Solar PV System Designing & Studies On Incorporation Of Solar Thermal Systems In Energy Intensive Industries

By

ABHILASH S G

College of Engineering
University of Petroleum & Energy Studies
Dehradun
May, 2013

SOLAR PV SYSTEM DESIGNING & STUDIES ON INCORPORATION OF SOLAR THERMAL SYSTEMS IN ENERGY INTENSIVE INDUSTRIES

A thesis submitted in partial fulfilment of the requirements for the Degree of

Master of Technology

(ENERGY SYSTEMS)

By

ABHILASH S G

Under the guidance of

MRS. MADHU SHARMA **ASST. PROFESSOR** **UPES** **DEHRADUN**	**MR. P. SAMPATH KUMARAN** **JOINT DIRECTOR** **CPRI** **BENGALURU**

Approved

……………………………….

Dean

College of Engineering
University of Petroleum & Energy Studies
Dehradun
May, 2013

केन्द्रीय विद्युत अनुसंधान संस्थान
(भारत सरकार की सोसाइटी, विद्युत मंत्रालय)
प्रो सर सी. वी. रामन रोड़, सदाशिवनगर डाक घर, पो. बा. सं. 8066, बेंगलूर - 560 080
CENTRAL POWER RESEARCH INSTITUTE
(A Govt of India Society under Min. of Power)
Prof. Sir C.V. Raman Road, Sadashivanagar P.O., P.B. No. 8066, Bangalore - 560 080, India
वेबसाइट/website : http://www.cpri.in

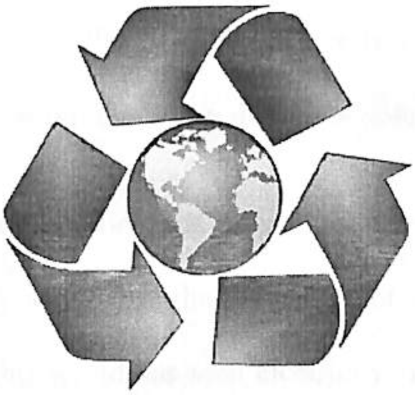
CERTIFICATE

This is to certify that the dissertation entitled **"SOLAR PV SYSTEM DESIGNING AND STUDIES ON INCORPORATION OF SOLAR THERMAL IN ENERGY INTENSIVE INDUSTRIES"** carried out by **Mr. ABHILASH S.G.** bearing **REG No.R660211001** in partial fulfilment of the requirement for the award of degree of **MASTER OF TECHNOLOGY** in **ENERGY SYSTEMS of University of Petroleum & Energy Studies, Dehradun,** during the year 2013.

Dr. P. Sampathkumaran
Joint Director
Central Power Research Institute
Bangalore – 560 080.

संयुक्त निदेशक / JOINT DIRECTOR
सामग्री प्रौद्योगिकी प्रभाग
MATERIALS TECHNOLOGY DIVISION
केन्द्रीय विद्युत अनुसंधान संस्थान
CENTRAL POWER RESEARCH INSTITUTE
पो. बो सं.8066, बेंगलूर - 560 080
PB No.8066, BANGALORE-560 080

Date : 18.04.2013
Place : Bangalore



ABSTRACT

ABSTRACT

Due to the scarcity of the fossil fuels which were the prime source for energy for many years, a continuous research is being made in search of the most efficient alternative power source. This has landed us to the turn where there is a striking urge to make use of the abundantly available renewable resources. Today the use of solar energy has reached a remarkable edge.

Sun being one of the most powerful sources of energy known to mankind, in just one second has the capacity to produce the same amount of energy that mankind has produced till date from the day since this world has seen electricity. The energy produced by sun in just an hour is enough for the whole world to consume on for a whole year. This makes solar energy one of the most powerful energies. Solar energy conversion is widely used to generate heat and produce electricity. A comparative study on the world energy consumption released by International Energy Agency (IEA) shows that in 2050, solar array installations will supply around 45% of energy demand in the world.

