 1: Environmental consequences of various energy sources (Source: Conclusions of the research projects at the Nordic Council of Ministers 1986)

	Air Pollution		Water/ Sea	Fauna	Vegetat ion	Area	Aestheti c	Comments
	Global/ Region al	Local						
Coal								
Oil								
Peat								
Household waste								
Hydropower								
Wind Power								Sound/noise
Forest energy tree-stumps								
Energy forest arable land								
Forest energy residues								
Straw								
Energy crops arable land								
Solar heat								
Solar electricity								In production HF, PH_3, etc
Energy efficiency								

	Minor or no environmental consequences	The table shows a comparison of the environmental consequences of various energy sources. Environmental consequences include production, extraction, distribution, and consumption
	Some environmental consequences	
	Major environmental consequences	

1.1. Principle of Operation of Solar Energy

Solar energy is available in abundance in most parts of the world. The amount of solar energy incident on the earth's surface is approximately1.5 x 10^{18} kWh/year, which is about 10,000 times the current annual energy consumption of the entire world. The density of power radiated from the sun (referred to as **solar energy constant**) is 1.373 kW/m^2.

Solar cell is a device which converts photons in Solar rays to direct-current (DC) and voltage. The associated technology is called Solar Photovoltaic (SPV). A typical silicon PV cell is a thin wafer consisting of a very thin layer of phosphorous-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact (the P-N junction).

When the sunlight hits the semiconductor surface, an electron springs up and is attracted towards the N-type semiconductor material. This will cause more negatives in the n-type and more positives in the P-type semiconductors, generating a higher flow of electricity. This is known as **Photovoltaic effect**. Figure 1 below shows the working mechanism of a silicon solar cell.

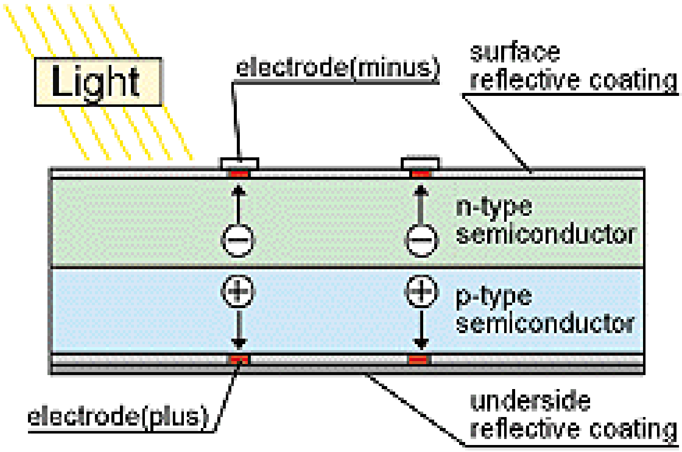


Figure 1: Silicon Solar Cell and its working mechanism (Source: global.kyocera.com)

The amount of current generated by a PV cell depends on its efficiency, its size (surface area) and the intensity of sunlight striking the surface. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of about 25 square inches will produce about 2 watts peak power.

1.2. Governing principles of Solar Energy

1.2.1. Solar Irradiance

The Sun is the fundamental driving force for energy in the Earth's climate system. It is of crucial importance to understand fully the conditions of its arrival at the top of the atmosphere and its transformation through the earth. The amount of solar power available per unit area is known as **irradiance**. Irradiance is a radiometric term for the power of electromagnetic radiation at a surface, per unit area. It is used when the electromagnetic radiation is incident on the surface.

Irradiance fluctuates according to the weather and the sun's location in the sky. This location constantly changes through the day due to changes in both the sun's altitude (or elevation) angle and its azimuth (or compass) angle. Figure 2 below shows the two angles (the sun's elevation angle and the sun's compass angle) used to specify the sun's location in the sky.

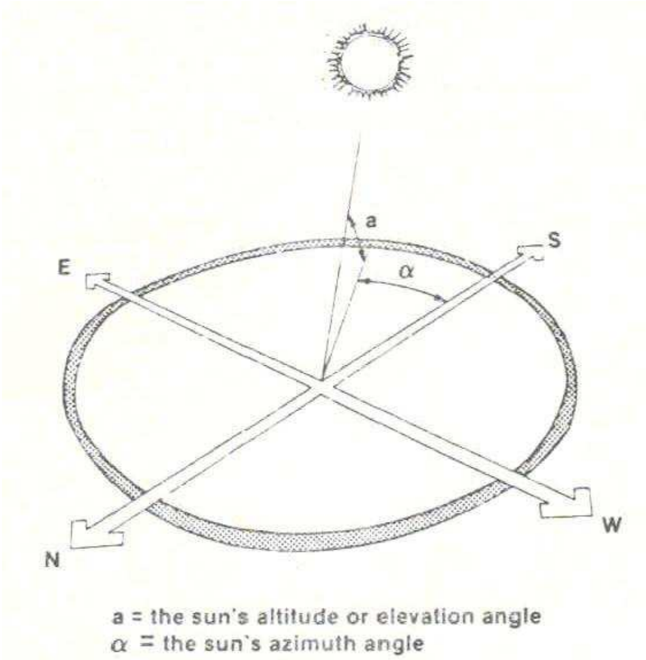


Figure 2: Sun's location in the sky (Source: Photovoltaic system design course manual)

1.2.2. Solar Constant

The solar constant is the amount of incoming solar electromagnetic radiation per unit area, measured on the outer surface of Earth's atmosphere on a plane perpendicular to the rays. The solar constant includes all types of solar radiation, not just the visible light. It is estimated to be roughly 1,366 watts per square meter (W/m^2) according to satellite measurements, though this fluctuates by about 6.9 % during a year (from 1,412 W/m^2 in early January to 1,321 W/m^2 in early July) due to Earth's varying distance from the Sun. For the entire planet (Earth has a cross section of 127,400,000 km^2), the power is (1366 W/m^2 x 1.274×10^{14} m^2) 1.740×10^{17} W, plus or minus 3.5 %. The solar constant does not remain constant over long periods of time. The average value cited, 1,366 W/m^2, is equivalent to 1.96 calories per minute per square centimeter, or 1.96 langleys (Ly) per minute. Figure 3 below shows solar insolation level on the world map.

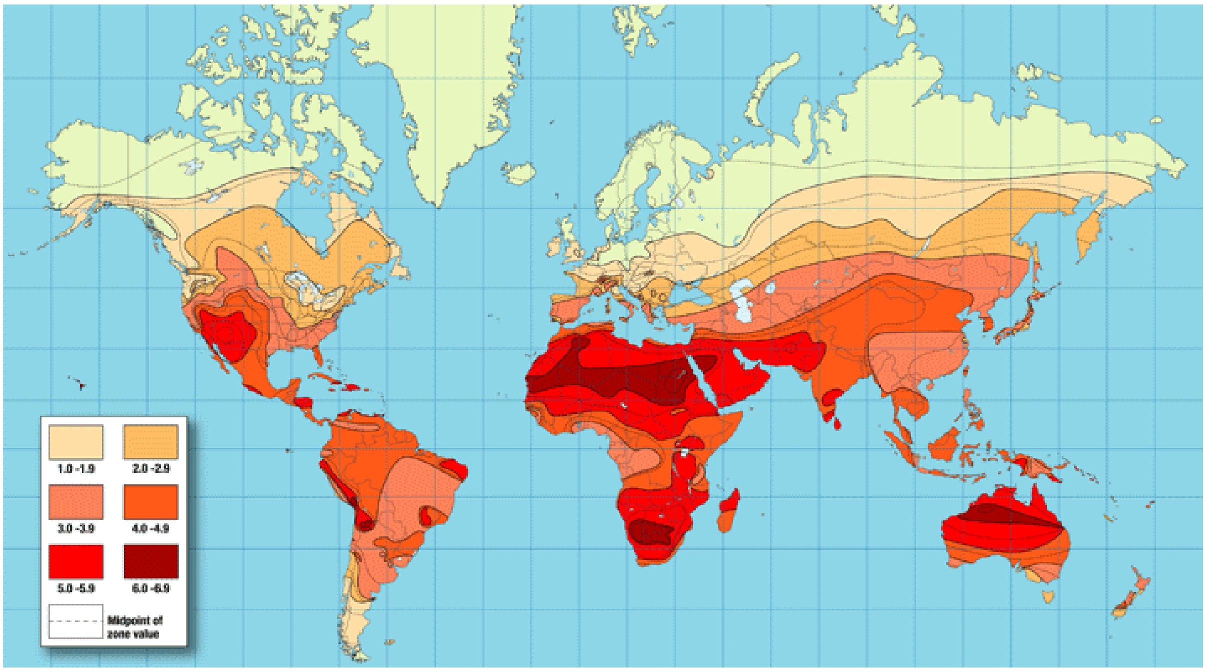


Figure 3: The map shows the amount of solar energy in hours, received each day on an optimally tilted surface during the worst month of the year. (Based on accumulated worldwide solar insolation data). Source: www.altestore.com

1.2.3. Solar Window

The solar window represents the effective area through which useful levels of sunlight pass throughout the year for a specific location. It is used to determine potential shading problems when designing a photovoltaic system as illustrated in Figure 4.

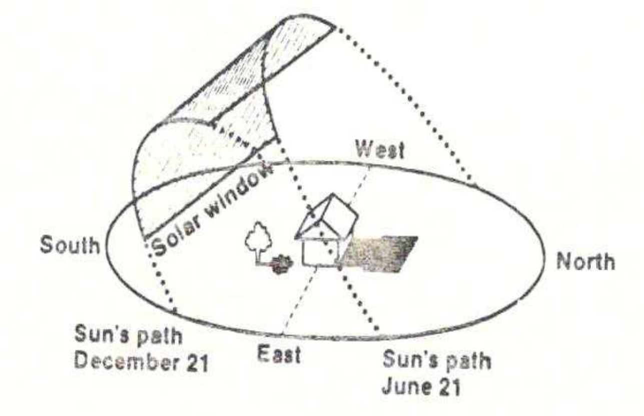


Figure 4: Solar Window (Source: Photovoltaic system design course manual)

1.2.4. Solar Spectrum

The sun radiates power over a continuous band or spectrum of electromagnetic wavelengths. The power levels of the various wavelengths in the solar spectrum are not the same.

Ultraviolet, Visible and Infrared Radiation

The sun’s total energy is composed of 7% ultraviolet radiation, 47% visible radiation and 46% infrared (heat) radiation. Ultraviolet (UV) radiation causes many materials to degrade and is significantly filtered out by the layer of Ozone in the upper atmosphere.

Photovoltaic cells primarily use visible radiation. The distribution of colours within light is important, because, a photovoltaic cell will produce different amounts of current depending on the various colours reflecting on it.

Figure 5 illustrates the relative amounts of power in the various wavelengths of the solar spectrum.

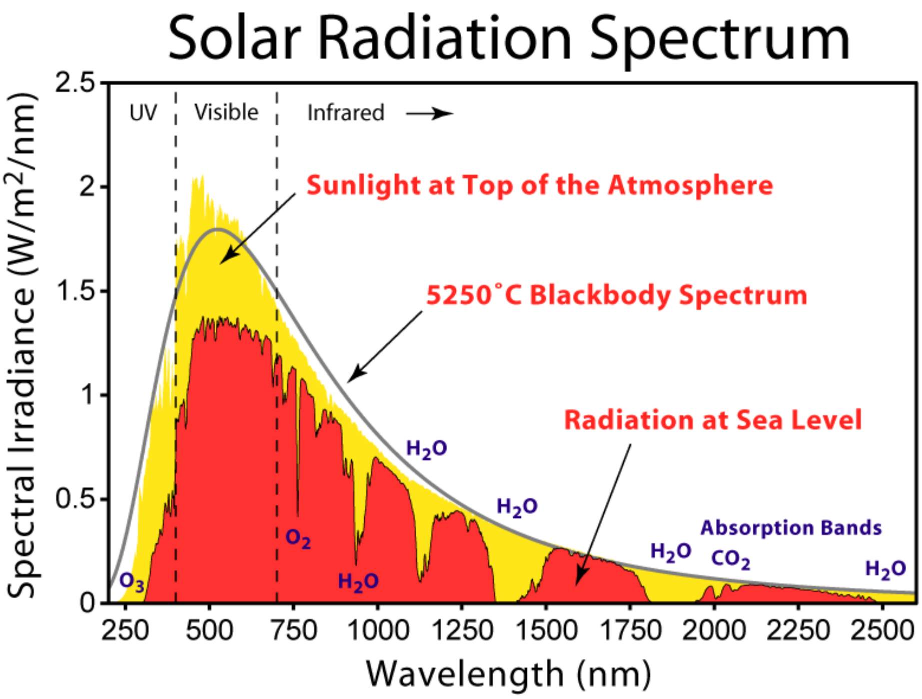


Figure 5: Solar Spectrum (Source: www.juliantrubin.com)

Infrared radiation contributes to the production of electricity from crystalline silicon and some other materials. In most cases, however, infrared radiation is not as important as the visible portion of the solar spectrum.

1.2.5. Solar Insolation

The results of the earth's motion and atmospheric effects at various locations have led to essentially two types of solar insolation data. These are daily and hourly.

Solar irradiance is related to *power per unit area* where as solar insolation is related to *radiant energy per unit area*. Solar insolation is determined by summing solar irradiance over time, and is usually expressed in units of kWh/m^2 /day.

Average Daily Solar Radiation

To provide long-term average daily solar radiation data, an average of daily solar radiation is calculated for each month over a period of typically 30 years. This data is useful both in predicting long-term performance and in analyzing the economics of solar energy systems. The actual average daily solar radiation for a given month may vary significantly from the long-term average for that month.

Peak Sun Hours

The number of peak sun hours per day at a given location is the equivalent number of hours at peak sun conditions (i.e., at 1 kW/m^2) that produces the same total insolation as actual sun conditions. Figure 6 below shows how Peak Sun Hours is determined by constructing a graph having the same area as that for the actual irradiance versus time.

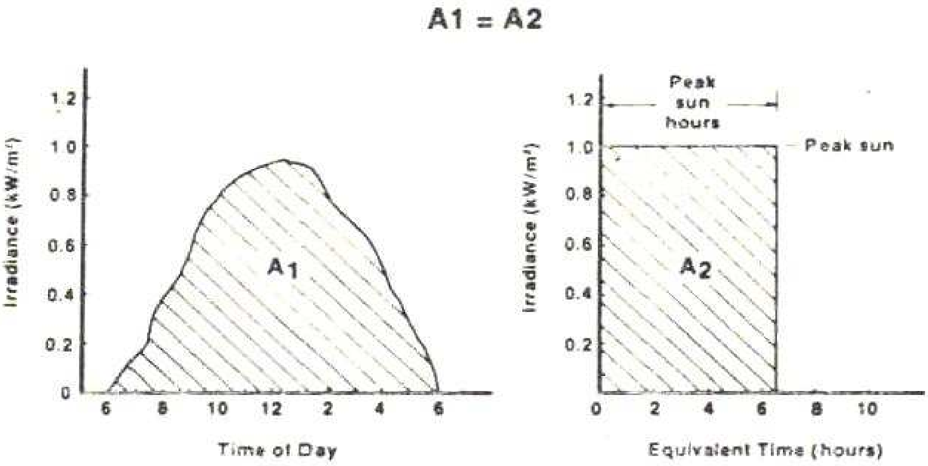


Figure 6: Peak sun hours (Source: Photovoltaic system design course manual)

Hourly Solar Radiation data for each month of a typical year

Typical Meteorological Year (TMY) data is the result of statistical analysis of SOLMET (Solar and Meteorological) rehabilitated weather data for past years. The TMY consists of a selection of each of the twelve months, so that it best represents the average of that particular month over past years. The TMY is, therefore, a composite year with representative months selected from different years.

For Example, Consider a representative month as January. Every January month of past years is compared with the average of all years (January month) and the one closest to the average is considered. The selection is weighted 50% on solar radiation and 25% each on ambient temperature and wind speed. TMY data is useful for photovoltaic system analysis.

1.2.6. Direct and Diffuse Solar Radiation

Sunlight coming from the sun is reduced by about 30% before it reaches the earth due to

- Scattering by atmospheric particles
- Scattering by aerosol, dust particles etc.
- Absorption by atmospheric gases

It is common to consider separately the ‘direct’ (or beam) radiation coming from solar disk and the ‘diffuse’ radiation from elsewhere in the sky with their sum known as ‘global’ radiation.

The component of the radiation coming from all direction in the sky is diffused.

When the sun is directly overhead, it has diffuse component of about 10% when skies are clear. Percentage increases with increased Air Mass.

1.3. Advantages and Limitations of Solar Energy

Renewable energy sources in general, and Solar Energy source in particular, has the potential to provide energy services with zero or almost zero emission. The solar energy is abundant and no other source in renewable energy is like solar energy. Every technology has its own advantages and disadvantages. As the solar insolation and atmospheric conditions vary significantly from place to place, efficiency of solar energy also differs accordingly.

Advantages

- It is an abundant Renewable Energy
- This technology is Omnipresent and it can be captured for conversion on a daily basis
- It is a Non-polluting technology, which means that it does not release green house gases
- It is a Noiseless technology as there are no moving parts involved in energy generation
- This technology requires Low-maintenance because of lack of moving parts
- It can be installed on modular basis and expanded over a period of time
- Most viable alternative for providing electricity in remote rural areas as it can be installed where the energy demand is high and can be expanded on modular basis.

Limitations

- As the technology is in an *evolving stage*, the efficiency levels of conversion from light to electricity is in the range of 10 to 17%, depending on the technology used.
- The initial investment cost of this technology is high. At present the technology is basically surviving because of subsidy schemes available by the government.
- Solar energy is available only during daytime. Most load profiles indicate peak load in the evening/night time. This necessitates *expensive storage devices* like battery, which need to be replaced every 3 to 5 years. Generally, the cost of the Battery is 30 to 40% of the system cost.
- As the efficiency levels are low, the space required is relatively high. For instance, with the existing levels of technologies, the land required for putting up a 1 MW solar PV power plant is between 6 to 9 acres. However, research is going on to increase the efficiency levels of the cell.
- Solar energy is heavily dependent on atmospheric conditions.
- Solar insolation varies from location to location, so there are certain *geographic limitations* in generating solar power.

- With the existing module and inverter manufacturing technologies, it may not be worthwhile in terms of costs to deploy solar energy for certain loads which require very high starting power (e.g. air conditioners).

1.4. Solar Receiver Technologies

The types of receivers used for collecting solar energy are classified as follows:

1.4.1. Flat Plate Arrays

Flat plate arrays use both diffused and direct sunlight. They can operate in either fixed orientation or in a sun-tracking mode. For most applications, flat plate arrays are in fixed orientation. However, with the advent of low-cost passive sun-trackers, flat plate tracking arrays are becoming more popular. Figure 7 below depicts a flat plate collector.

Figure 7: Flat plate collector

1.4.2. Tracking Arrays

In this case, Solar array follows the path of the sun and maximizes the solar radiation incident on the photovoltaic surface. The two most common orientations are:

- One-axis tracking: In this tracking mechanism, the array tracks the sun east to west. It is used mostly with flat-plate systems and occasionally with concentrator systems.
- Two-axis tracking: In this tracking mechanism, the array points directly at the sun at all time. It is used primarily with PV concentrator systems

Figure 8 below depicts a pole mounted tracking solar array

Figure 8: Pole mounted tracking array

A compromise between fixed and tracking arrays is the adjustable tilt array, where the array tilt angle is adjusted periodically (usually seasonally) to increase its output. This is mostly done manually.

1.4.3. Concentrator Arrays

Concentrator arrays use optical lenses and mirrors to focus sunlight onto high-efficiency cells. Figure 9 below shows three forms of concentrator devices. The major advantage of concentrating device is that they use relatively small areas of expensive photovoltaic material. The larger aperture areas are made up of less expensive plastic lenses or other materials.