Though Solar thermal power have enjoyed limited success compared to solar PV in the energy market to date, it was found that solar thermal is getting remarkable popularity in industrial applications. The present thesis work is aimed to design a solar photovoltaic system for an institute to replace the present lighting system, to study the solar thermal energy systems utilization in industrial applications and looked into the incorporation of solar thermal energy systems in different energy intensive industries like fossil fuel fired plants, textile, building, chemical or even food industries and a case study of solar steam cooking system using a scheffler's reflector.

ACKNOWLEDGEMENT

My sincere thanks to my Dean **Dr. Kamal Bansal,** College of Engineering, UPES and my HOD **Dr. Narendra Soni** for giving permission to do my project in CPRI, Bengaluru.

I am highly indebted to **Mr. P. Sampath kumar** of CPRI and **Mrs. Madhu Sharma** of UPES for providing their guidance and constant supervision as well as for providing necessary information regarding the project & also for their support in completing the project.

My sincere thanks to **Dr. Seetharamu,** Director, CPRI, Bengaluru for his constant supervision and guidance throughout the project.

I would like to express my gratitude towards my parents & friends for their kind co-operation and encouragement which helped me in completion of this project.

TABLE OF CONTENTS

Chapter 1: Introduction .... **i**

1.1. Background 1

1.2. Solar Technologies 2

1.3 Classification Of Solar Collectors 3

1.3.1 Solar Thermal Collectors 3

1.3.11 Flat Plate Collector 4

1.3.12 Evacuated Tube Collector 6

1.3.13 Concentrating Collectors 7

1.4 Major Components Of Solar Pv System 13

1.5 Major Components Of Solar Thermal System 14

1.6 Solar Energy And India 18

Chapter 2: Literature Review **20**

Chapter 3: Objectives **28**

Chapter 4: Methodology **29**

Chapter 5: Solar Pv System Designing **30**

5.1 Procedure 30

1. Determine Power Consumption Demands 30

2. Size The Pv Modules 30

3. Inverter Sizing 31

4. Battery Sizing 31

5.2 Calculations: 32

5.3 Subsidy Provided By The Mnre For Solar Pv: 35

Chapter 6: Incorporation Of Solar Thermal Energy In Industrial Systems 37

6.1 Solar Thermal Energy For Industries 40

6.2 Solar Thermal In Fossil Fuel Fired Power Plants 43

6.2.1 Solar Heated Feed Water Preheating Options 44

6.3 Solar Tehrmal In Food Industry 46

6.4 Solar Thermal In Building Industry 48

6.5 Solar Thermal In Textile Industry 49

Chapter 7: Case Study 50

Chapter 8: Conclusion And Scope 53

References 54

LIST OF FIGURES

Figure 1.1 Classification of various solar collectors 3

Figure 1.2 Cross-section and isometric view of flat-plate collector 5

Figure 1.3 Glass evacuated tube solar collector with U-tube. (a) Illustration of the glass evacuated tube and (b) cross section 7

Figure 1.4.1 Parabolic trough collector (PTC) 9

Figure 1.4.2 Linear Fresnel reflector (LFR) collector 11

Figure 1.4.3 Central receiver system. 12

Figure 1.4.4 Schematic of a parabolic dish collector. 13

Figure 1.5 Components of PV system 13

Figure 1.6 DNI in India 20

Figure 5.1 Site selected for PV system 37

Figure 6.1. Block diagram of a typical industrial energy system 39

Figure 6.2 Schematic of a solar-thermal conversion system 40

Figure 6.3 Schematic diagram of ordinary steam turbine plant 46

Figure 6.4 Integration of solar collectors to an industrial system 50

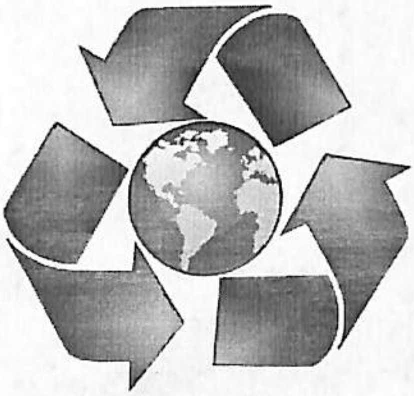
Figure 7.1 Scheffler reflector installed at SRVM 51

LIST OF TABLES

Table 1.1 Types of solar thermal collectors 4

Table 6.1 Solar energy applications, technologies and the type of systems that are commonly used in industries. 38

Table 6.2 Heat demand industries and range of temperatures 41



INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

Amongst all of the renewable energy resources available in today's world, solar energy is the most attention grabbing option that has attracted most of the industries. This is mainly because of the reason that the solar energy is clean, available in abundance and saves a lot of economy as it is available freely. Another reason why solar energy is preferred is because of its pollution free nature i.e., it does not cause any pollution. Solar energy is not only useful for the industries but also for household purposes. This widens its application which in turn increases its advantages and demand.

One of the main reasons why the solar energy is in demand right now is also because of the other renewable resources becoming scarce. Another reason is the fact that the convectional fuels carry a burden to the environment in the form of pollution. This has led to the increased demand for solar energy. Until today the solar energy available has been collected and made use of through solar collectors, sun trackers and huge mirrors. Thus collected energy can later be used to make output mimic grid demand, compensate for variation in radiation levels throughout the day, or provide 24-hour on-demand solar-thermal power. This makes solar energy, the energy of the future since it is flexible and increases the economy in the market.

1.2. SOLAR TECHNOLOGIES

Basically there are three primary technologies that are used in the technology for the conversion of solar energy to consumable form of energy. The three forms are:

Solar Photovoltaic (PV): This technology converts solar energy directly into usable electrical energy by making use of photo voltaic cells. Their speciality being that the cells can be added together or separated depending on the amount of watts of output required. They can be used to generate power from the range of just few watts used to light a bulb to huge megawatts used for large scale purposes.

Solar Thermal: This technology is used to covert solar energy into heat that is used for other that electricity. This is basically used in residential and commercial applications such as heating water, in industries for heat application and in agriculture for drying purposes. This can drastically reduce the use of fossil fuels and the pollution rate.

Concentrated Solar Thermal Power Technologies (CSP): This technology is meant for utility scale production. Here mirrors are made use of to compose a solar field that is used to concentrate the solar energy onto the receiver. The temperature is used to heat the fluids running in the pipes. This heat energy can now be stored and used in a turbine which in turn produces electricity by making use of the heat energy.