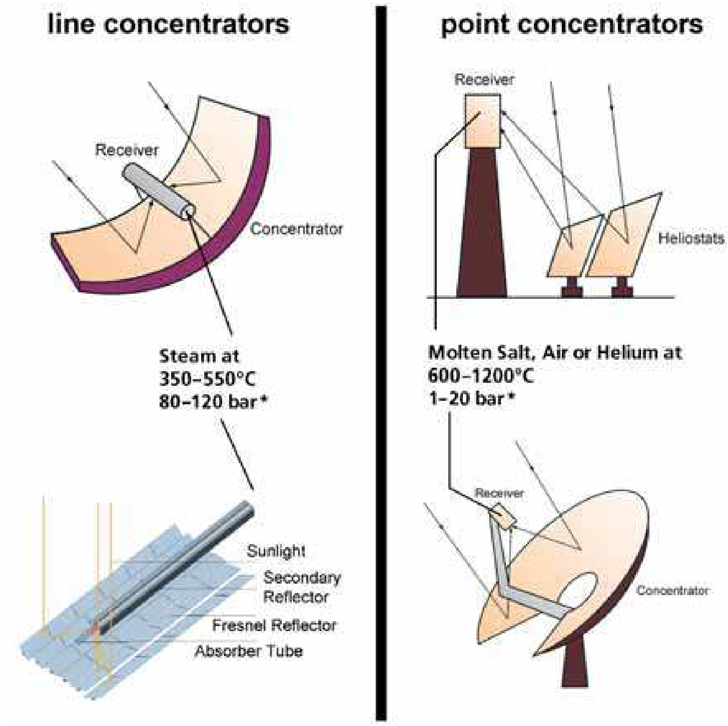


Figure 9: Concentrator arrays (Source)

Concentrator arrays must track the sun because they rely on the ability to focus direct sunlight. Concentrators are best used in the areas with high direct beam radiation.

1.5. Solar Photovoltaic Technologies

The heart of the Solar energy generation system is the Solar cell. It consists of three major elements, namely:

- The semiconductor material which absorbs light and converts it into electron-hole pairs.
- The junction formed within the semiconductor, which separates the photo-generated carriers (electrons and holes)
- The contacts on the front and back of the cell that allow the current to flow to the external circuit.

Two main streams of technologies have been evolved for the manufacture of Solar Cells/Modules namely

- Flat plate Technology
- Concentrated Technology

The Flat Plate Technology is further classified in two ways namely Crystalline Technology and Thin Film Technology. The Concentrated Photovoltaic Technology has been classified according to the Type of cell and the Optical system.

1.5.1. Crystalline Technology

Crystalline Silicon (c-Si) was chosen as the first choice for solar cells, since this material formed the foundation for all advances in semiconductor technology. The technology led to development of stable solar cells with efficiency up to 20%.

Two types of crystalline silicon are used in the industry. They are

- Monocrystalline Silicon
- Multicrystalline Silicon

Mono-Crystalline Silicon

Mono-Crystalline Silicon cells are produced by growing high purity, single crystal Si rods and slicing them into thin wafers. Single crystal wafer cells are expensive. They are cut from cylindrical ingots and do not completely cover a square solar module. This results in substantial waste of refined silicon. The efficiency of mono-crystalline silicon cells remains between 17-18% because of the purity level. Figure 10 below depicts the Monocrystalline Cell

Figure 10: Mono crystalline silicon cell

Multi-Crystalline Silicon

Poly-crystalline silicon cells are made from sawing a cast block of silicon first into bars and then wafers. This technology is also known as Multi crystalline technology. Poly-Si cells are less expensive to produce than single crystal silicon cells as the energy intensive process for purification of silicon is not required. They are less efficient than single crystalline cells. The efficiency of poly crystalline silicon cells ranges from13-14%.

1.5.2. Thin Film Technology

In Thin Film Solar technology, a very thin layer of chosen semiconductor material (ranging from nanometer level to several micrometers in thickness) is deposited on to either coated glass or stainless steel or a polymer substrate.

Various thin-film technologies are being developed to reduce the amount of light-absorbing materials required to construct the solar cell. This results in reduction of processing cost. However, conversion efficiencies are also lower in these cases (average 7-10%). As the modules are of lesser efficiency for same level of energy requirement, longer collector area is required and consequently more requirement of land. This technology is, therefore, apt where non productive land is available for example deserts of Rajasthan. They have become popular compared to wafer silicon due to lower costs, flexibility, lighter weights, and ease of integration. Figure 11 below depicts the Thin Film Cell

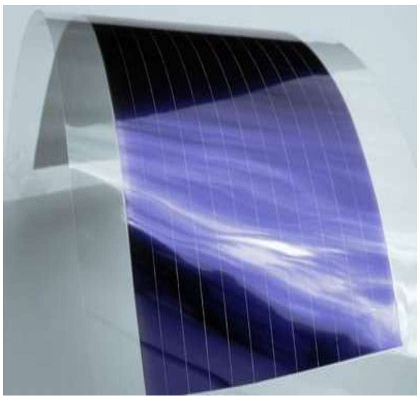


Figure 11: Thin film solar cell

Amorphous Silicon Thin Film Technology

Silicon thin-film cells are mainly deposited by chemical vapor deposition (typically plasma-enhanced PE-CVD process) from silane gas and hydrogen gas. Depending on the deposition parameters, this can yield:

- Amorphous silicon (a-Si or a-Si:H)
- Protocrystalline silicon
- Nanocrystalline silicon (nc-Si or nc-Si:H), also called microcrystalline silicon.

It has been found that protocrystalline silicon with a low volume fraction of nanocrystalline silicon is optimal for high open circuit voltage. The solar cells made from these materials tend to have lower energy conversion efficiency than bulk silicon, but are also less expensive to produce. The quantum efficiency of thin-film solar cells is also lower due to reduced number of collected charge carriers per incident photon.

Cadmium Telluride Thin Film Technology

A Cadmium Telluride (CdTe) solar cell is a solar cell based on cadmium telluride, an efficient light-absorbing material for thin-film cells. Compared to other thin-film materials, CdTe is easier to deposit and more suitable for large-scale production.

CdTe technology significantly refined over the past few years. It is uniquely capable of producing high-volume, low-cost modules, making widespread, affordable solar electricity a reality.

The physical characteristics of CdTe are such that it is almost perfectly matched to the solar spectrum. This allows CdTe modules to absorb more of the available solar energy in low and diffuse light situations – such as dawn and dusk and under cloudy skies and convert it into electricity more efficiently than conventional cells. As a result, CdTe thin film modules will generally produce more electricity under real world conditions than conventional solar modules with similar power ratings.

1.5.3. Concentrated Photovoltaic Technology

In Concentrated Photovoltaic (CPV) systems, solar energy collected over large area is focused on each cell having smaller area, to achieve higher power output and improved conversion efficiency. Thus the expensive semiconductor material required for power generation is reduced giving a substantial cost advantage. Although Si based SPV technology is fairly mature, CPV technology is still evolving and has a huge potential.

Primary reason for using CPV is that, same amount of semiconductor material can produce higher amount of energy thus reducing the cost of power generation significantly. In CPV systems, optical materials like mirror or lenses are used to collect sunlight on large area and focused onto each cell having smaller area. Despite the advantages of CPV technologies, their application has been limited because of the costs of focusing, sun tracking and cooling arrangements. Figure 12 below depicts a Concentrated PV Module.

Figure 12: Concentrated PV Module (Source: green and gold energy)

1.6. Solar Thermal Technologies

Concentrating Solar Thermal technologies (CSP) is used to produce heat or electricity. CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated light is then used as heat or as a heat source for a conventional power plant (solar thermoelectricity).

A concentrating collector system can have a stationary collector or tracking one to track the sun. In stationary systems, the reflector and absorber are in fixed position, usually oriented directly to true south. Tracking devices shift the position of the reflector and the receiver to maximize the amount of sunlight concentrated on to the receiver.

Tracking collectors are either single-axis or double-axis. Single-axis tracking devices move the collector on one axis: East to West or North to South. Dual-axis tracking devices track the sun on all axes. The entire collector, containing the reflector and receiver, generally moves as a unit in both types. Systems with dual-axis tracking facility concentrate most of the solar energy and generate very highest temperature. These are the most complex in structure and so expensive.

Wide ranges of concentrating technologies are prevalent. A list of few technologies is given below. They are

- Parabolic Trough
- Dish Stirling
- Concentrating Linear Fresnel Reflector
- Solar chimney

Each concentration method is capable of producing high temperature and correspondingly high thermodynamic efficiencies, but they vary in the way they track the sun and focuses light. Due to new innovations in technology, concentrating solar thermal is becoming more and more cost-effective.

1.6.1. Parabolic Trough

A parabolic trough consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned right above the middle of the parabolic mirror and is filled with a working fluid (e.g. molten salt). The reflector follows the sun during the daylight hours by tracking along a single axis. The working fluid is heated to 150-350°C as it flows through the receiver, and is then used as a heat source for a power generation system. Trough systems are the most developed CSP technology. Figure 13 below depicts a parabolic trough system.

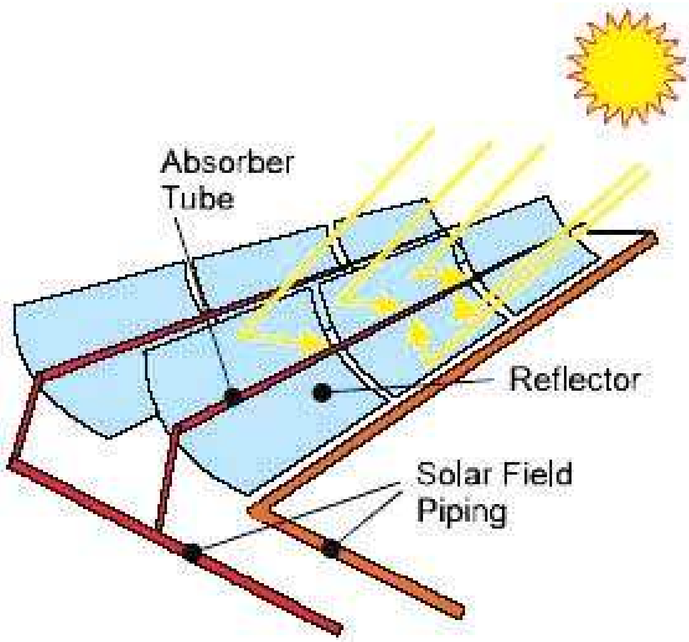


Figure 13: Parabolic Trough (Source www.hkengineer.org.hk)

A brief list of prominent CSP plants is given below:

- Solar Energy Generating System (SEGS) plants in California
- Acciona's Nevada Solar One, Nevada,
- Plataforma Solar de Almería's SSPS-DCS plant in Spain

1.6.2. Concentrating Linear Fresnel Reflectors

Concentrating Linear Fresnel Reflectors are CSP plants which use many thin mirror strips instead of parabolic mirrors to concentrate sunlight into two tubes with working fluid. The advantage is that flat mirrors are cheaper than parabolic mirrors. Space utilization can also be better in these. Figure 14 below depicts the Concentrating Linear Fresnel Reflector System.

Concentrating Linear Fresnel Reflectors can be deployed in large plants or smaller ones.

Figure 14: Concentrating Linear Fresnel Reflectors

1.6.3. Dish Stirling

A Dish Stirling or dish engine system consists of a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point. The reflector tracks the sun along two axes. The working fluid in the receiver is heated to 250-700°C and then used by a Stirling engine to generate power. Parabolic dish systems provide the highest solar-to-electric efficiency, which is currently about 25%, and their modular nature supports scalability. Figure 15 below depicts Dish Stirling System. Some of the major installations are the Stirling Energy Systems (SES) and Science Applications International Corporation (SAIC) dishes at UNLV and the Big Dish in Canberra, Australia.

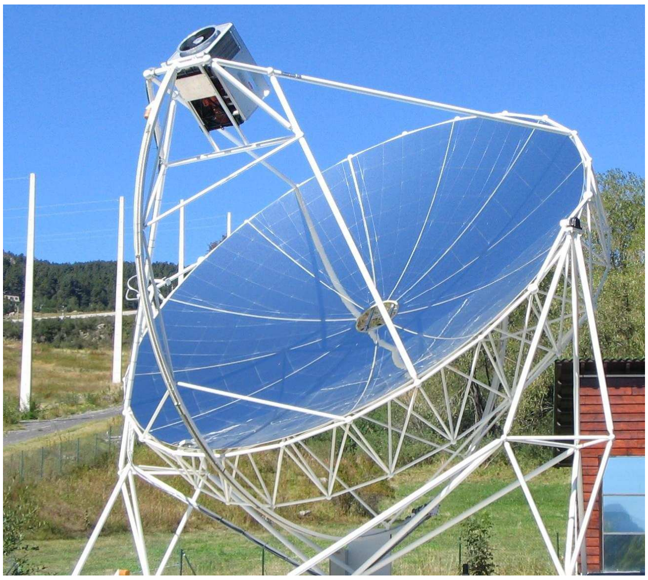


Figure 15: Dish Stirling (Source: intersol.se)

1.6.4. Solar Chimney

A solar chimney consists of a transparent large room (usually made of glass) which is sloped gently up to a central hollow tower or chimney. The sun heats the air in this greenhouse-type structure which then rises up the chimney, thereby driving an air turbine as it rises. This air turbine then creates electricity. Figure 16 below is example of Solar Chimney

Solar chimneys are very simple in design and could therefore be a viable option for projects in the developing world.

Figure 16: Solar Chimney (Source: www.volker-quaschning.de)

Solar Power Tower

A solar power tower consists of an array of dual-axis tracking reflectors (heliostats) that concentrate light on a central receiver atop a tower. The receiver contains a fluid deposit, which could contain seawater. The working fluid in the receiver is heated to 500-1000°C and then used as a heat source for a power generation or energy storage system.

Power tower development is less advanced than trough systems, but they promise higher efficiency and better energy storage capability. Figure 17 below is a representation of Solar Power Tower.

The two solar power towers in Daggett, California and the Planta Solar 10 (PS10) in Sanlucar la Mayor, Spain are working examples of this technology.

Figure 17: Solar Power Tower

Concentrating Solar Thermal Power (CSP) is the main technology proposed for a cooperation to produce electricity and desalinated water in the arid regions of North Africa and Southern Europe by the Trans-Mediterranean Renewable Energy Cooperation DESERTEC.

1.7. Applications of Solar Energy

1.7.1. Solar Photovoltaic Applications

Three most important and widely used applications of Solar PV have been considered here. These are

- Solar home lighting systems
- Solar water pumping systems
- Solar power plants

Solar home lighting system

Home lighting systems are powered by solar energy using solar modules. The generated electricity is stored in batteries and used for the purpose of lighting whenever required. These systems are most widely used in non-electrified rural areas and as reliable emergency lighting system for important domestic, commercial and industrial applications. The Solar Home Lighting system is a fixed installation designed for domestic application. The system comprises of Solar PV Module (Solar Cells), charge controller, battery and lighting system (lamps & fans). The schematic of the Home lighting system is shown in Figure 18 below. The solar module is installed in the open on roof/terrace - exposed to sunlight and the charge controller and battery are kept inside a protected place in the house. The solar module requires periodic dusting for effective performance.

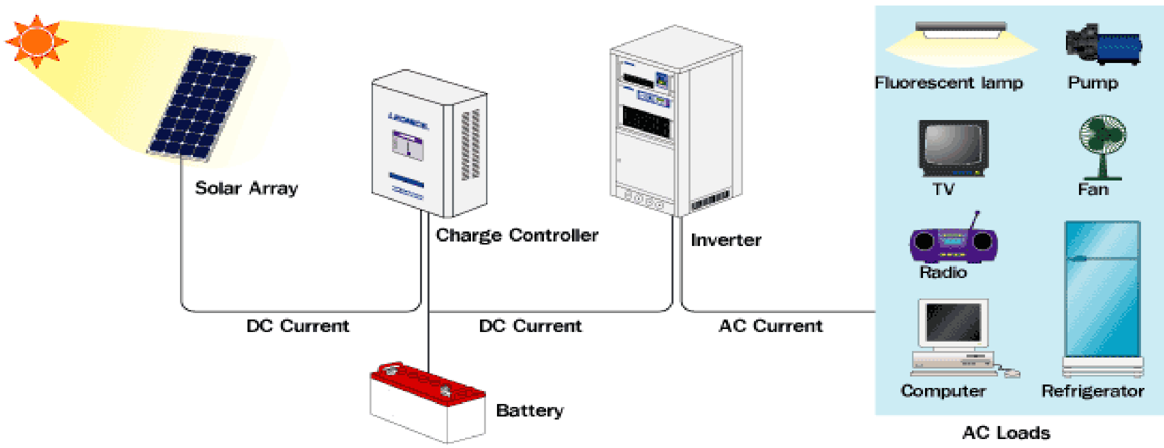


Figure 18: Schematic of Solar Home Lighting System

Typical specifications of a Home lighting system are given below in Table 2:

Table 2: Typical Home lighting system specifications

S.No	SPV Module	Battery Tabular Plate	Luminaries with Electronics	Charge controller	12V 20W DC fan
1	12V 18Wp	12V 20AH	1x9W 4Pin CFL	3 Amps.	Optional
2	12V 37Wp	12V 40AH	1x9W 4Pin CFL	6 Amps.	1 Fan
3	12V 74Wp	12V 75AH	1x9W 4Pin CFL	10 Amps.	1 Fan

Solar water pumping system

These water pumping systems are powered by solar energy. It is a stand-alone system. The power generated by solar module is used for operating DC surface centrifugal mono-block pumpset for lifting water from bore / open well or water reservoir for minor irrigation and drinking water purpose. The system schematic is shown in the Figure 19. The system requires a shadow-free area for installation of the Solar Panel

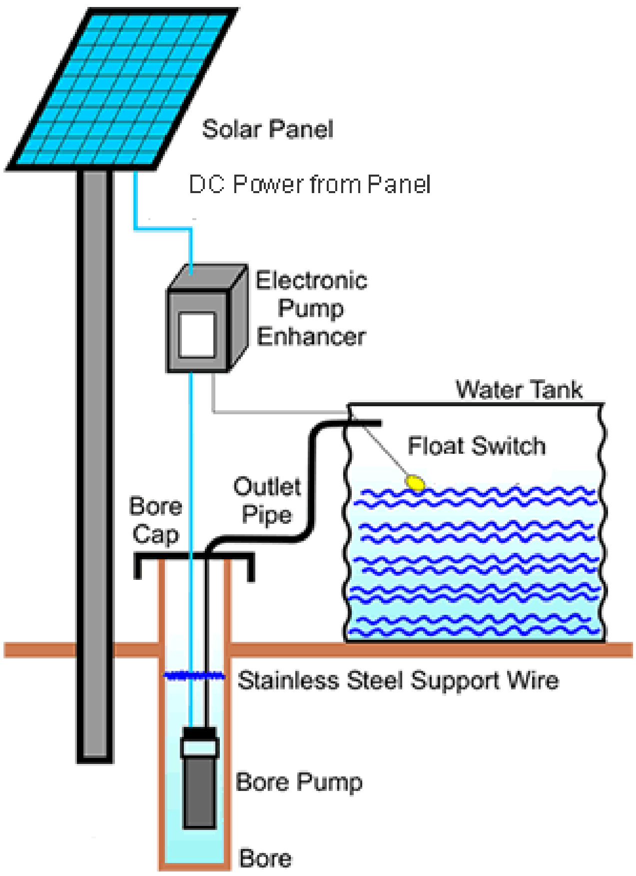


Figure 19: Schematic of Solar Water pumping System

Typical specification of solar water pumping system is furnished below:

- A SPV water pumping system is available with a photovoltaic array of capacity in the range of 200 watts to 3000 watts. (Capacity of motor pump set is from 0.5 hp to 2 hp).
- A SPV water pumping system is expected to deliver a minimum of 65,000 liters per day with a 900 watts panel and 135,000 liters per day with a 1800 watts panel from a depth of 7 meters on a clear sunny day.
- In case of deep well submersible pumps, the water output will be about 45000 liters from a 1200 watts panel.
- The discharge from the pump would vary with the intensity of the sunrays from morning till evening. It would be maximum around noontime. The water output from the pumping would considerably drop with the increase in the depth from which water needs to be pumped.
- The SPV water pumping system can be used to irrigate 0.5-6 hectares, if the water is to be pumped from a depth of 10 meters. However, water table, type of soil and water management are other factors that influence the areas that can be irrigated using the system.
- Considering an average peak power of SPV water pumping system to be 900 watts, an indication of irrigation area for different crops with different types of irrigation methods used is given below.

Solar Power Plants

Power supply in most of the cities and towns is unreliable, which has forced the people to use small generators. These generators are operated with fossil fuels like kerosene, petrol or diesel cause pollution. It also leads to increase dependence on oil imports.

A solar power plant is a good option for electrification in areas that are located away from the grid line or where other sources are neither available nor can be harnessed in a techno economically viable manner. A solar power plant of the size 10–100 kW (kilowatt), depending on the load demand, is preferable particularly with a liberal subsidy and low-interest soft loan from financial institutions. The idea is to raise the quality of life of the people subjected to poverty in these areas. This coupled with low-gestation remote areas of many states that need electrification. Typical Stand alone solar power plant for the power generation comprises of Solar PV module array, Module mounting structures, Charge controller, Battery bank, Inverter and Load circuitry. A typical stand alone Solar PV power plant is shown in the Figure 20. The control panel (inset of photograph) with all the peripheral components is housed as shown below.

Figure 20: A16 kW SPV Power Plant established in Jharkhand, India

Typical specification of a solar power plant for village electrification is as follows:

- A clean, silent and eco-friendly source of power
- Power in the range of 1 kWp to 10 kWp capacity
- Module Rating
    - 75 Wp or more, 24 V
- Battery
    - 300AH OR 48 V 150 AH Low maintenance lead acid tubular plate.

1.7.2. Solar Thermal Applications

Solar Water Heating Systems

In a Solar water heating system water is heated by the use of solar energy. These generally comprise of solar thermal collectors, a fluid system to absorb the heat from the collector toughened glass shield, insulated storage tank, cold water supply tank and insulated piping. These systems use the solar energy to heat either water or a heat-transfer fluid, such as a water-glycol antifreeze mixture, in collectors generally mounted on a roof. The sun rays penetrate through the glass and fall on the absorber. The heat of the sunrays is absorbed by the cold water inside the absorber thereby increasing its temperature. The storage is either through the thermosyphon or the forced flow system. In the Thermosyphon system up to 3000 liters per day can be installed; however, for higher capacities it is necessary to use forced flow system. The water temperature can be raised up to 85^{0}C. Atypical schematic diagram of solar water heating system is shown in the Figure 21. The solar water heating system can be used for bathing, washing, boiler feed water pre heating and other similar purposes. The cost of solar water heating system range from Rs.140/- to Rs.220/- per litre. The investment made can be recovered in 4 to 6 years time. The life of the system is around 10-15 years, if maintained properly. The operation and maintenance cost is negligible.

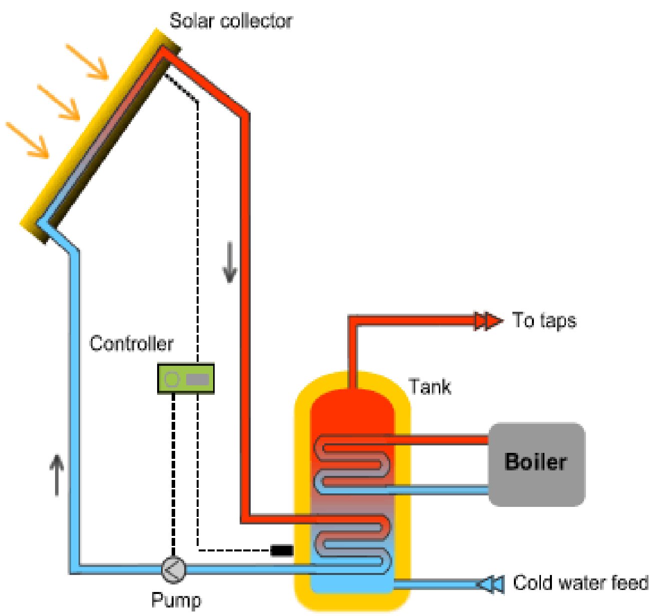


Figure 21: Schematic of Solar Water Heating system

Some factors about Solar Thermal system is given below:

- Hot water availability is in 60 to 120 degree temperature range
- 100 liters per day system cost is Rs. 22,000 /-
- Saves about Rs. 2200/- worth units of electricity annually
- Payback period range from 3 to 5 years
- Prevents emission of 1.5 tones of CO_2 annually

1.8. Factors to be considered in Solar System Design

1.8.1. Solar Radiation

Solar Energy is a perennial and pervasive source of energy. Solar electricity is ideal for remote electrification in the current context. Standalone SPV power plants is the ideal choice for rural remote villages where conventional grid extension is not viable either due to inhospitable terrain or due to poor density of load.

Figure 22 shows regions of high insolation where solar energy conversion systems will produce maximum amount of energy from a specific collector field size.[1]

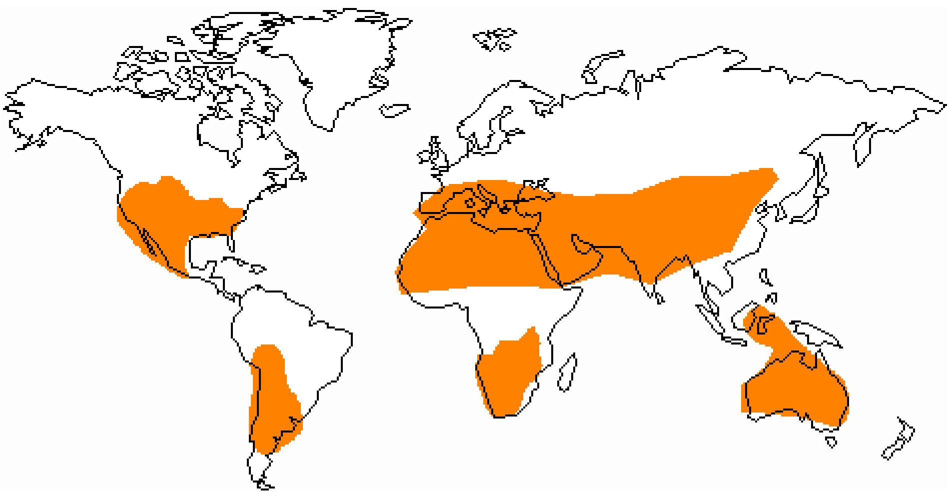


Figure 22: Areas of the world with high insolation (Source: Power from the sun)

The annual average insolation level can be found out in the NASA website given longitude, latitude, altitude and certain other details.

Solar technologies using concentrating systems for electrical production require sufficient direct beam radiation, which is the beam radiation from the sun that passes through the planet's atmosphere

[1] www.powerfromthesun.net

without deviation and refraction. Consequently, appropriate site locations are normally situated in arid to semi-arid regions. Acceptable production costs of solar electricity occur where radiation levels exceed about 1700 kWh/m^2-yr.

Most Suitable regions include the southwest United States, Northern Mexico, the North African desert, the Arabian Peninsula, major portions of India, Central and Western Australia, the high plateaus of the Andean states, and Northeastern Brazil. Promising site locations in Europe are found in Southern Spain and several Mediterranean islands.

1.8.2. Atmospheric effect on Solar Radiation

For utilization of solar energy, it is necessary to know the amount of depletion of incoming solar radiation by the atmosphere. It has been reported that for clear sky conditions, the fractions of direct solar radiation which is depleted due to various reasons[2] are:

1. Atmospheric scattering 9%
2. Surface reflection 6%
3. Other gases, smoke, dust etc. 3%

In astronomy, air mass is the optical path length through the earth's atmosphere for light from a celestial source. As it passes through the atmosphere, light is attenuated by scattering and absorption; the more atmosphere through which it passes, the greater the attenuation. Consequently, celestial bodies on the horizon appear less bright than when at the zenith. The attenuation, known as atmospheric extinction, is described quantitatively by the Beer-Lambert-Bouguer law.

Air Mass

"Air mass" normally indicates relative air mass, the path length relative to that at the zenith at sea level. By definition, the sea-level air mass at the zenith is one. Air mass increases as the angle between the source and the zenith increases, reaching a value of approximately 38 at the horizon. Air mass can be less than one at an elevation greater than sea level. However, most closed-form expressions for air mass do not include the effects of elevation, so adjustment must usually be accomplished by other means. Designation of Solar Air Masses is shown in Figure 23 below.

[2] BYERS, H. R., "Genera1 Meteorology"

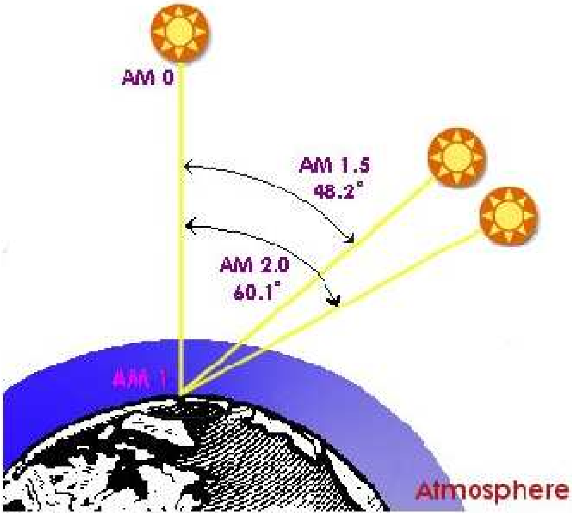


Figure 23: Designation of Solar Air Masses (Source: solarlight.com)

1.8.3. Daily and Seasonal Temperature Variations

One of the most popular myths about the use of solar energy is that on cloudy days there will not be any electricity generation. This is classified in detail below:

Solar PV Systems

In a cloudy day Solar PV panels produce electricity from **diffused sunlight**. The amount of energy that can be collected is certainly less than the amount that can be captured on a sunny day, the process of collection depends on degree of sunlight. This energy can be stored in batteries, which can cater to needs during the night.[3]

Concentrating Solar Thermal Heating Systems

Concentrating collectors produce electricity from direct sunlight. So they work best in climates that have a high amount of **direct solar radiation**. They do not function on cloudy days, when available solar radiation is mostly diffused. The amount of useful heat they produce is mainly a function of the intensity of solar radiation available, the size of the reflector, how well they concentrate solar energy onto the receiver, the characteristics of the absorber, and the control of the flow rate of the heat transfer fluid.[4]

[3] www.greenlivinganswers.com
[4] www.cogeneration.net

1.8.4. Physical Parameters

The following are the list of a few physical parameters that needs to be considered while selecting suitable location for the installation of solar energy system. These parameters are most appropriate for large scale solar systems like solar power plants.

Availability of Land and Foundation needs

The land must be plain and continuous. Non fertile, barren land should only be considered. Rocky terrain shall be preferred so that the cost of foundation will be cheaper.

Orientation and Obstructions

The proposed land for SPV power generation must have a clear south facing without any obstruction in Southern hemisphere.

Proximity of Power Evacuation

Proximity of high tension substation is an important factor for the proposed site as the cost of laying transmission line is significant.

Water Availability

Water is required for the construction purpose and for periodic cleaning of solar panels as a part of daily Operation and Maintenance.

Any industries of pollution nearby

It is suggested that the site be selected, which does not have any Polluting industries in the neighborhood. Otherwise the smoke and dust emitted by these industries forms a deposition on top of panels resulting in Array losses.

Power supply for construction

Availability of adequate power supply for construction work is necessary.

1.8.5. Typical Site Evaluation Methodology

A methodology that can be used for evaluation of sites allocating weights to various attributes is described below:

Let us consider a case where two sites called Site A and Site B need to be evaluated. The scores allotted are as follows:

- 3 points for Excellent,
- 2 points for Average, and
- 1 point for Below Average

The weighted score aggregated for the two sites are observed. Weighted grade of a particular attribute is the product of weight of the attribute and score assigned to the site with respect to that attribute. The site which gains the highest aggregated weighted score is to be preferred for the solar power project. In the present scenario, Site B has the highest score and hence it is the most preferable location.

Table 3: Ranking for Site Evaluation

S. No.	Attribute	Weight	Site A	Site B	Weighted Score	
					Site A	**Site B**
1.	Solar Insolation (NASA Data)	21	2	3	42	63
2.	Bay availability at the substation	20	2	3	40	60
3.	Availability of land	19	2	3	38	57
4.	Orientation -Clear South facing	18	3	2	54	36
5.	Shadow possibilities	17	3	1	51	17
6.	Proximity for power evacuation(Distance as crow flies)	16	1	3	16	48
7.	Cost of land	15	3	1	45	15
8.	Foundation needs	14	1	3	14	42
9.	Level land	13	3	1	39	13
10.	Demand position at the substation	12	1	3	12	36
11.	Substation load profile (Type of load)	11	2	2	22	22
12.	Pvt. land in between for drawing transmission line	10	1	1	10	10
13.	Water availability for construction and O&M	9	1	1	9	9
14.	Logistic Convenience(Transportation and accessibility from Road)	8	3	2	24	16
15.	Abundance of tech manpower	7	1	3	7	21
16.	Any industries of pollution nearby	6	3	3	18	18
17.	Familiarity of S/S personnel with RE power evacuation	5	2	2	10	10

18.	Nearest City	4	2	3	8	12
19.	Air connectivity	3	1	3	3	9
20.	Local political scenario	2	1	1	2	2
21.	Power supply for construction	1	2	3	2	3
			Total		**466**	**519**

Score:	
3	Excellent
2	Average
1	Below Average

1.9. System Design of Solar PV Systems

1.9.1. Load Analysis

Accurate Sizing

Accurate sizing of the load involves analyzing the various components in the load list in terms of energy requirements. It includes the current drawn by each component, Operating voltage range of that component and its expected duty cycle.

Peak current loads

For equipment loads that are variable or pulsating, identify "peak" current levels unless definite patterns or duty cycles are determinable.

Worst case scenarios

Assessment of worst case scenario is extremely important because any small increment in load apart from already assessed load can lead to system unbalance or a cycling down of battery capacity. So, assessing worst case load scenario is important. Worst case load scenario could be consequent to any load variations due to seasonal conditions.

Plan for the future

The system must be designed focusing on the future needs. The system must be scalable to cater to the needs of expansion.

Compatibility issues

The system must be compatible with existing systems to meet the load requirements. All the loads must be cross checked to ensure their compatibility of operation throughout the upper and lower voltage ranges of the solar system.

Determine design margins

Additional design margins to be considered and kept at minimum level to make the system more cost effective because of the early consideration of worst case load scenario and possible system expansions.

1.9.2. Solar Array Design

Solar array is one of the major subsystems of any solar power generating system. Solar array is formed by connecting solar "modules" in series and/or parallel arrangement. This array produce direct current with respect to the incident solar radiation. The following are the factors that need to be considered in designing solar array for power generation.

Collector size

The required solar collector area depends on the solar insolation level of a particular region. A region with poor insolation level will need a larger collector area than one with high insolation levels. Once insolation level of a region is known, the required collector size and energy output can be computed with some precision.

Selection of most appropriate module

Solar modules are often rated on the basis of *peak watts*, and their electrical characteristics are described on a current-voltage curve popularly known as I-V curve. However, the most important factor is the module's behavior under expected operating conditions. One very important concern is module's charging voltage generation under expected high temperature. It must be adequate to charge the battery after providing for system losses.

Dirt and Other contaminating effects

Dirt and other contaminants (e.g. bird-droppings) on the face of the solar array can reduce the power output. Site conditions should be assessed to gauge the problems associated with contaminants. The mitigating solutions like special mounting considerations, more frequent cleaning could be recommend. If the tilt angle of the array is less than 30°, buildup of dirt and other contaminants can be expected.

Orientation and Tilt issues

The specific orientation and tilt of the solar array should be adopted to optimize system power during the worst-case periods of the year and when the average solar insolation is lowest and load requirements are highest. It may be desirable in certain locations to increase the array tilt to aid the clearing of snow and ice.

Design of Balance of Systems (BOS)

Design of Balance of Systems is a very important factor in system design. Balance of systems include the Charge controller, Battery, Cables etc. Balance of systems must be designed in such a way that it is neither too small nor too large.

1.9.3. Battery Design

Battery selection and sizing is critical to overall system performance and reliability. The battery serves as an energy buffer, storing excess energy produced by the solar array during the day and releasing that energy as required during night and periods of inclement weather, when the array is unable to support the load. The following are some important factors that need to be considered in designing a battery bank.

Physical and Performance Requirements

The battery should be capable of handling both the physical and electrical rigors of the application, while providing the desired life expectancy and reliability. Key areas to be considered include:

- Cycle life
- Capacity to withstand extended undercharged condition
- Capability to withstand extended overcharging when array output is not regulated
- Charge efficiency and degree of self-discharge
- Need for equalization
- Performance and life effects of temperature extremes
- Tolerance of abuse
- Maintenance requirements

Reserve Capacity

The capacity of the battery should be sized to override:

1. Expected uncertainties in solar insolation
2. Any seasonal periods when the array power is unable to fully match the load requirements.

Temperature and Ageing deration

Battery performance is not static but will vary with age and environmental conditions. Battery performance should be derated to compensate for loss of capacity due to ageing and the reduction in available capacity due to low temperature.

These factors will vary with type of battery. An additional consideration for certain applications will be the life-shortening effects of sustained high-temperature environments.

Regulation and Charge control

A system regulator or Charge controller may be necessary to prevent excessive overcharge during peak periods of solar radiation, which could damage some batteries, particularly flat plate lead acid batteries and sealed maintenance-free batteries. A regulator or controller may also be desirable to reduce battery water consumption and extend required maintenance intervals.

CHAPTER 2

GUIDING PRINCIPLES FOR A RESOURCE ASSESSMENT PROGRAMME

2.1. Resource Assessment Sources

Solar radiation is the main fuel and resource for solar energy systems. The availability of radiation directly determines the revenue of solar energy power plants. Knowledge of this resource is crucial to determine economical viability.

The direct normal irradiance is the amount of solar radiation received directly from the sun (ignoring radiation from the rest of the sky), falling onto a plane perpendicular to the direction of the sun. It can be used for electricity generation via concentrating solar thermal power plants or concentrated PV. Direct irradiance has the advantage that it can be concentrated with mirrors to reach high temperature or high radiative flux. The disadvantage is that it is only available in cloud-free situations. Therefore, energy systems that use direct irradiance are only possible in sunny regions where cloud-free conditions are prevalent.[5] Table 4 furnished below give the priority level for resource assessment.

Table 4: Priority of the resource assessment on Country, Region and Local Level

S. No.	Resource	Entire Country	Province or Region	Local Situation
1.	Meteorological Data: Solar Insolation, Temperature, Humidity, Wind, Air-mass, Non Sunny days	Low	Medium	High
2.	Land: Altitude, Shading, Type	Low	Medium	High

[5] www.earthzine.org

3.	Accessibility to Land	Low	Medium	High
4.	Availability of Hardware	Low	High	Medium
5.	Availability of skilled man power	Low	High	Medium

2.2. Resource Assessment through Solar Energy Maps

The solar energy impinging on the surface of the earth is shown in the Figure 24 below. The white shaded area in the figure gets relatively better solar radiation on an annual basis.

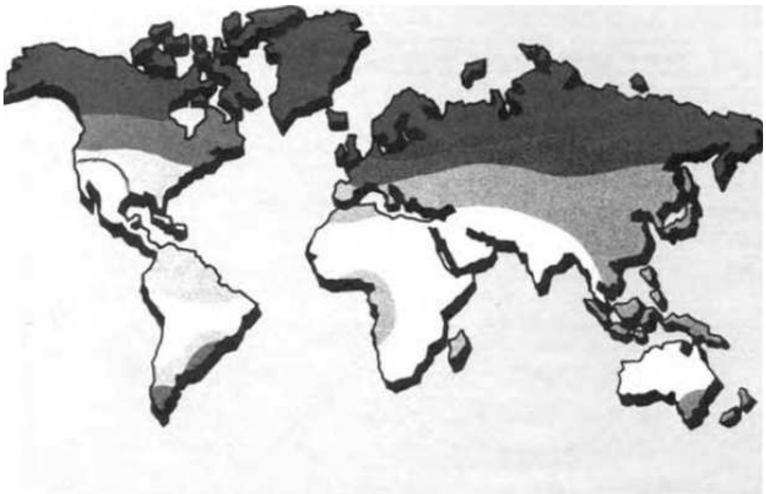


Figure 24: Solar radiation by region of the world (higher energy potential in the white areas)

The yearly 24-h average solar flux reaching the horizontal surface of the earth in the month of December is shown in Figure 25 below. It could be observed that the 24-h average decreases in December because of the shorter days and the presence of the clouds and not due to the low altitude of the sun and cold temperatures. The PV cell converts more solar energy into electricity at low temperature.