1.3 CLASSIFICATION OF SOLAR COLLECTORS

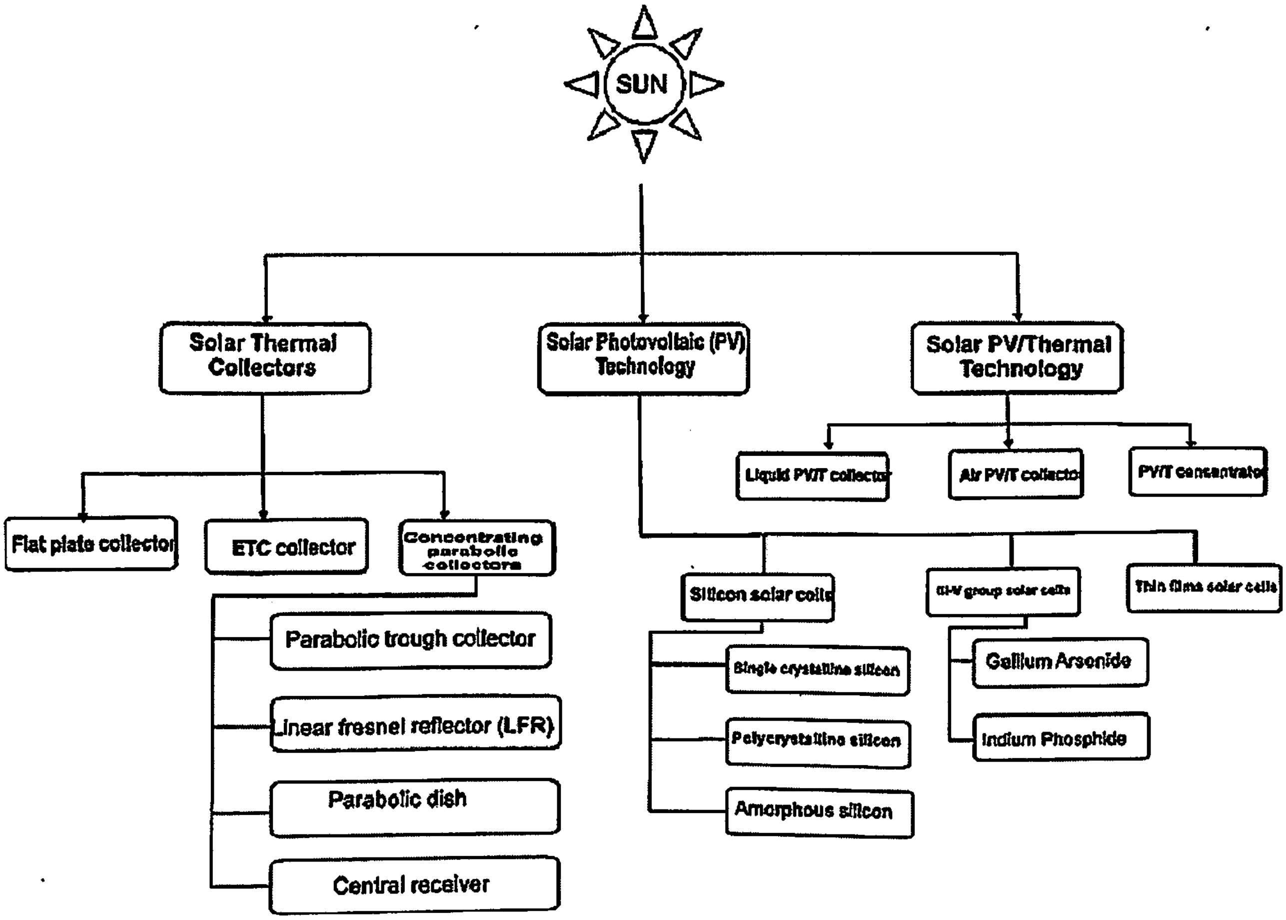


Figure 2.1 Classification of various solar collectors.

1.3.1 SOLAR THERMAL COLLECTORS

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. A large number of solar collectors are available in the market. A comprehensive list is shown in

Table1.1. In this section a review of the various types of collectors currently available will be presented. This includes flat plate collector (FPC), evacuated tube collector (ETC), and concentrating collectors.

Motion	**Collector type**	**Absorber type**	**Concentration ratio**	**Indicative temperature range (°C)**
Stationary	Flat plate collector (FPC)	Flat	1	30 to 80
	Evacuated tube collector (ETC)	Flat	1	50 to 200
	Compound parabolic collector (CPC)	Tubular	1 to 5	60 to 240
Single-axis tracking	Fresnel lens collector (FLC)	Tubular	10 to 40	60 to 250
	Parabolic trough collector (PTC)	Tubular	15 to 45	60 to 300
	Cylindrical trough collector (CTC)	Tubular	10 to 50	60 to 300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100 to 1000	100 to 500
	Heliostat field collector (HFC)	Point	100 to 1500	150 to 2000

Table:1.1 Types of solar thermal collectors

1.3.11 Flat plate collector

The flat plate collector (FPC) is the heart of any solar energy collection system designed for operation in the low temperature range (less than 60^0C) or in the medium temperature range (less than 100^0C). It is used to absorbed solar energy, convert it into heat and then to transfer that heat to stream of liquid or gases. Flat-plate solar collectors, being mechanically simpler than concentrating collectors, are mainly used for domestic and industrial purposes.

The essential features of the conventional fiat plate collectors are:

(i) A flat blackened absorbing plate (normally metallic) upon which the solar radiation falls and gets absorbed, thus changing to thermal energy.

(ii) Tubes, channels or passages attached to the blackened absorber plates to circulate the fluid required to remove the thermal or heat energy from the plate.

(iii) Insulation which is provided at the back and sides of the absorber plate to minimize conductive heat losses.

(iv) A transparent cover (one or two sheets) of glass or plastic to reduce the upward convection and radiation heat losses from the absorber plate.