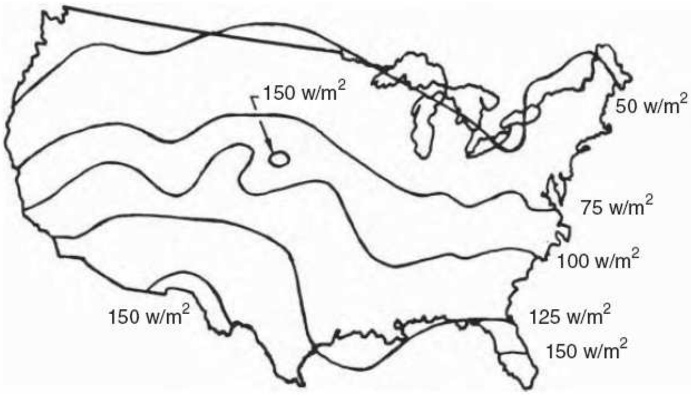


Figure 25: December 24-h average solar radiation in watts/m2 reaching the horizontal surface of the earth.

2.3. Resource Assessment Tools

2.3.1. Measurement of Solar Irradiance

Global Solar Irradiance – Pyranometer

The primary instrument used to measure global solar irradiance is the pyranometer, It measures the sun's energy received from all directions (2πsteradian) in the hemisphere, above the plane of the instrument. Global solar irradiance is the sum total of direct solar radiance and diffused solar irradiance.

The most common pyranometer design uses a thermopile (multiple thermocouples connected in series) attached to a thin blackened absorbing surface, shielded from convective loss and insulated against conductive losses as shown in the Figure 26.

When placed in the sun, the surface attains a temperature proportional to the amount of radiant energy falling on it. The temperature is measured and converted through accurate calibration into a readable format of the global solar irradiance.

Pyranometers may also be used to measure the global solar irradiance on inclined surfaces. An example would be measurements from a pyranometer placed in the same plane as a tilted solar collector. As can be seen from the sketch in Figure 26, this measurement now includes solar energy reflected from surrounding surfaces.

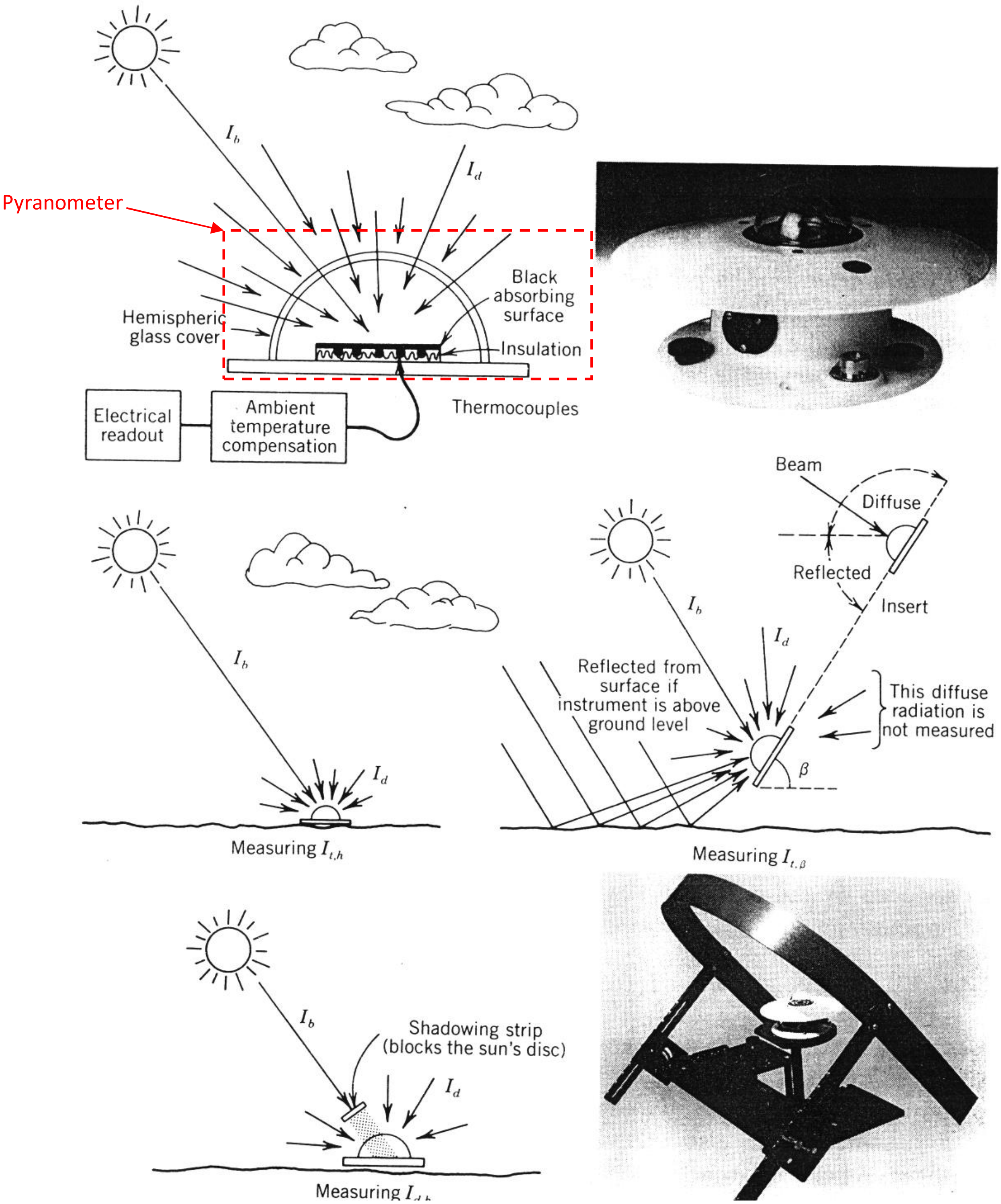
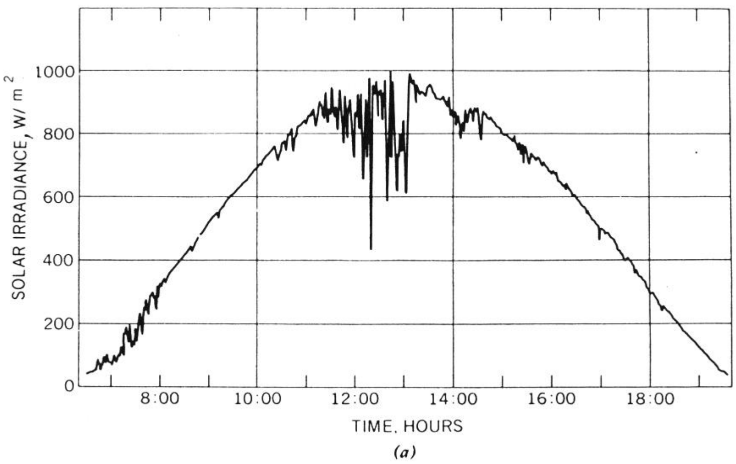
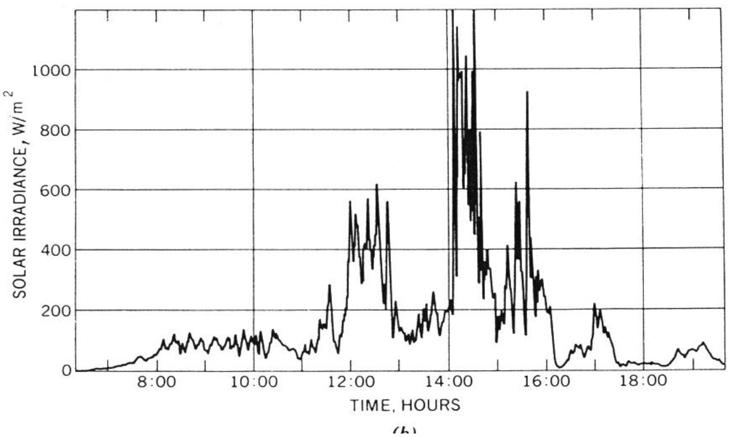


Figure 26: The pyranometer and its use in measuring global horizontal, tilted global, and the diffuse components of solar irradiance (Source: Eppley Laboratory, Inc.)

Figure 27 below shows typical global solar irradiance data recorded by a horizontally oriented pyranometer on both clear and cloudy day. The reading from the pyranometer is obtained for a particular instance, which can be stored in a data logger. At the end of the day, daily solar insolation can be obtained which will be expressed in kWh/m^2/day.



a. Mostly clear day



b. Mostly cloudy day

Figure 27: Example of global (total) irradiance on a horizontal surface for a mostly clear day and a mostly cloudy day in Greenbelt, MD (Thekaekara, 1976): (a) global solar radiation for the day was 27.1 MJ/m2; (b) global solar radiation for the day was 7.3 MJ/m2. (Source: www.powerfromthesun.net)

Direct normal Solar Irradiance – Pyrheliometers

The direct normal component of the solar irradiance can be measured by an instrument called Normal Incidence Pyrheliometer (NIP). This device, shown in Figure 28 is essentially a thermopile pyranometer placed at the end of a long tube that is aimed at the sun. A two-axis tracking mechanism is incorporated to maintain the sun's disc within the acceptance cone of the instrument.

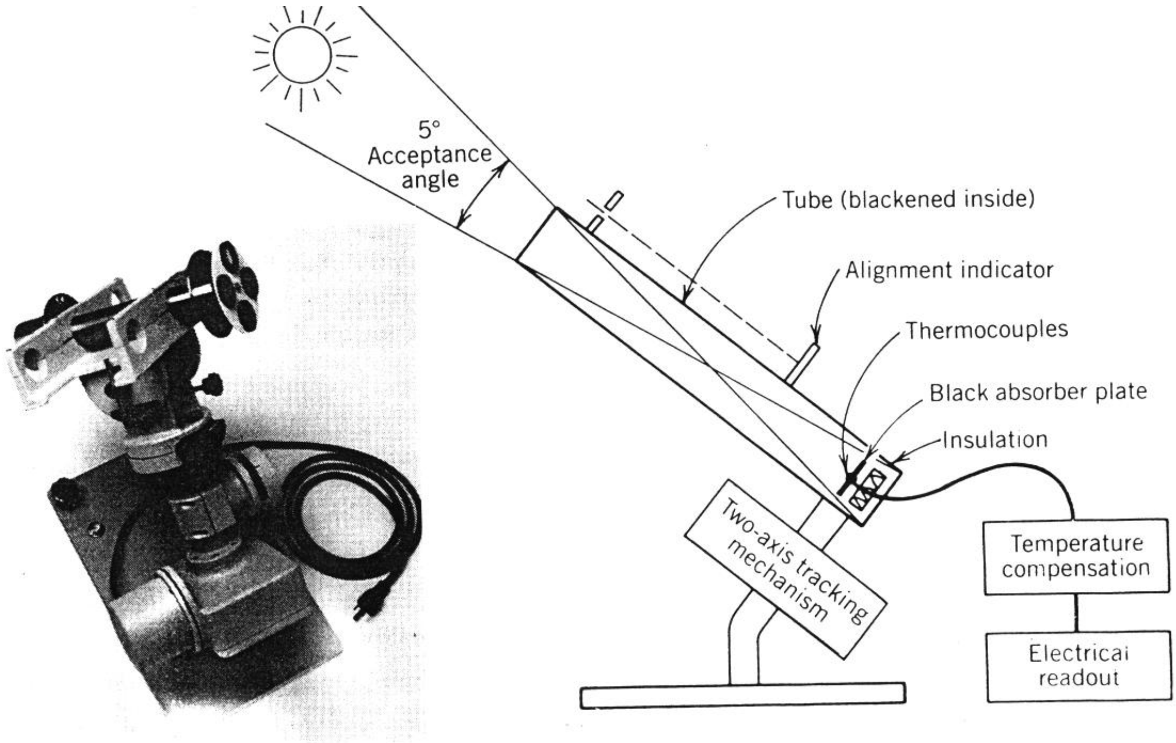


Figure 28: A Normal Incidence Pyrheliometer (NIP) used for measuring the direct component of solar radiation (Source: Eppley Laboratory, Inc.)

Diffused Solar Irradiance

Pyranometers can also be used to measure the diffuse component of the global horizontal radiation. It can be done by providing a "shadowing" device just large enough to block out the direct irradiance coming from the sun's disc. An example of this technique is shown in Figure 27.

To avoid moving a shadowing disc throughout the day, a shadow band is often incorporated. This band must be adjusted often during the year to keep it in the ecliptic plane. Since the shadow band blocks part of the sky, corrections for this blockage must be used.

Recently, rotating shadow band pyranometers have come into general use. With this design, the shadow band rotates slowly about the pyranometer, blocking the direct irradiance from the sun every time it passes in front of the pyranometer. The signal from the pyranometer reads global horizontal irradiance most of the time, with reductions down to the diffuse irradiance level when the shadow band passes between the sun and the pyranometer. This design gives the advantage of using a single pyranometer to measure both global horizontal and diffuse horizontal solar irradiance.

2.3.2. Other Measurement Tools

Sunshine Recorders

In addition to the pyranometer and the normal incidence pyrheliometer, which measure global and direct solar irradiance respectively, there is a traditional measurement often reported in meteorological observations. This is the "duration of sunshine". The traditional standard instrument used to measure this parameter is the Campbell-Stokes sunshine recorder. This instrument consists of a glass sphere that focuses the direct solar radiation and burns a trace on a special pasteboard card. These recorders have been replaced in most installations by photo detector activated ‘sunshine switches.’ The data produced by these instruments are of minimal use to engineers because there is no measure of intensity, other than a “threshold” intensity.

Cloud -Cover Observations

Another source of solar irradiance data is from periodic ground observations of cloud-cover. These are made on an hourly-basis at weather observation stations around the world. Examining the SOLMET weather data tape format, the analysis of these observations are carried out in the United States. Cloud-cover data along with other weather data have been used to predict solar irradiance levels for the locations which do not have solar irradiance measurement capabilities.

Satellite Observations

A similar type of measurement correlation using satellite images appears to provide accurate solar irradiance data over a wide region to a resolution of about 10 km. The results obtained with the use of satellite images made half-hourly in the visible (0.55-0.75 micrometer) and IR (9-12 micrometer) regions of the spectrum.

Recently, efforts have been made to predict accurately solar irradiance from ground reflectance. The models for producing reliable solar irradiance data from satellite have been developed and validated.

2.3.3. Solar Radiation Databases

When designing a solar energy system, the best way to predict its energy-production performance is by calculating the minute-by-minute solar irradiance levels over the lifetime of the system with respect to exact location of the system. Since weather patterns are difficult to predict, and are somewhat random with regard to time and place, the system designer is forced to accept historical data, recorded at a different location, with values reconstructed from incomplete data records. Because of the inherent variability of future solar irradiance, historical records are an extremely useful analytical tool, appropriate for a wide range of applications. However, the designer must keep in mind that system performance predicted using even the best historical data, may not necessarily represent the future output of the system.

Typical Meteorological Year Data Sets - TMY2

A typical meteorological year data set is made up from historical weather observations for a set of 12 typical months, at a specific location. Each typical month is chosen from a multi-year set of data for a specific month, and selected because of having the 'average' solar radiation for that month.

For example, solar radiation data for January, of maybe 30 different years, is searched to determine the year in which the January was typical or average. Next, 30 different February data sets are searched to determine the typical February. As is usually the case, the typical January and the typical February may not be from the same year. Typical months are determined for the remaining months and some data smoothing done for the transition between months. An hour-by-hour database of readings for all recorded weather parameters from each of the 'typical' months is then generated, and is called a Typical Meteorological Year.

A recent set of typical meteorological year data sets for the United States, called TMY2 data sets, has been derived from the 30-year historical National Solar Radiation Data Base. This database consists of hourly values from 239 sites of global and direct solar irradiance, and numerous associated weather parameters from the years 1961 to 1990. This data, along with a user's manual, describing the derivation and format of the data may be found at the NREL internet site: User's Manual for TMY2.

European and Worldwide Solar Radiation Data Bases

A solar radiation database atlas has been developed under the auspices of the European Union (Scharmer & Greif, 2000). This atlas offers a unique instrument dedicated to the knowledge and exploitation of the solar resources for Europe in a broad sense, from Ural to Azores and from Northern Africa to Polar Circle, covering the period 1981-1990.

A computer program permitting calculation of hourly values of solar radiation data throughout the world is available and has been validated at many sites (METEONORM, 2000). The program is continually being updated to include more weather station data, reducing the amount of extrapolation necessary between sites.

Surface Meteorology and Solar Energy – Sponsored by NASA

This is actually Atmospheric Science Data Center which is sponsored and maintained by NASA (National Aeronautics and Space Administration). This center holds the data collected on various parameters of atmosphere and earth. The Surface meteorology and Solar Energy division of this center holds the data associated with Solar Energy. The following are the salient features of this division.

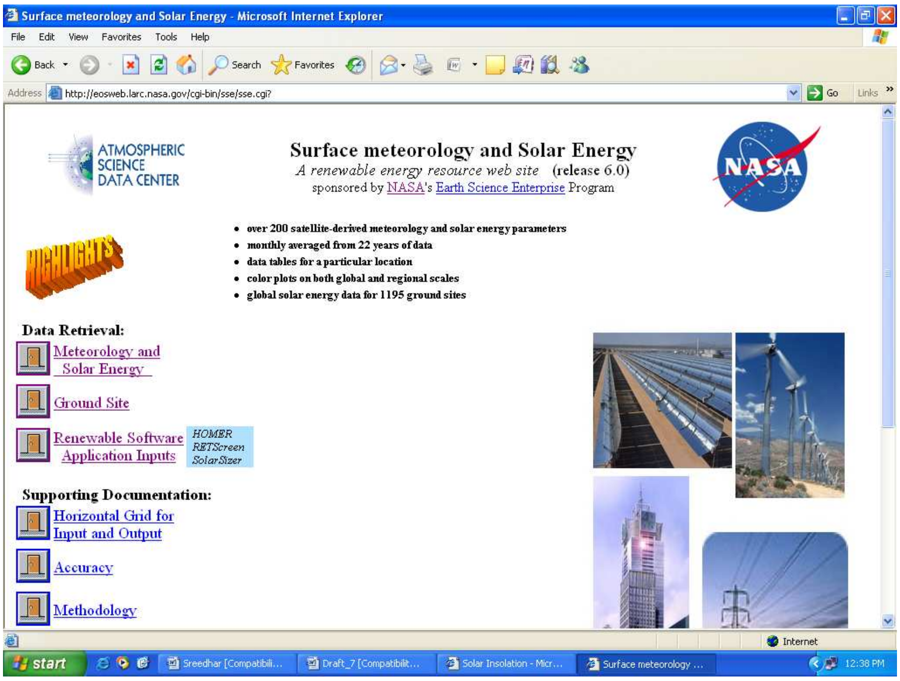
- Over 200 satellite-derived meteorology and solar energy parameters
- Monthly averaged from 22 years of data
- Data tables for a particular location
- Color plots on both global and regional scales
- Global solar energy data for 1195 ground sites

The following steps need to be followed to collect the Solar Energy Resource data of any location in the world.

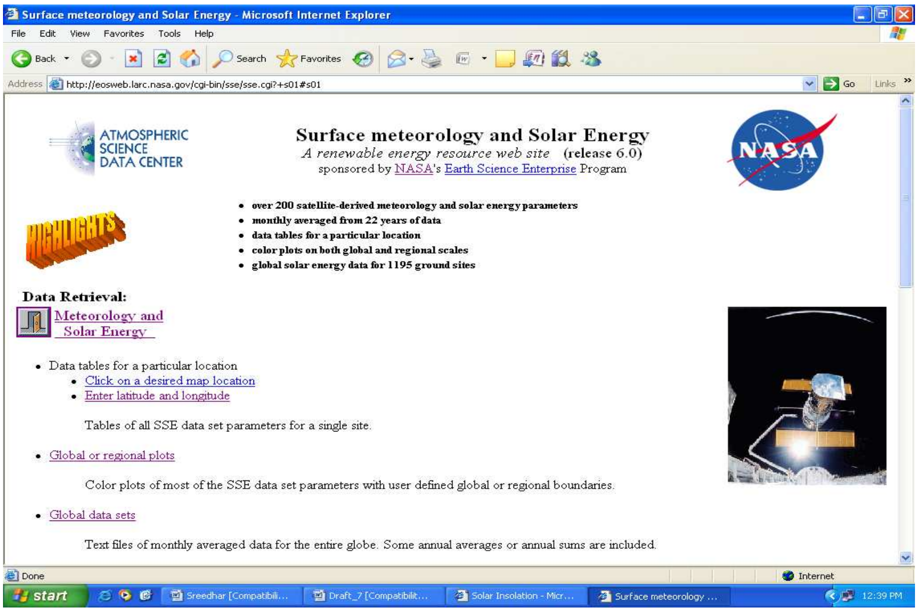
Step 1: Type the following link in the web browser as Internet Explorer/Mozilla

http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?

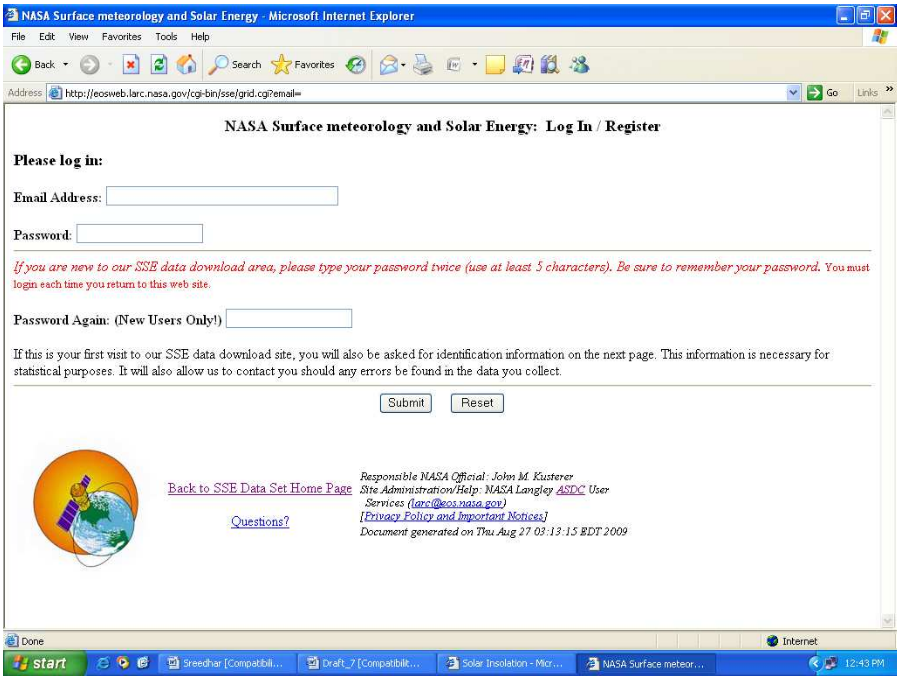
The following page will be displayed



Step 2: Click on **Meteorology and Solar Energy** section. The following page will be displayed



Step 3: Click on **Enter Latitude and Longitude** part of Data tables for a particular location. The following page will be displayed

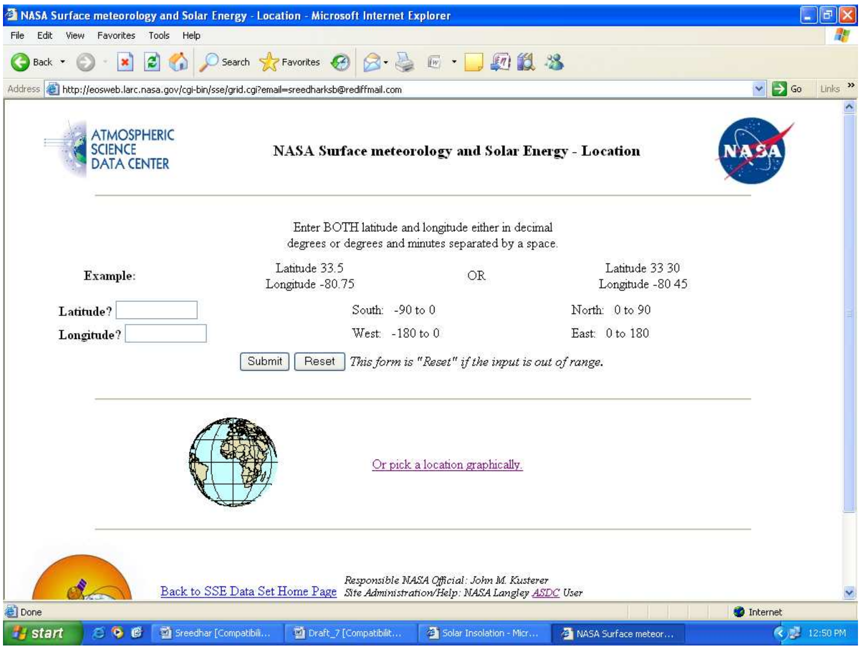


Step 4: This is known as Login screen. If the use is first logging into the site, he has to enter

- His E-Mail ID
- Password of his choice
- Re enter the same password in third field*

*For an already existing user, he need not enter the password in this field

After entering all the details, if the user clicks on **Submit** button, the following screen will appear



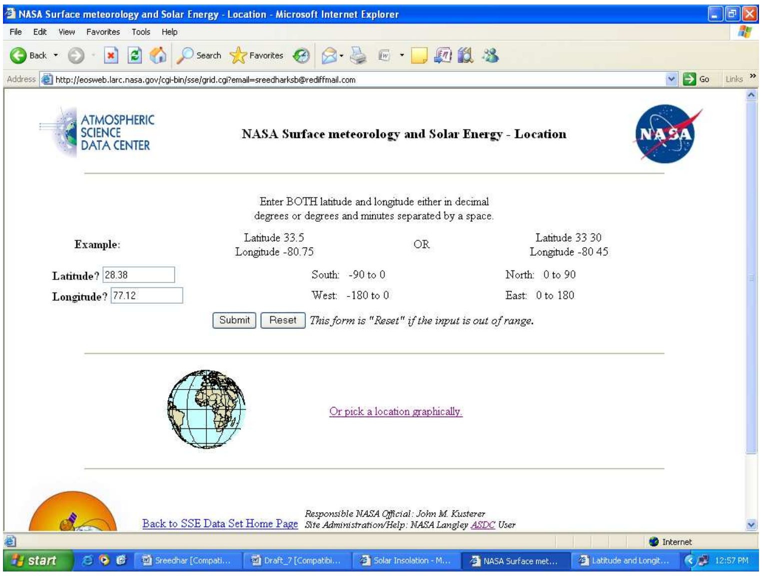
Step 5: The user has to enter the Longitude and Latitude of the location for which he is interested in measuring the solar radiation data.

For example: If the use is interested in solar radiation assessment in Delhi, he has to enter the following values in the latitude and longitude field of the screen.

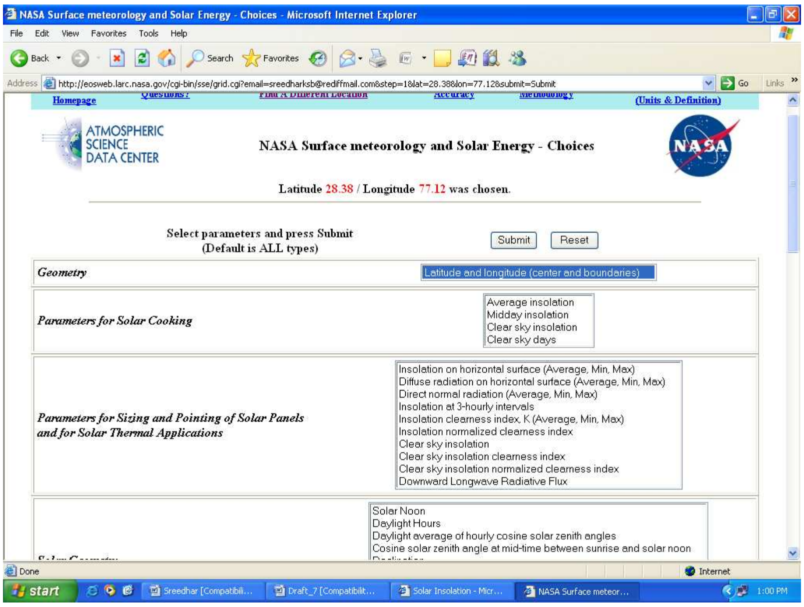
Latitude : 28.38 N

Longitude : 77.12 E

After entering the values, the screen will be as shown below. Now, Click on **Submit**

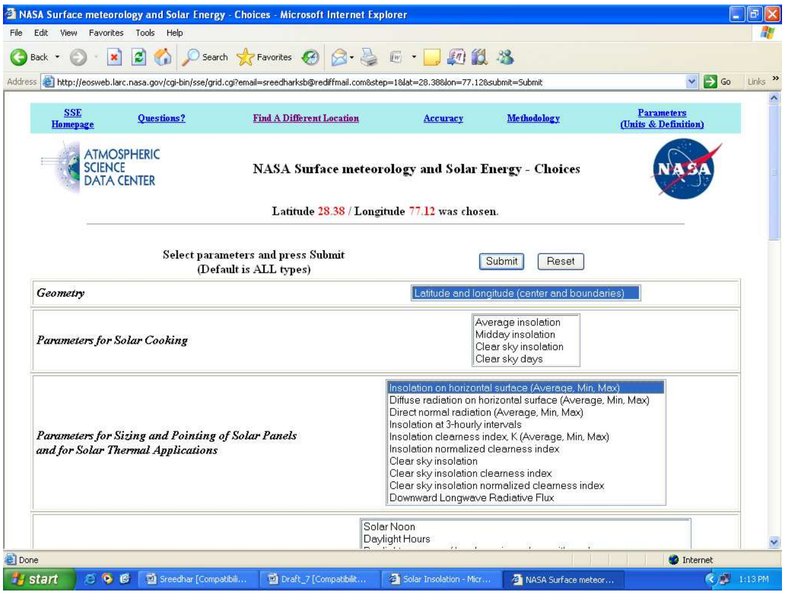


After clicking on Submit button, the following screen describing various parameters will appear.

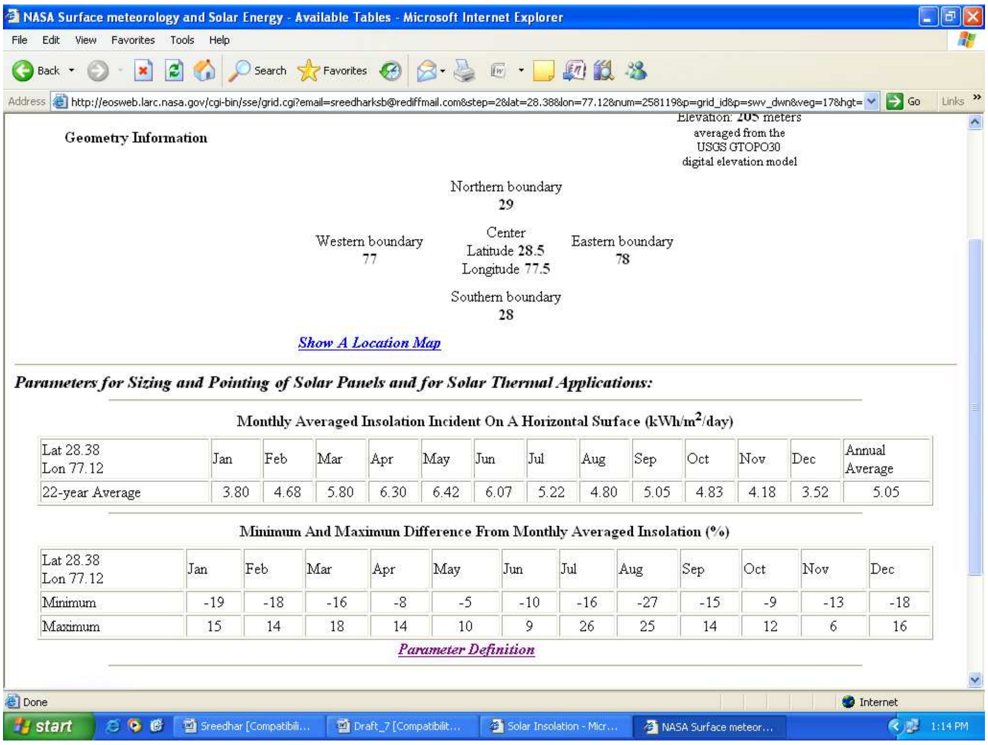


Step 6: The user can select the parameters interested for his system design.

For example: If the user is interested in getting the data associated with Diffused radiation in Delhi, he has to select **Insolation on horizontal surface (Average, Min, Max)** option of *Parameters for sizing and Pointing of Solar panels and for Solar Thermal applications* as shown in the screen below.



Step 7: Now click on Submit. The following screen will appear



Lat 28.38 Lon 77.12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	3.80	4.68	5.80	6.30	6.42	6.07	5.22	4.80	5.05	4.83	4.18	3.52	5.05

Lat 28.38 Lon 77.12	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	-19	-18	-16	-8	-5	-10	-16	-27	-15	-9	-13	-18
Maximum	15	14	18	14	10	9	26	25	14	12	6	16

The figure shows that the **Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day)** particular to that location is 5.05 kWh/m^2/day.

CHAPTER 3
ESTIMATION OF SIZING USING RESOURCE ASSESSMENT TOOLS

3.1. General issues of System Designers

Designing solar power systems involves great deal of judgment before and after any computations are made using appropriate software based system design tool. Skilled system designers are critical of their own assumptions and try to validate inferences to see if all contingencies have been considered.

The following is a brief list of steps that must be followed by the system designers to gather the initial information required for their system design.

3.1.1. Identify potential applications

System design cannot begin until a cost effective application has been identified. The qualities that indicate an opportunity for photovoltaic power are given as follows.

Remoteness: Certainly remoteness and any requirement for high reliability clearly points to consider Photovoltaic power.

Critical loads: If there are critical loads at a site, more than one source of power is desirable

Low voltage: Low voltage of the modules can be considered when compared to the extremely high voltages of transmission lines.

Noise or Pollution: Concern about noise or air pollution or environmental sensitivity, are flags for an appropriate photovoltaic solution

Modularity: There may be desire for a modular approach to power generation, where some power is needed now and some will be needed in the future

High Insolation: If there is abundant solar insolation, photovoltaics should be considered.

3.1.2. Handle customer objections

After potential applications have been identified, designers may face questions related to the technical aspects of the photovoltaic power systems. Certainly a common objection is the relatively high initial cost of photovoltaic power compared to a generator. This must be addressed by presenting the true costs of operating a generator over a time including maintenance, parts, labor, fuel and other invisible costs. A model can be developed considering a creative financing arrangement, where users pay for their energy over time just as they do for conventional.

3.1.3. Gather load information

The individual loads must be well understood, like their voltage and current requirements, and hours of usage each day etc. The profile of the load demand over a typical week or month must be specified. List of a few factors that need to be considered is given below:

- Is the load greater in summer or winter; This information can be used to provide proper tilt arrangement for modules.
- Is the load used only a few days in a week or only on weekends; This information can be used to balance battery storage and hence system cost.
- Has AC loads been included; This information can be used to choose a proper DC to AC inverter
- Are there any critical loads; This information can be used to size the array and battery to handle unexpected bad weather.

3.1.4. Gather Information about the climate

Accurate location and Weather data is important for proper system sizing. Data on solar radiation or insolation must be obtained not for a season or a year but accumulated over many years.

Temperature range must be well known as modules loose power potential and batteries loose life expectancies with higher temperature.

Local knowledge about the variability of the weather is important to gather. The severity and duration of seasonal storms would be helpful.

3.1.5. Considering Trade offs

System design involve some degree of compromise between competing and desirable qualities. The various choices that needs to be considered are Type and Size of equipment, Location, Amount of Back up, Degree of safety and protection required, Initial costs and Time period etc. All these factors create a dilemma to the designer in terms of:

- Efficiency Vs Simplicity
- Reliability
- Initial cost Vs Lifetime cost
- Centralized Vs Distributed generation

3.1.6. Anticipate and Guess

System designers should think about what could go wrong and try to incorporate equipment that can help prevent abuse of the system and premature failures. Consider an example:

Often photovoltaic power systems are installed where no electrical power was available before. Once user becomes accustomed to using it, they may use much more than the system designer was told they would. Lights and Appliances may be left ON for more hours than planned or extra loads might get added. Feed back to the users from low voltage alarms can help educate them about their overuse, so that non essential loads can be stopped before the batteries are over discharged.

3.2. System Design Philosophy

The data gathered as indicated above is used to make the choices needed during system design. Design is not just plugging in some numbers in respective formulae. It involves balancing calculations with judgments and selecting elements and subsystems based on information about climate, load and the client background.

A few important steps that need to be considered in system design is given below.

3.2.1. System design issues

Array sizing: The number of modules to be connected in series and parallel to build the array can be calculated depending on the basis of energy requirement

Battery bank sizing: The capacity and voltage of the battery bank can be calculated based on the depth of discharge, duty cycle and autonomy required.

Wiring and Safety components: Design should consider safe hardware required like circuit breaker, fuse etc. for safety of the system.

User interface: Hardware needed to provide user interface like simple dials or fancy digital meters can be chosen. Remote transmission of system parameters can be designed incase necessary.

DC or AC or Hybrid: Type of systems like DC system, AC system, Standalone system, Hybrid system etc. need to be considered.

Array mounting: Mounting structure design must be made allowing provision for module additions in future.

3.2.2. Installation issues

In a theoretically well designed system, if the equipment is not installed properly, the system could fail. Bad communications between designers and installers can lead to wasted time and money resulting in a faulty system.

The following are installation issues that need to be considered in system design:

Pre assemble as much as possible: System should be pre-assembled as much as possible, and shipped to the site, ready for installation. This ensures that all the components are working together. If required, finer adjustments can be done at the site as needed.

Site selection: Site investigation shall be carried out before or during system design to assimilate the terrain conditions. Foundation design shall depend on the type of soil, the wind loading, growth of vegetation, subsoil water etc.

Safe practices and codes: Safe practices should be followed during the installation. All local and regional building codes and safety measures need to be considered.

Inspection: Each component and the sub systems should be fully tested before the installation is considered complete. Abnormal operations should be corrected.

3.2.3. Delivery issues

One of the parameters that need to be considered during system design is packaging and transportation issues. The users may not understand the importance of shading on the modules or regular battery maintenance etc. It is important to visualize post commissioning scenarios while carrying out system design.

System description manual: User shall be provided with a user manual in simple language. Working principle of system shall be explained with the help of sketches and diagrams.

Trouble shooting guide: The guide should provide the Symptoms, Possible causes, and Corrective actions.

Service and Maintenance manual: The manual should show the user with simple pictures what to check and when and how they should perform the service.

3.3. System Design Procedure

3.3.1. Load Estimation

Load estimation is associated with careful investigation and calculation as loads influence every aspect of system design. The most important concern is to know what influences load efficiency and how to reason out with a client to replace their existing or proposed load with a more efficient one.

The entire system design is based on size of the load. If the information is inaccurate, the initial costs will be too high or the array and battery could be too small and system will eventually fail. So assessment of load is the critical factor in system design. The following are few important points that need to be considered in load assessment.

- The load profile throught the year must be accurately determined
- Any seasonal variation might influence the choice of tilt angle or battery size for autonomy
- The duty cycle or hours of operation for intermittent loads must be estimated carefully

Required Formulae

1. **DC load demand = DC load current (amps) X Hours of operation**
2. **AC load demand = AC load power (watts) X Hours of operation**
3. **DC load current (amps) = DC load power (watts) / Nominal DC voltage***

*This formula is used if DC loads are given in watts instead of amps.

Example 1:

A small remote cabin owner wants to install some lights and appliances. The remote cabin will only be occupied on the weekends. He will have two 40 watt fluorescent lights for bright kitchen lighting, three compact fluorescent lamps (PL Lights) at 11 watts each for other rooms, a small 40 Watt TV and a 24 watt ceiling fan. All these loads are to be DC so no inverter is required. All loads will operate at 12V nominal.

DC Loads	Quantity	Amps	Hours of operation	Days/week	Weekly demand (Wh)
Lights	2	3.3	4	2	52.8
PL Lights	3	0.92	5	2	27.6
TV	1	3.3	4	2	26.4
Fan	1	2	8	2	32
			Weekly DC Loads (Ah)		138.8

Example 2:

A small school in a remote area wants to remove their generator and use only photovoltaics to power all their loads. The school is to be occupied only during the week (Monday-Friday). The school has eight 40 watt fluorescent lights, small lights in the bath rooms, four computers, an overhead projector and a small microwave oven for heating lunches and a refrigerator. Note that the refrigerator is not turned off and must be kept operating during all seven days.

DC Loads	Quantity	Watts	Hours of operation	Days/week	Weekly demand (Wh)
Lights	8	40	8	5	12800
PL Lights	2	11	2	5	222
Computer	4	200	4	5	8000
Projector	1	300	3	5	4500
Microwave	1	800	2	5	8000
Refrigerator	1	300	3	7	16800
			Weekly AC loads (Wh)		50320

Week averaged daily load (Wh) **= Weekly loads (Wh) / 7**

= 50320 / 7

= 7188

3.3.2. Battery Sizing

A storage battery is an electrochemical cell which stores energy in chemical bonds. In Standalone PV systems, the electrical energy produced by the PV array cannot always be used when it is produced. The three primary functions of a storage battery in a PV system are:

Energy storage capacity and Autonomy:

The purpose of storage system is to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand. In system sizing process, the PV array is generally sized to satisfy the average daily load demand during the period with the lowest insolation to electrical load ratio to ensure that sufficient energy is available at all the times of the year.

Autonomy or days of storage: It is referred in the context of battery capacity of a standalone PV system. A stand alone PV system is said to have autonomy if sufficient battery storage capacity is available to operate the electrical loads directly from the battery, without any energy input from PV array.

The Depth of Discharge (DOD) of a battery: It is defined as the percentage of capacity that has been drawn from a battery compared to the total fully charged capacity.

Voltage and Current Stabilization: To supply power to electrical loads at stable voltages and currents, by smoothing out transients that may occur in PV systems

Supply surge currents: To supply surge or high peak operating currents to electrical loads or appliances

Maximum percentage usable: The battery cannot be discharged completely without affecting its life. Manufacturers recommend only 80% of deep cycling batteries and about 50% of shallow cycling batteries be discharged.

Temperature derating: This factor make sure that more capacity is installed at 25^0C, so that when the battery gets cold and loses some capacity, there will still be required capacity present.

Rate Factor: This factor is included to bring the calculations back to the manufacturer's standard rate.

Required Formulae

1. **Battery Voltaic Efficiency = Voltage during discharge / Voltage during charge**
2. **Battery Coulombic Efficiency = Discharge Ah output / Charge Ah input**

3. **Amp-hours PV array must produce = Daily load demand in Ah /**

   Battery Coulombic Efficiency

4. **Battery Energy Efficiency = Voltaic Efficiency X Coulombic Efficiency**
5. **Battery Capacity = (Number of Days of Reserve X Daily load) /**

   (Maximum % usable X Temperature derate X Rate factor)

6. **Number of Series Batteries = Load nominal voltage / Battery nominal voltage**

Example 1:

A battery is charged at about 14 volts and discharged at about 12 volts Calculate the voltaic efficiency of the battery

Battery Voltaic Efficiency = Voltage during discharge / Voltage during charge

= 12 volts / 14 volts

= 0.85

= 85%

Example 2:

The load demand for a remote home is estimated to be 200 Ah/day at 12 V. Using an average battery coulombic efficiency of 90%, calculate the total Ah that the array must produce.

Amp-hours PV array must produce = Daily load demand in Ah /

Battery Coulombic Efficiency

= 200 / 0.90

= 222 Ah

Example 3:

Calculate the battery capacity needed for the remote school with the following assumptions

- The local meteorologist reports that it gets to an average of $-20^{0}C$ in the winter at the site.

- School will operate for 5 days in a week
- Daily load is 421 Ah
- Number of days of reserve is 5 days
- Battery capacity assumed 1560 Ah, 2 V

Solution:

1. Considering the freezing phenomenon, the maximum allowable depth of discharge is about 50% or 0.5, even though we are using 'deep cycling' type batteries that usually can be discharged to 80%

   Avg. rate of discharge = No. of days of operation X No. of hours a day / Depth of discharge

   = (5 x 24) / 0.5

   = 240 hr rate

2. The rate factor for a battery can be obtained from the specific battery table. Assume the rate factor is 1.56

3. Calculating Battery capacity

   Battery Capacity = (Number of Days of Reserve X Daily load) / (Maximum % usable X Temperature derate X Rate factor)

   = (5 days X 421 Ah/day) / (0.5 X 0.85 X 1.56)

   = 3175 Ah

4. Number of batteries

   Parallel batteries = Battery capacity / Chosen battery capacity

   = 3175 / 1560 (assumed)

   = 2.03

Series batteries **= System voltage / Chosen battery voltage**

= 24 / 2 (assumed)

= 12

3.3.3. Inverter Issues

A photovoltaic array and battery produce DC current and voltage. If the load is driven by AC power, an inverter can be used to convert from DC to AC. Commonly available inverters can output in Single or Three phase, 50 or 60 Hz and 117 or 220 volts. The following are the list of important factors that needs to be considered in inverter design.

Inverter efficiency: The inverter should be as efficient as possible, certainly above 90% over most of its normal operating range. Many moderately priced inverters can achieve above 94% efficiency. Inverter efficiency varies with respect to the amount of power being generated.

Inverter Output Waveform: The wave form of the inverter output can be an important factor in matching inverter to load. The waveform describes the way the current and voltage vary over time. There are three different kinds of wave forms. They are Square wave, Sine wave, Modified square wave or Modified sine wave.

DC Input voltage: The input DC voltage tends to be a function of the size of the inverter. As the power through the inverter increases, more current flows and there is greater internal heating. Small inverters tend to operate in 12V while large inverters tend to operate in 24V.

Voltage Regulation: At higher power levels, the inverter draws large currents from the battery. This causes the battery voltage to fall. The inverter should be able to compensate for this voltage drop and maintain output AC voltage fairly well.

Serviceability: The inverter design should allow easy servicing in the field

Adjustable Threshold: Most Inverters have some threshold of load power requirement before they actually turn on and commutate to produce AC power. If the load threshold is higher than some small loads in a house, the inverter may not sense the load and it will not operate alone. Some inverter models offer an adjustable threshold level.

3.3.4. Charge Controllers

Battery charge regulation and control of the energy produced by the PV array is a critical function in the PV system. The most important functions of charge controllers are listed below.

- Prevent battery overcharge
- Prevent battery over discharge
- Provide load control functions
- Provide status information to system users
- Interface and Control back up energy sources
- Divert PV energy to an Auxiliary load
- Serve as wiring center

3.3.5. Array Sizing

The basic method to calculate the array size is to divide the average daily **Ah** load by the number of **Ah** that one module will produce in a day. This gives us the number of modules connected in parallel to produce the current for the load. The number of modules needed in series is given by dividing the nominal system voltage by the nominal voltage of one module. The module duration and the coulombic efficiency, the array sizing can be done.

Required Formulae

1. **Number of modules in parallel = Daily load (Ah) /**

   (Coulombic Efficiency X Module Output X Derating factor)

2. **Number of modules in series = Daily load (Ah) /**

   (Coulombic Efficiency X Module Output X Derating factor)

   = Nominal system voltage /

   Nominal voltage of one module

Example 1:

For the remote school 24V DC load demand was determined to be 421 Ah/day. The insolation data from the NASA source is worked out 4.0 kWh/m^2/day. The module considered is 75 Wp with Imp of 4.4.A. Calculate the number of modules in series and parallel. Assume that the conservative battery coulumbic efficiency of 90% and module duration of 10%

Module output = 4.0 X 4.4 = 17.6 Ah/day

Number of modules in parallel **= Daily load (Ah) /**

(Coulombic Efficiency X Module Output X Derating factor)

Number of modules in parallel **= 421 (Ah) / (0.9 X [1.76 X 0.9])**

= 29.5

= 30 modules in parallel

Number of modules in series **= 24 volts / 12**

= 2 in series

Total modules = 2 X 30 = 60 modules

3.4. Designing Solar Home Lighting Systems (Case study)

3.4.1. Case description

A small school in a remote area of city Jessor in Bangladesh wants to remove their generator and use only solar photovoltaics to power all their loads. The school is to be occupied in two shifts first in morning from 10 am to 4 pm and second in evening from 4:30 pm to 8:30 pm during the week. The school has three class rooms, one office room and two toilets.

The solution for this case starts with load assessment.

3.4.2. Assessment of Load profile

Assessment of load profile includes the various appliances, wattage of the appliance and the number of hours the appliance will operate a day. The connected appliances in the school is given in the form of table below. Typical format for the load assessment is provided in Annexure 1

Table 5: Load assessment profile

Lighting Load						
S. No.	Space	No. of CFL	Wattage of CFL	Total Wattage	Hours of operation	Total Watt-hours
1	Class room 1	4	15	60	4	240
2	Class room 2	4	15	60	4	240
3	Class room 3	4	15	60	4	240
4	School office	2	15	30	4	120
5	Toilet 1	1	6	6	4	24
6	Toilet 2	1	6	6	4	24
		Total		**222**		**888**

Fans Load						
S. No.	Space	No. of Fans	Wattage of Fan	Total Wattage	Hours of operation	Total Watt-hours
1	Class room 1	3	60	180	10	1800
2	Class room 2	3	60	180	10	1800
3	Class room 3	3	60	180	10	1800
4	School office	2	60	120	10	1200
		Total		**660**		**6600**

Computer						

S. No.	Space	No. of Computers	Wattage of Computer	Total Wattage	Hours of operation	Total Watt-hours
1	Office	1	300	300	6	1800
		Total		**300**		**1800**

Water Cooler						
S. No.	Space	No. of Coolers	Wattage of Cooler	Total Wattage	Hours of operation	Total Watt-hours
1	Common	1	200	200	5	1000
		Total		**200**		**1000**
*Assumed that the water cooler/refrigerator is functional for 24 hours a day, but the compressor of the water cooler operates only 5 hours a day.						

Total Watt Hours	**10288**
Total kW Hours	**10.288**

Load Profile at a glance

Table 6: Load profile at a glance

No.	Appliance	Wattage	Number	Rated wattage	Operational hours / day	Energy / day (Watt-hours)
1	CFL Lamps	15	14	210	4	840
2	CFL Lamps	6	2	12	4	48
3	Fans	60	11	660	10	6600
4	Computer	300	1	300	6	1800
5	Water cooler	200	1	200	5	1000
Total				**1382**		**10288**

- Total units required per day is 10.28 kWh
- Rounded off to 12 kWh/day

3.4.3. Typical System Design

Assumptions in System Design

- Solar PV system is considered.
- Latitude considered for site (Jessor city) – 23.2°N

- Longitude considered for site (Jessor city) – 89.2°E
- Daily solar insolation at 30° slope – 4.98 kWh/m2/day (high at 30^0C)
- PV module considered – MBPV 125
- Battery considered – LMS400
- Depth of discharge – 0.8
- Days of autonomy – 2
- Array output efficiency – 85%
- Inverter efficiency – 90%
- Battery efficiency – 85%

Battery Design

- Battery output required – 300Ah, 48 V
- At 80% depth of discharge, capacity required – 375Ah
- Capacity required with 2 days autonomy – 720Ah at 48V
- Selected battery – Exide LMS750, 2V, 750Ah
- Number of batteries in series – 24 nos.
- Number of batteries in parallel – 1 no.
- Total number of batteries = 24 x 1 = 24 nos.

PV Array Design

- PV array output required – 16.5 kWh, 48V
- Array output considering losses of 15% - 19.4 kWh
- Considering solar insolation of 4.98 hours array capacity – 3.89 kWp
- Module selection – MBPV125 (130Wp, 28.5Vmp, 4.5 Imp)
- Number of modules is series = 48/28.5 = 2
- Number of modules in parallel = 70/4.5 = 16

Inverter Capacity

- Inverter capacity required – 2 kVA, 1 phase, 48V/230V

Charge Controller

- Rating for charge controller – 70 Amps, 48 V.

Overall System Design

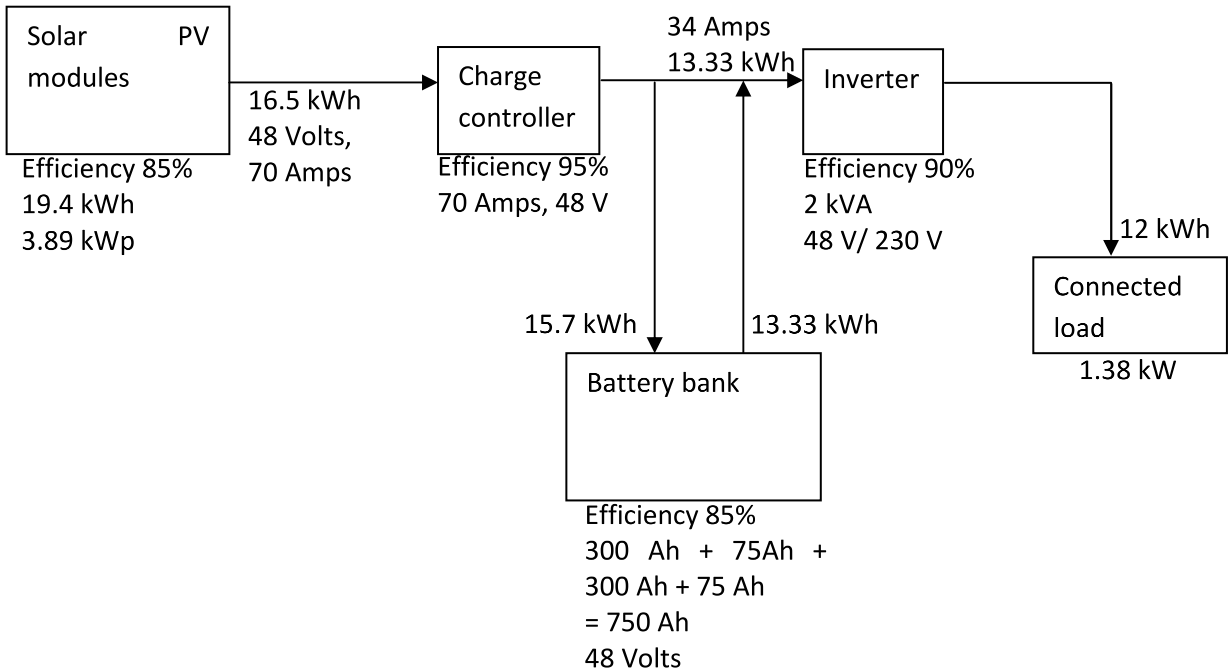


Figure 29: SPV Home Lighting System design diagram

After completion of the typical system design, the specification sheet for the system needs to be prepared. Typical checklist of the SPV home lighting system is provided in Annexure 2

3.4.4. Request for Quotation (RFQ)

Once the preliminary system has been designed based on the load requirement, the enquiry forms should be send to various Manufacturers or System integrators requesting for quotations. The process of inviting quotations also be done through 'Tender' process. Typical enquiry form must seek quotations in the following sections.

- General Terms & Conditions to the supplier
- Technical specifications
    - Specifications of the load
    - Specifications of the SPV Home lighting System
        - SPV modules
        - Battery
        - Inverter
        - Charge controller
    - Scope of Civil Works
    - Scope of Operations & Maintenance
- Commercial Details
    - Cost of the SPV System
    - Cost of Civil works
    - Cost of Operations & Maintenance
    - Summary of Costs
- Annexure (if any)

3.4.5. Evaluation of Quotations

The quotations received in response to enquiry have to be evaluated in detail. If the quotations are not meeting the techno-commercial criteria, those will have to be rejected. The following points have to be considered while evaluating the quotations.

- Are all the General Terms & Conditions satisfied by the supplier
- Is system technically correct
- Are the commercial aspects and calculations correct

Once the bidder has been qualified in all the respects mentioned above, the commercial details have to be recorded for evaluation purpose. A typical format for the Technical and Commercial evaluation of Solar home lighting system is provided in Annexure 3.

3.4.6. Negotiation with the Parties

After successful evaluation of quotations, the discussions have to take place with the successful parties for negotiation and finalization of the order. The following points need to be considered during the discussion phase.

1. **Credibility of the company:** Is the company credible for negotiation is the first point we need to look at. The credibility of the company is assessed in terms of

    - **Financial strength of the company:** The aggregate turnover and profitability of the company during the last three years
    - **Organizational strength of the company:** The organizational strength of the company can be assessed in terms of
        - Existing Infrastructure of the company
        - Organizational mission and quality policy
        - Managerial strength of the company
        - Technical strength of the company

2. **Technical parameters:** This is another important parameter to be considered while negotiating. This is based on the technical specification of the components used for the system. The following are the various attributes to be reckoned:

    - **Modules:** Are the modules proposed for the system complying with the standards like IEC or Any other International standards
    - **Inverters:** Are the Inverters proposed for the system complying with the standards like IEC or Any other International standards. Is the Inverter field proven?
    - **Battery:** Are the Batteries proposed for the system complying with the standards like IEC or Any other International standards. Are these batteries from renowned make?
    - **Warranty/Guarantee:** The period of warrantee/guarantee offered by the supplier for all the system components is also an important parameter.
    - **Track Record:** Has the company got track record in installing similar system so far. If so, Are those systems running without any major faults?

3. **Financial parameters**: This is the most important parameter of interest during the negotiation period. This is based on the pricing offered by the supplier with respect to each component and also system as a whole. The following are the various attributes conducive for this.

    - **Price:** Is the price quoted by the supplier at par with the technical performance offered.

- **Payment Terms:** Has the supplier agreed for the payment terms given by us or any modification required in that regard.

Once the discussions and negotiations are held with all the parties, they are shortlisted by ranks and order is finalized with the party offering both techno commercial benefits.

3.4.7. Finalization of Order

After finalization of the party, the order has to be released incorporating the minutes of the discussions. The following points need to be incorporated in the order.

- **System design parameters:** Any deviations between the enquiry specifications and trial offer shall be taken of.

- **Cost estimates:** The revised cost estimates finalized during the discussion phase shall be incorporated in the final order.

3.4.8. Inspections of goods Received

Once the order has been placed, the supplier starts supplying the components of the system. A quality check has to be performed even though the components have been tested by the respective agency. The following are various attributes to be considered during the inspection of goods.

1. **Items complying with general standards:** Are all the items/components supplied matching the standards specified like
   a. Design standards
   b. Safety standards etc.
2. **Acceptance test standards:** Once the components are satisfying the general standards, the components have to be examined for acceptance standards. The following are few categories of acceptance standards that need to be considered.

- **Type test:** Type testing is to check whether the component is meeting the rated conditions specified in the standards to which the component is affiliated.
- **Routine test:** Routine test is testing the components for its voltage, current and test whether the component is satisfying the I-V curve etc.
- **System performance test:** Testing the overall system performance after integrating all the components is as System performance test.

3. **Acceptance test standards:** Inference against all the standards used to test various components of the system and the overall system performance testing have to be reported properly.

3.4.9. Parameters to be checked during Installation

The following factors are to be considered during the installation.

1. **Mounting structures:** How the structures are mounted? What is the material used for that? What is the angle considered? What is the soil condition? What are the tools used?
2. **Protective measures taken:** What are the protection measures taken for various components and system? Are they in line with the protection standards
3. **Grounding and Cabling:** Weather suitable grounding mechanism has been adopted or not. Are all the cabling done as per standard techniques
4. **Training to the operator:** Has the supplier trained the operator properly to handle the system carefully
5. **Operation & Maintenance manual:** Whether the operation & maintenance manual has been handed over to the operator or not.

3.5. Designing Stand alone Solar PV Power Plant

Case study 1

3.5.1. Case Description

A small village in a remote area of city Amravati in Maharashtra has been facing a lot of problems because of the frequent load shedding. The villagers are well educated and are interested in having a 2 kW standalone solar photovoltaic power plant to cater to their daily most critical domestic electricity needs for 5 hours a day.

3.5.2. Power Generation

The power generated from the 2kW SPV power plant is 10 units a day. The system design computation is supplemented along with this in the form of XL sheet.

3.5.3. Typical System Design

Assumptions in System Design

- Solar PV system is considered.
- Latitude considered for site (Amravati city) – 21.0°N
- Longitude considered for site (Amravati city) – 77.8°E
- Daily solar insolation at 25° slope – 5.54 kWh/m2/day
- PV module considered – MBPV 125
- Battery considered – LMS650
- Depth of discharge – 0.8
- Days of autonomy – 2
- Array output efficiency – 85%
- Inverter efficiency – 90%
- Charge controller efficiency – 95%
- Battery efficiency – 85%

Battery Design

- Battery output required – 250Ah, 48 V
- At 80% depth of discharge, capacity required – 315Ah
- Capacity required with 2 days autonomy – 630Ah at 48V
- Selected battery – Exide LMS650, 2V, 650Ah
- Number of batteries in series – 24 nos.
- Number of batteries in parallel – 1 no.
- Total number of batteries = 24 x 1 = 24 nos.

PV Array Design

- PV array output required – 13.78 kWh, 48V

- Array output considering losses of 15% - 16.21 kWh
- Considering solar insolation of 5.54 hours array capacity – 3.00 kWp
- Module selection – MBPV125 (130Wp, 28.5Vmp, 4.5 Imp)
- Number of modules is series = 48/28.5 = 2
- Number of modules in parallel = 60/4.5 = 14
- Total number of modules = 14 x 2 =28 nos.

Inverter Capacity

- Inverter capacity required – 2 kVA, 1 phase, 48V/230V

Charge Controller

- Rating for charge controller – 60 Amps, 48 V

Overall System Design

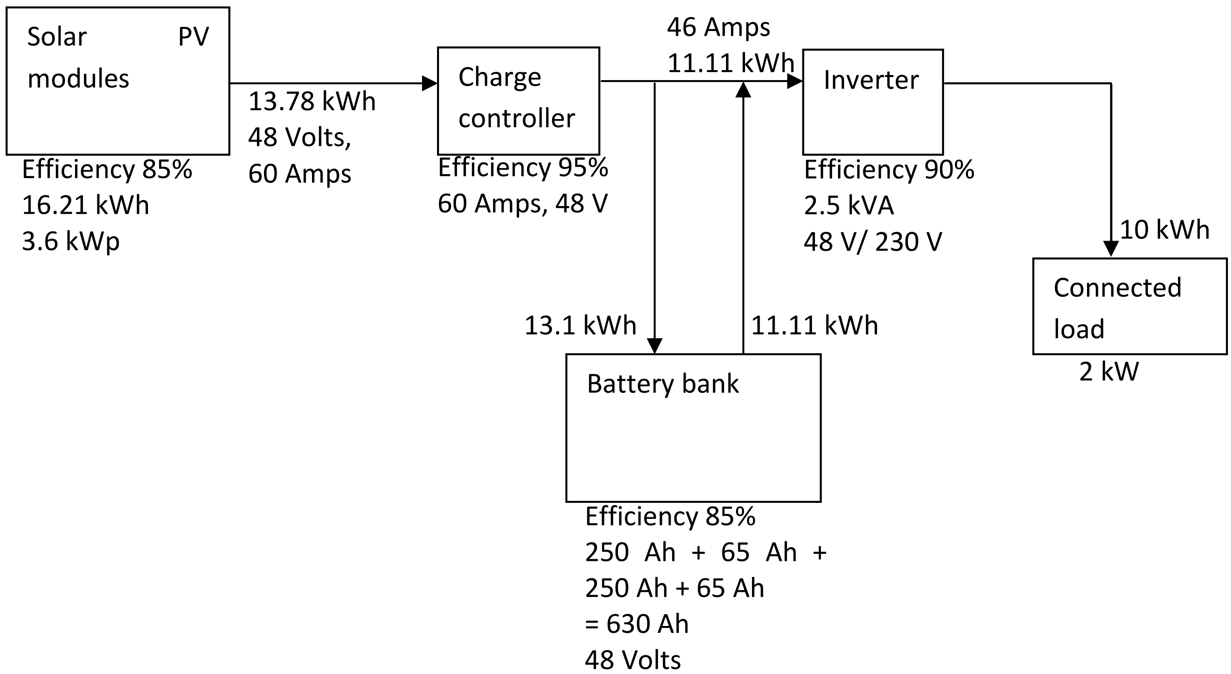


Figure 30: Standalone solar PV power plant design diagram

Case study 2

3.5.4. Case description

Let's consider a typical case of putting up of a 100kW grid-connected Solar PV power plant. The following are the different sites considered for this purpose.

1. Chandrapur, Maharashtra, India
2. Bhuj, Gujarat, India
3. Jaisalmer, Rajasthan, India

3.5.5. Site Evaluation

Step 1:

The first step in the system design is to locate proper site for the power plant. It is assumed that a clear south faced and Non fertile barren land is available in following places.

1. Chandrapur, Maharashtra, India
2. Bhuj, Gujarat, India
3. Jaisalmer, Rajasthan, India

Step 2:

The second step is to calculate the insolation level at all the three places. This can be done either from the NASA Surface Meteorology and Solar Energy as explained in section 2.3.3 or it can also be done by using RET Screen software.

The process of selecting suitable location using RET Screen software is explained here. The atmospheric data provided by the software considers various effects such as air temperature, humidity, daily solar radiation (plane surface), wind speed, earth temperature etc. on a monthly basis.

Step 3:

The third step is to choose most preferable site by comparing the necessary atmospheric data. The necessary atmospheric data for all the three sites is given in Table 7, 8 and 9 respectively.

Table 7: Climate data for Chandrapur Site

Site	Chandrapur							
Latitude	20.0 ˚N							
Longitude	79.3 ˚E							
Elevation	293 m							
Month	**Air temperature**	**Relative humidity**	**Daily solar radiation (horz.)**	**Atmospheric pressure**	**Wind speed**	**Earth temp.**	**Heating degree-days**	**Cooling degree-days**
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	23.2	45.7%	4.80	98.1	2.5	25.3	0	410
February	26.0	40.2%	5.65	97.9	2.8	29.4	0	448
March	30.0	34.5%	6.23	97.6	2.7	34.9	0	620
April	31.6	40.0%	6.64	97.3	2.9	36.9	0	648
May	33.6	38.5%	6.51	97.0	2.9	38.4	0	732
June	30.0	61.3%	4.76	96.9	3.0	32.4	0	601
July	27.5	72.6%	3.91	97.0	3.0	28.5	0	542
August	26.9	73.8%	3.77	97.1	2.9	27.5	0	523
September	27.1	69.2%	4.60	97.3	2.3	28.2	0	514
October	26.4	59.2%	5.02	97.6	2.2	27.7	0	508
November	24.6	47.1%	4.91	98.0	2.5	25.9	0	438

December	22.6	44.2%	4.66	98.2	2.5	23.9	0	391
Annual	27.5	52.3%	**5.12**	97.5	2.7	29.9	0	6,375
	Average						Total	

Table 8: Climate data for Bhuj Site

Site	Bhuj							
Latitude	23.3 ˚N							
Longitude	69.7 ˚E							
Elevation	80 m							
Month	**Air temperature**	**Relative humidity**	**Daily solar radiation (horz.)**	**Atmospheric pressure**	**Wind speed**	**Earth temp.**	**Heating degree-days**	**Cooling degree-days**
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	17.4	60.5%	4.24	101.2	1.4	23.9	19	229
February	21.2	56.2%	4.95	101.0	1.8	26.2	0	314
March	26.2	55.5%	5.67	100.8	2.3	30.7	0	502
April	29.9	54.7%	6.31	100.5	3.4	33.4	0	597
May	31.9	60.7%	6.47	100.1	4.3	33.9	0	679
June	32.2	65.8%	6.18	99.7	4.6	33.0	0	666
July	30.1	74.6%	5.24	99.7	4.6	31.0	0	623
August	29.0	74.8%	4.96	99.9	4.2	30.3	0	589
September	29.1	71.4%	5.28	100.3	3.0	31.7	0	573
October	28.6	58.5%	4.94	100.7	1.5	32.5	0	577
November	23.7	54.0%	4.33	101.0	1.1	29.4	0	411
December	18.8	56.5%	3.99	101.2	1.0	25.3	0	273
Annual	26.5	62.0%	**5.21**	100.5	2.8	30.1	19	6,033
	Average						Total	

Table 9: Climate data for Jaisalmer Site

Site	Jaisalmer							
Latitude	26.9 ˚N							
Longitude	70.9 ˚E							
Elevation	130 m							
Month	**Air temperature**	**Relative humidity**	**Daily solar radiation (horz.)**	**Atmospheric pressure**	**Wind speed**	**Earth temp.**	**Heating degree-days**	**Cooling degree-days**
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	16.3	34.9%	3.87	100.1	3.6	17.9	53	195
February	18.8	29.9%	4.60	99.9	3.7	21.1	0	246
March	24.6	25.2%	5.33	99.5	3.9	27.9	0	453
April	29.0	29.0%	6.14	99.1	4.0	33.2	0	571
May	31.8	37.4%	6.59	98.7	4.4	36.0	0	675
June	31.9	51.5%	6.62	98.4	4.9	35.8	0	657
July	30.6	63.7%	5.86	98.3	3.9	33.9	0	638
August	29.5	66.4%	5.54	98.6	3.5	32.4	0	605
September	29.5	53.4%	5.32	99.0	3.8	32.8	0	584
October	27.8	31.9%	4.74	99.5	3.4	30.7	0	552
November	22.9	27.1%	3.92	99.9	3.6	24.7	0	388
December	18.2	31.0%	3.55	100.2	3.7	19.4	0	253
Annual	25.9	40.2%	**5.17**	99.3	3.9	28.8	53	5,817
	Average						Total	

One can conclude from the tables that the annual average daily solar insolation is highest in the Bhuj site, which is 5.21 kWh/m^2/day. Hence, the solar power plant located in Bhuj will yield highest electrical energy.

3.5.6. Typical System Design

Technology Selection

The calculation of energy generation pertaining to the location is also based on the type of modules used for energy generation. The SPV technologies considered in this scenario are Crystalline and Thin Film technologies.

After site identification and evaluation, one has to look for the appropriate technology which yield maximum energy in that location. With the help of RET Screen, the technology which produces highest energy output at Bhuj Site can be identified. Tables 10 and 11 provide the typical energy generated by 100kW PV system at the Bhuj site considering poly-Si (poly silicon) and a-Si (amorphous silicon) technologies, respectively.

Table 10: Energy generation for Bhuj Site with poly-Si technology

Photovoltaic	**Unit**	
Type		poly-Si
Power capacity	kW	100.00
Efficiency	%	13.0%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.40%
Solar collector area	m^2	769
Miscellaneous losses	%	1.0%
Inverter		
Efficiency	%	95.0%
Capacity	kW	100.0
Miscellaneous losses	%	3.0%
Summary		
Capacity factor	%	19.0%
Electricity exported to grid	MWh	166.77
Resource assessment		
Solar tracking mode		Fixed
Slope	°	22.0
Azimuth	°	0.0

Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid
	kWh/m²/d	**kWh/m²/d**	**MWh**
January	4.24	5.32	14.21
February	4.95	5.77	13.66
March	5.67	6.08	15.56
April	6.31	6.25	15.24
May	6.47	6.04	15.16
June	6.18	5.63	13.73
July	5.24	4.87	12.49
August	4.96	4.80	12.34
September	5.28	5.45	13.43
October	4.94	5.57	14.16
November	4.33	5.25	13.21
December	3.99	5.11	13.59
Annual	**5.21**	**5.51**	**166.77**
	Average		**Total**

Table 11: Energy generation for Bhuj Site with a-Si technology

Photovoltaic	**Unit**	
Type		a-Si
Power capacity	kW	100.00
Efficiency	%	7.0%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.11%
Solar collector area	m^2	1,429
Miscellaneous losses	%	1.0%
Inverter		
Efficiency	%	95.0%
Capacity	kW	100.0
Miscellaneous losses	%	3.0%
Summary		
Capacity factor	%	20.4%
Electricity exported to grid	MWh	178.82
Resource assessment		
Solar tracking mode		Fixed
Slope	°	22.0
Azimuth	°	0.0

Month	**Daily solar radiation - horizontal**	**Daily solar radiation - tilted**	**Electricity exported to grid**
	$kWh/m^2/d$	**$kWh/m^2/d$**	**MWh**
January	4.24	5.32	14.81
February	4.95	5.77	14.44
March	5.67	6.08	16.74
April	6.31	6.25	16.59
May	6.47	6.04	16.56
June	6.18	5.63	14.95
July	5.24	4.87	13.42

August	4.96	4.80	13.24
September	5.28	5.45	14.51
October	4.94	5.57	15.31
November	4.33	5.25	14.05
December	3.99	5.11	14.21
Annual	**5.21**	**5.51**	**178.82**
	Average		**Total**

In the case of Bhuj, it could be observed from the above tables that poly-Si technology will generate 166.77 MWh/year (166770 kWh /year) and a-Si technology will generate 178.82MWh/year (178820 kWh /year). So it is clear that the a-Si (amorphous silicon) technology is a better option for 100kW solar PV system at Bhuj Site.

Load Estimation

The equipments connected to the plants also have some efficiency factor. Therefore before designing the system it is necessary to calculate the efficiency of all the equipments so that the plant can cater to 100 kW of load. Following are the details of the various loads which are to be catered by the system. It includes inverter efficiency, power backup for the day in hours and so on.

A.	**Loads**			
A1	Inverter efficiency (decimal)	0.95		
A2	Battery Bus Voltage (DC)	220	volts	
A3	Inverter AC Voltage (3Ph, 50 Hz, AC)	415		
A4	Rated Wattage (Watts)	100,000		
A5	1.0 for DC (A1 for AC)	0.95		
A6	Adjusted Wattage (A4/A5)	105,263.16		
A7	Hours per day	4		
A8	Energy per day (A6 x A7) (Watt-hour)	421,052.63		
A9	Total energy demand per day (Summation A8)	421,052.63		
A10	Total amp-hour demand per day (A9/A2)	1913.8756		
A11	Max AC Power requirement	100,000		
A12	Max DC power requirement	105,263.16		

Battery Design

After estimating the loads the second part is battery sizing, for this case the power backup capacity is designed for four hours in a day, the depth of discharge for the batteries is taken as 0.5. Voltage and current rating of battery is 2 Volts and 1000 Ah respectively. For this particular case the Exide make of battery has been considered. By knowing the voltage and current capacity of the battery the series and parallel combination can be made to meet the demand.

B.	**Battery Sizing**			
B1	Days of storage desired	1		
B2	Allowable depth of discharge (d.o.d.)	0.5		
B3	Required battery Capacity (A10*(B1/B2))	3827.75		
B4	Amp - hour Capacity of selected battery (2 Volts)	1000	Ah	
B5	Number of batteries in parallel (B3/B4)	3.83	4	Nos
B6	Number of batteries in series (A2/Batt. Voltage)	110.00		
B7	Total number of batteries (B5*B6)	421.05		
B8	Total battery amp-hour capacity (B5*B4)	3827.75		
B9	Total battery kilowatt-hour capacity (B8*(A2/1000))	842.11		
B10	Average d.o.d (A10/B8)	0.5		

PV Array Design

The module type considered in this case is T-EC120 of Kaneka make, the rated capacity of the module is 120Wp at STC (Standard Test Condition), for estimating the number of modules it is necessary to calculate the connected load which has to be fed by the SPV modules. Battery efficiency also has to be considered. The following table represents the number of modules required to build up the required voltage and current.

C.	**Photovoltaic Array Sizing**			
C1	Total energy demand per day (A9)	421,052.63	Watt hour	
C2	Battery round-trip efficiency	0.85		
C3	Required array output / day (C1/C2)	495356.04	Watt hour	
C4	Selected PV Modules Max power voltage (at STC x 0.85)	67	Volts	
C5	Selected PV modules guaranteed power output at STC	120	Watts	
C6	Annual average solar insolation	5.21		
C7	Energy Output/module/day (C5 x C6)	625.2	Watt hour	
C8	Module energy output at operating temperature (C7 x 0.81)	506.41	Watt hour	
C9	Number of modules required (C3/C8)	978.17		
C10	Number of modules required/string (A2/C4)	3.28	4	Nos.
C11	Number of strings in parallel (C9/C10)	297.90	298	Nos.
C12	Number of modules to be purchased (C10 x C11)	978.17	979	Nos.
C13	Nominal rated PV modules output	120	Watts	
C14	Nominal rated array output (C13 x C12)	117380.17	Watts	

Inverter Capacity

The heart of the SPV power plant will be the inverter. The inverter converts DC power supply to AC power supply. The continuous AC power output required is determined by (A11) and maximum DC power requirement is determined by (A12).

D.	**Inverter**			
D1	Max. DC power requirement (A12)	105,263.16	Watts	
D2	Max. AC power requirement (A11)	100,000.00	Watts	

3.5.7. Request For Quotation (Case study 1&2)

Once the preliminary system has been designed based on load requirement, the enquiry forms should be send to various manufacturers or System integrators requesting for quotations. The process of inviting quotations also be done through 'Tender' process. Typical enquiry form must seek quotations in the following sections.

- Selected site and the Corresponding Drawings
- General Terms & Conditions to the supplier
- Technical specifications
    - Specifications of the load
    - Specifications of the SPV system
        - SPV modules
        - Battery
        - Inverter
        - Charge controller
    - Scope of Civil Works
    - Scope of Operations & Maintenance
- Commercial Details
    - Cost of the SPV System
    - Cost of Civil works
    - Cost of Operations & Maintenance
    - Summary of Costs
- Annexure (if any)

3.5.8. Evaluation of Quotations (Case study 1&2)

The quotations received in response to enquiry have to be evaluated in detail. If the quotations are not meeting the techno-commercial criteria, those will have to be rejected. The following points have to be considered while evaluating the quotations.

- Are all the General Terms & Conditions satisfied by the supplier

- Is system technically correct
- Are the commercial aspects and calculations correct

Once the bidder has been qualified in all the respects mentioned above, the commercial details have to be recorded for evaluation purpose. A typical format for the Technical and Commercial evaluation of Solar PV power plant is provided in Annexure 4.

3.5.9. Negotiation with the Parties (Case study 1&2)

After successful evaluation of quotations, the discussions have to take place with the successful parties for negotiation and finalization of the order. The following points need to be considered during the discussion phase.

1. **Credibility of the company:** Is the company credible for negotiation is the first point we need to look at. The credibility of the company is assessed in terms of

- **Financial strength of the company:** The aggregate turnover and the profitability of the company during the last three years
- **Organizational strength of the company:** The organizational strength of the company can be assessed in terms of
    - Existing Infrastructure of the company
    - Organizational mission and quality policy
    - Managerial strength of the company
    - Technical strength of the company

2. **Technical parameters:** This is another important parameter to be considered while negotiating. This is based on the technical specification of the components used for the system. The following are the various attributes to be reckoned:

- **Modules:** Are the modules proposed for the system complying with the standards like IEC or Any other International standards
- **Inverters:** Are the Inverters proposed for the system complying with the standards like IEC or Any other International standards. Is the Inverter field proven?
- **Battery:** Are the Batteries proposed for the system complying with the standards like IEC or Any other International standards. Are these batteries from renewed make?

- **Warranty/Guarantee:** The period of warrantee/guarantee offered by the supplier for all the system components is also an important parameter.
- **Track Record:** Has the company got track record in installing the similar system so far. If so, Are those systems running without any major faults?

3. **Financial parameters**: This is the most important parameter of interest during the negotiation period. This is based on the pricing offered by the supplier with respect to each component and also system as a whole. The following are the various attributes conducive for this.

- **Price:** Is the price quoted by the supplier at par with the technical performance offered.
- **Payment Terms:** Has the supplier agreed for the payment terms given by us or any modification required in that regard.

Once the discussions and negotiations are held with all the parties, they are short listed by ranks and order is finalized with the party offering both techno-commercial benefits.

3.5.10. Finalization of Order (Case study 1&2)

After finalization of the party, the order has to be released incorporating the minutes of the discussions. The following points need to be incorporated in the order.

- **System design parameters:** Any deviation between the enquiry specifications and final offer shall be taken of.
- **Cost estimates:** The revised cost estimates finalized during the discussion phase shall be incorporated in the final order.

3.5.11. Inspections of goods Received (Case study 1&2)

Once the order has been placed, the supplier starts supplying the components of the system. A quality check has to be performed even though the components have been tested by the respective agency. The following are various attributes to be considered during the inspection of goods.

1. **Items complying with general standards:** Are all the items/components supplied matching the standards specified like

    a. Design standards

    b. Safety standards etc.

2. **Acceptance test standards:** Once the components are satisfying the general standards, the components have to be examined for acceptance standards. The following are few categories of acceptance standards that need to be considered.

- **Type test:** Type testing is to check whether the component is meeting the rated conditions specified in the standards to which the component is affiliated.
- **Routine test:** Routine test is testing the components for its voltage, current and test whether the component is satisfying the I-V curve etc.
- **System performance test:** Testing the overall system performance after integrating all the components is as System performance test.

3. **Acceptance test standards:** Inference against all the standards used to test various components of the system and the overall system performance testing have to be reported properly.

3.5.12. Parameters to be checked during installation (Case study 1&2)

The following factors are to be considered during the installation.

1. **Mounting structures:** How the structures are mounted? What is the material used for that? What is the angle considered? What is the soil condition? What are the tools used?
2. **Protective measures taken:** What are the protection measures taken for various components and system? Are they in line with the protection standards
3. **Grounding and Cabling:** Weather suitable grounding mechanism has been adopted or not. Are all the cabling done as per standard techniques
4. **Training to the operator:** Has the supplier trained the operator properly to handle the system carefully
5. **Operation & Maintenance manual:** Whether the operation & maintenance manual has been handed over to the operator or not.

3.6. Designing Solar PV Water Pumping System (Case study)

3.6.1. System Design Methodology

The following steps need to be followed to design a SPV system for water pumping applications.

1. **Solar Insolation availability:** Calculation of solar insolation availability in that region is an important parameter in the system design

2. **Pumping flow requirements:** It is a part of the actual load assessment each day. Determination of pumping flow requirements includes

    - Quantity of water requirement (gallons per day)
    - Determination of peak flow rate
    - Pipe inside diameter
    - Peak velocity

3. **Pumping head requirements (Static):** Next step is to calculate the static pumping head requirement which includes

    - Suction head requirement
    - Discharge head requirement
    - Static head requirement

4. **Pumping head requirements (Dynamic):** Next step is to calculate the dynamic pumping head requirement which includes

    - Velocity head requirement
    - Effective pipe length
    - Friction head requirement

5. **Pumping energy requirements:** Next step is to calculate the pumping energy requirement which includes

    - Hydraulic energy requirement
    - Hydraulic power requirement

6. **Selection of suitable pump:** Once the data required for pump has been calculated, the next step is to select the suitable pump. This can be done by looking into the efficiency graph of various

pump manufacturers. The following Figure 31 shows the efficiency graph for Jacuzzi SJ1 D10 pump. The selection of the pump can be done by considering

- Motor voltage at the design operating point
- Electric power required to drive the pump motor
- Daily energy requirement to meet the water demand

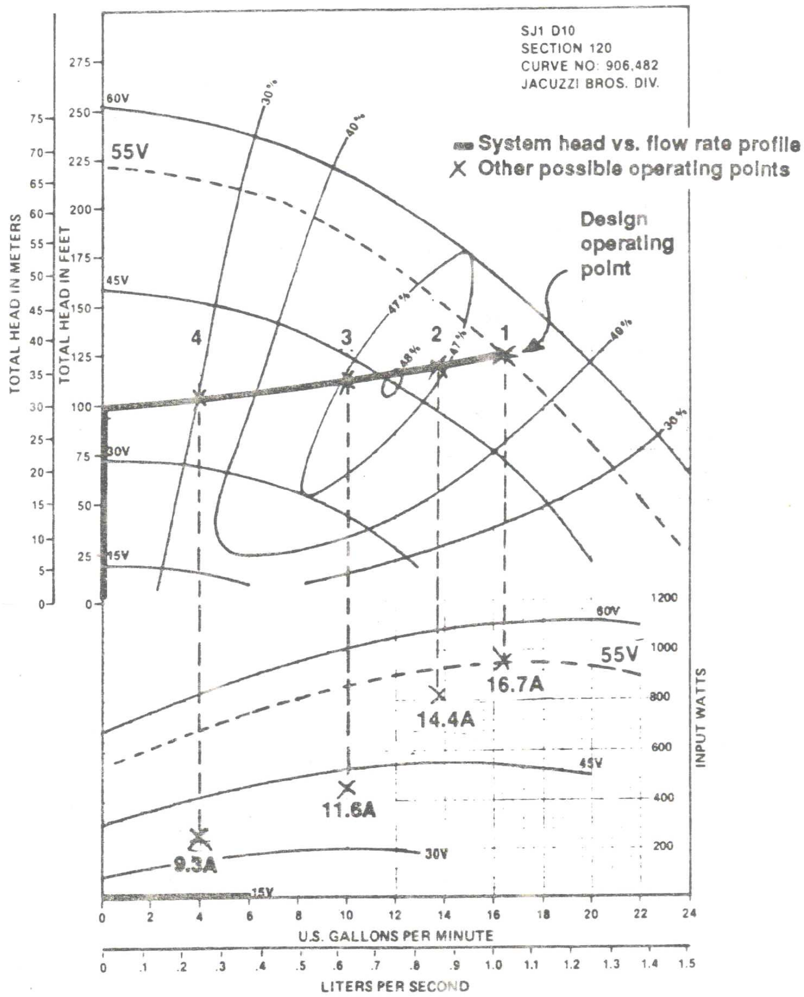


Figure 31: Efficiency graph for Jacuzzi SJ1 D10 pump
(Source: photovoltaic system design course manual)

3.6.2. Typical System Design

Case Description

A farmer in a small village near Raipur of Chhattisgarh, India is facing lot of problems from load shedding. Land and Water are available with him but due to lack of adequate electricity he is not able to irrigate his forms. So he is interested to irrigate his fields with the help of solar water pumping system to overcome the problems.

Assumptions in System Design

- Solar PV system is considered.
- Latitude considered for site (Raipur city) – 21.2°N
- Longitude considered for site (Raipur city) – 81.6°E
- Daily solar insolation at 25° slope – 5.38 kWh/m2/day
- PV module considered – MBPV 125
- Array output efficiency – 85%

Insolation Availability

A.	**Insolation availability**	**Qty**	**Unit**
A1	Daily insolation	5.38	$kWh/m^2/day$
A2	Usable insolation (95% of A1) (A1 x 0.95)	5.11	$kWh/m^2/day$
A3	Peak sun hours (A2)	5.11	$kWh/m^2/day$

Pumping Flow Requirement

B.	**Pumping flow requirement**	**Qty**	**Unit**
B1	Daily quantity of water requirement	4000	gallons/day
B2	Peak flow rate [B1/(A3x60)] (Gallons/day is divided by peak sun hours and 60 for converting into gallons/min)	13.04	gallons/min
B3	Pipe inside diameter	1	inches
B4	Peak velocity [$(B2/B3^2)$ x 0.408] (Peak flow rate is divided by square of diameter of pipe and multiplied by conversion factor of 0.408 to convert into ft/sec)	5.32	ft/sec

Pumping Head Requirement (Static)

C.	Pumping head requirements	Qty	Unit
	Static head		
C1	Suction lift (or head) (vertical distance from water surface to pump center) (refer Figure 32 below)	15	ft
C2	Discharge head (total vertical distance from pump center to free discharge point) (15 + 40 + 60)	115	ft
C3	Final discharge pressure higher than atmospheric pressure	0	Psig
C4	Pressure head (C3 x 2.31) (2.31 is the conversion factor for psig to ft)	0	ft
C5	Static head (60 + 40)	100	ft

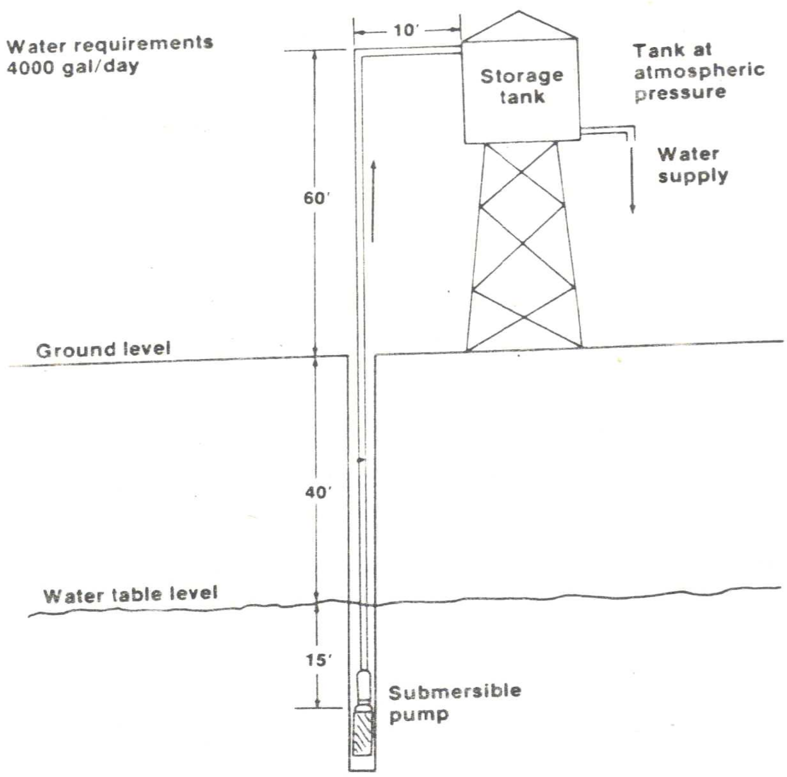


Figure 32: System Sizing of Solar PV Water pump

Pumping Head Requirement (Dynamic)

C.	Pumping head requirements	Qty	Unit
	Dynamic head		
C6	Velocity head ($B4^2$ x 0.0155) (0.0155 conversion factor used to convert ft/sec to ft)	0.44	ft
C7	Number of 90° bands required for fitting	1	no.
C8	Effective length of fitting	2.70	ft
C9	Actual pipe length (15 + 40 + 60 + 10)	125	ft
C10	Total effective length (C8 + C9)	127.70	ft
C11	Friction head (Friction head for 1 inch diameter pipe for 100 ft length is 17.8 ft therefore for 127.70 ft it will be 22.73 ft)	22.73	ft
C12	Total dynamic head (C6 + C11)	23.17	ft
C13	Total system head (C5 + C12)	124	ft

Pumping Energy Requirement

D.	Pumping energy requirements	Qty	Unit
D1	Hydraulic energy (B1 x C13 x 0.0031) (0.0031 conversion factor of units to watt-hours per day)	1538	Wh/day
D2	Hydraulic power (B2 x C13 x 0.188) (0.188 conversion factor of units to watts)	304	Watts

Pump Selection

E.	**Pumping selection** (selection of pump is done by the graph given in Figure 31)	Qty	Unit
E1	Motor voltage at the design operating point	55	Volts DC
E2	Electric power required to drive the pump motor	900	Watts
E3	Daily electric energy required to provide the daily water requirements (E2 x A3)	4600	Wh/day

PV Array Design

F.	**Photovoltaic array sizing**	**Qty**	**Unit**
F1	Selected PV modules guaranteed power output at STC	200	Watts
	(at STC x 0.85)	170	Watts
F2	Selected PV modules Maxpower voltage at STC	28	Volts
	(at STC x 0.9)	25.2	Volts
F3	Selected PV modules Maxpower current at STC	7	Amps
	(at STC x 0.9)	6.3	Amps
F4	Total energy demand (E3)	4600	Wh/day
F5	Energy Output/module/day (F1 x A3)	868.87	Wh/day
F6	Module energy output at operating temperature (F5 x 0.81) (0.81 is the correction factor for operating temperature)	703.78	Wh/day
F7	Number of modules required to meet daily energy requirements (F4/F6)	7	Nos
F8	Number of modules required/string (E1/F2)	3	Nos
F9	Number of strings in parallel (F7/F8)	3	Nos
F10	Number of modules to be purchased (F8 x F9)	9	Nos

After completion of the typical system design, the specification sheet for the system needs to be prepared. Typical checklist for SPV water pumping system is provided in Annexure 5

3.6.3. Request For Quotation

Once the preliminary system has been designed based on the load requirement, the enquiry forms should be send to various manufacturers or System integrators requesting quotations. The process of inviting quotations also be done through 'Tender' process. Typical enquiry form must seek quotations in the following sections:

- General Terms & Conditions to the supplier
- Technical specifications
    - Specifications of the load
        - Pumping Requirement
        - Pipe requirement
        - Pumping energy requirement
    - Specifications of the SPV system
        - SPV modules

    - Specification of the Motor
    - Scope of Civil Works
    - Scope of Operations & Maintenance
- Commercial Details
    - Cost of the SPV System
    - Cost of Civil works
    - Cost of Operations & Maintenance
    - Summary of Costs
- Annexure (if any)

3.6.4. Evaluation of Quotations

The quotations received in response to enquiry have to be evaluated in detail. If the quotations are not meeting the techno-commercial criteria, those will have to be rejected. The following points have to be considered while evaluating the quotations.

- Are all the General Terms & Conditions satisfied by the supplier
- Is system technically correct
- Are the commercial aspects and calculations correct

Once the bidder has been qualified in all the respects mentioned above, the commercial details have to be recorded for evaluation purpose. A typical format for Technical and Commercial evaluation of SPV water pumping system is provided in Annexure 6.

3.6.5. Negotiation with the Parties

After successful evaluation of quotations, the discussions have to take place with the successful parties for negotiation and finalization of the order. The following points need to be considered during the discussion phase.

1. **Credibility of the company:** Is the company credible for negotiation is the first point we need to look at. The credibility of the company is assessed in terms of

- **Financial strength of the company:** The aggregate turnover and profitability of the company during the last three years

- **Organizational strength of the company:** The organizational strength of the company can be assessed in terms of
    - Existing Infrastructure of the company
    - Organizational mission and quality policy
    - Managerial strength of the company
    - Technical strength of the company

2. **Technical parameters:** This is another important parameter to be considered while negotiating. This is based on the technical specification of the components used for the system. The following are the various attributes to be reckoned:

- **Modules:** Are the modules proposed for the system complying with the standards like IEC or Any other International standards
- **Pump Motor:** Is the Motor pump proposed for the system complying with the standards like IS or Any other International standards.
- **Warranty/Guarantee:** The period of warrantee/guarantee offered by the supplier for all the system components is also an important parameter.
- **Track Record:** Has the company got track record in installing the similar system so far. If so, Are those systems running without any major faults.

3. **Financial parameters**: This is the most important parameter of interest during the negotiation period. This is based on the pricing offered by the supplier with respect to each component and also system as a whole. The following are the various attributes conducive for this.

- **Price:** Is the price quoted by the supplier at par with the technical performance offered.
- **Payment Terms:** Has the supplier agreed for the payment terms given by us or any modification required in that regard.

Once the discussions and negotiations are held with all the parties, they are shortlisted by ranks and order is finalized with the party offering both techno-commercial benefit.

3.6.6. Finalization of Order

After finalization of the party, the order has to be released incorporating the minutes of the discussions. The following points need to be incorporated in the order.

- **System design parameters:** Any deviation between the enquiry specifications and final offer shall be taken of.

- **Cost estimates:** The revised cost estimates finalized during the discussion phase will be incorporated in the final order.

3.6.7. Inspections of goods Received

Once the order has been placed, the supplier starts supplying the components of the system. A quality check has to be performed even though the components have been tested by the respective agency. The following are various attributes to be considered during the inspection of goods.

1. **Items complying with general standards:** Are all the items/components supplied matching the standards specified like
   a. Design standards
   b. Safety standards etc.
2. **Acceptance test standards:** Once the components are satisfying the general standards, the components have to be examined for acceptance standards. The following are few categories of acceptance standards that need to be considered.

- **Type test:** Type testing is to check whether the component is meeting the rated conditions specified in the standards to which the component is affiliated.
- **Routine test:** Routine test is testing the components for its voltage, current and test whether the component is satisfying the I-V curve etc.
- **System performance test:** Testing the overall system performance after integrating all the components is as System performance test.

3. **Acceptance test standards:** Inference against all the standards used to test various components of the system and the overall system performance testing have to be reported properly.

3.6.8. Parameters to be checked during Installation

The following factors are to be considered during the installation.

1. **Mounting structures:** How the structures are mounted? What is the material used for that? What is the angle considered? What is the soil condition? What are the tools used?

2. **Protective measures taken:** What are the protection measures taken for various components and system? Are they in line with the protection standards
3. **Grounding and Cabling:** Weather suitable grounding mechanism has been adopted or not. Are all the cabling done as per standard techniques
4. **Training to the operator:** Has the supplier trained the operator properly to handle the system carefully
5. **Operation & Maintenance manual:** Whether the operation & maintenance manual has been handed over to the operator or not.

3.7. Designing Solar Thermal Water Heating System (Case study)

3.7.1. Case description

A person in Surat city of Gujarat is facing a lot of problem with respect to gas availability. He is interested in purchasing a solar water heating system for his home needs. His requirement is for a 100 litres per day capacity

3.7.2. Typical System Design

Assumptions in System Design

- Solar thermal water heating system is considered.
- Latitude considered for site (Surat city) – 21.2°N
- Longitude considered for site (Surat city) – 72.8°E
- Daily solar insolation at 20° slope – 5.52 kWh/m2/day
- Daily water requirement – 100 liters
- Temperature of water required – 60°C
- Ambient water temperature – 20°C
- Solar water heater / collector efficiency – 30%*
- Specific heat of water is 4.2J/g/ °C
- 1kWh = 3.6MJ

Energy required for heating water

- Energy required in kilo Joule (kJ) = 4.2 x quantity of water in liters x temperature of water to be raised.

  kJ = 4.2 x 100 lt x (60°- 20°C) = 4.2 x 100 x 40 = 16800 kJ

  = 16.8 MJ (mega joule)

- Energy required in kilo Watt hour (kWh) = 16.8 / 3.6 = 4.67 kWh

* www.practicalaction.org

Collector Area Required

- Area required = energy demand / (solar insolation x collector efficiency)

  = 4.67 / (5.52 x 0.3)

  = 2.82 m^2

After completion of the typical system design, the specification sheet for the system needs to be prepared. Typical checklist for Solar thermal water heating system is provided in Annexure 7

3.7.3. Request for Quotation

Once the preliminary system has been designed, the enquiry forms should send be to various manufacturers or System integrators requesting quotations. The process of inviting quotations can also be done through ‘Tender’ process. Typical enquiry form must seek quotations in the following sections

- General Terms & Conditions to the supplier
- Technical specifications
    - Specifications of the load
    - Specifications of the Solar Thermal Water Heating System
        - Energy required for heating water
        - Collector area required
    - Scope of Civil Works
    - Scope of Operations & Maintenance
- Commercial Details
    - Cost of the Solar thermal water heating system
    - Cost of Civil works
    - Cost of Operations & Maintenance
    - Summary of Costs
- Annexure (if any)

3.7.4. Evaluation of Quotations

The quotations received in response to enquiry have to be evaluated in details. If the quotations are not meeting the techno-commercial criteria, those will have to be rejected. The following points have to be considered while evaluating the quotations.

- Are all the General Terms & Conditions satisfied by the supplier
- Is system technically correct
- Are the commercial aspects and calculations correct

Once the bidder has been qualified in all the respects mentioned above, the commercial details have to be recorded for evaluation purpose. A typical format for the Technical and Commercial evaluation of Solar thermal water heating system is provided in Annexure 8.

3.7.5. Negotiation with the Parties

After successful evaluation of quotations, the discussions have to take place with the successful parties for negotiation and finalization of the order. The following points need to be considered during the discussion phase.

1. **Credibility of the company:** Is the company credible for negotiation is the first point we need to look at. The credibility of the company is assessed in terms of

    - **Financial strength of the company:** The aggregate turnover and the profitability margins of the company during the last three years
    - **Organizational strength of the company:** The organizational strength of the company can be assessed in terms of
        - Existing Infrastructure of the company
        - Organizational mission and quality policy
        - Managerial strength of the company
        - Technical strength of the company

2. **Technical parameters:** This is another important parameter to be considered while negotiating. This is based on the technical specification of the components used for the system. The following are the various attributes to be reckoned:

    - **Solar Collector:** Is the solar collector proposed for the system complying with the standards like IEC or Any other International standards
    - **Warranty/Guarantee:** The period of warrantee/guarantee offered by the supplier for all the system components is also an important parameter.
    - **Track Record:** Has the company got track record in installing similar system so far. If so, Are those systems running without any major fault.

3. **Financial parameters**: This is the most important parameter of interest during the negotiation period. This is based on the pricing offered by the supplier with respect to each component and also system as a whole. The following are the various attributes conducive for this.

    - **Price:** Is the price quoted by the supplier at par with the technical performance offered
    - **Payment Terms:** Has the supplier agreed for the payment terms given by us or any modification required in that regard.

Once the discussions and negotiations are held with all the parties, they are shortlisted by ranks and order is finalized with the party offering both techno-commercial benefits.

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3. **Acceptance test standards:** Inference against all the standards used to test various components of the system and the overall system performance testing have to be reported properly.

3.7.8. Parameters to be checked during installation

The following factors are to be considered during the installation.

1. **Mounting the system:** How the system is mounted?
2. **Protective measures taken:** What are the protection measures taken for various components and system? Are they in line with the protection standards
3. **Grounding and Cabling:** Weather suitable grounding mechanism has been adopted or not. Are all the cabling done as per standard techniques
4. **Training to the operator:** Has the supplier trained the operator properly to handle the system carefully
5. **Operation & Maintenance manual:** Whether the operation & maintenance manual has been handed over to the operator or not.

CHAPTER 4

CONCLUSION

4.1. Summary

4.2. General Guide lines

BIBLIOGRAPHY

ANNEXURES