(v) A weather tight container which encloses the above components.

FPC is usually permanently fixed in position and requires no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10–15 °C more or less depending on the application. A typical flat plate solar collector is shown in Fig.1.2

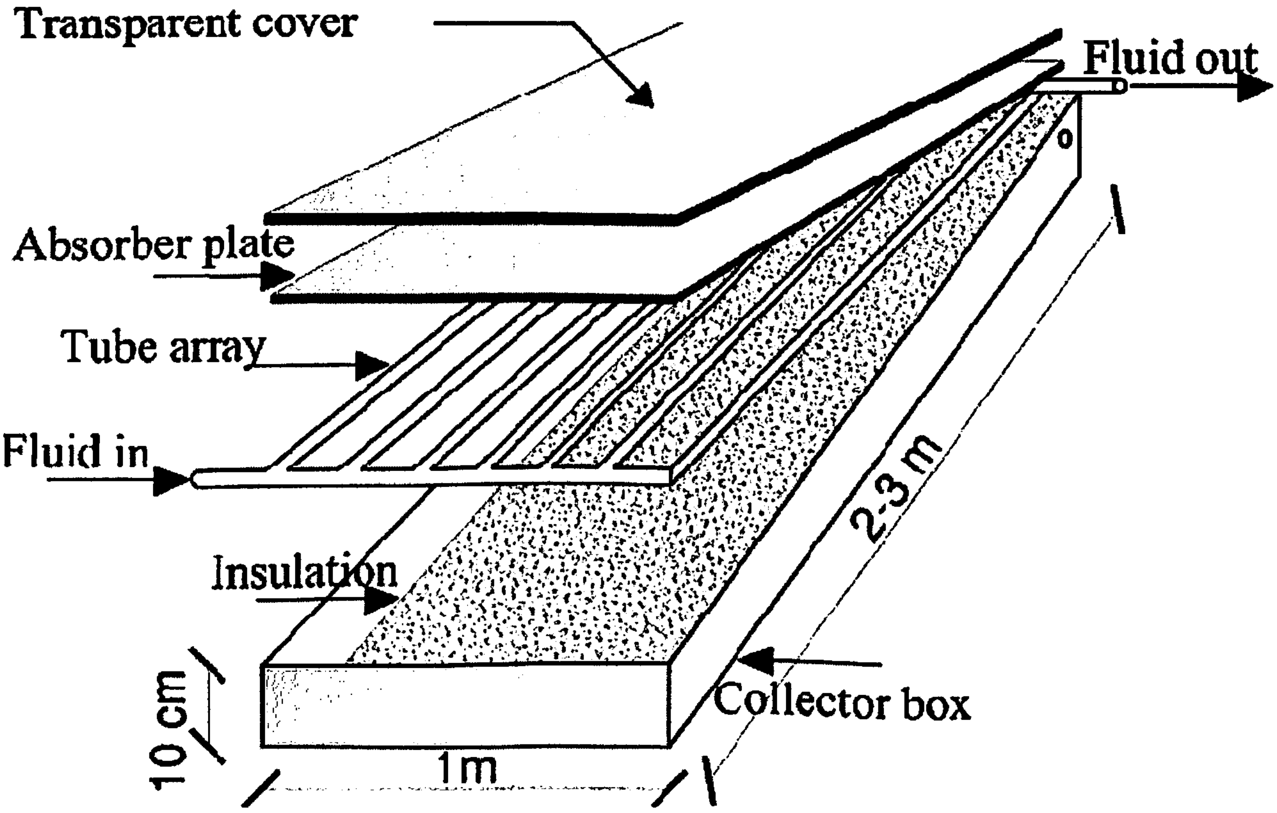


Figure: 1.2 Cross-section and isometric view of flat-plate collector

1.3.12 Evacuated tube collector

The evacuated tube solar collectors (ETC) provide the combined effects of a highly selective surface coating and vacuum insulation of the absorber element so they can have high heat extraction efficiency compared with flat plate collectors in the temperature range above 80 °C. At present, the glass evacuated tube has become the key component in solar thermal utilization and they are proved to be very useful especially in residential applications for higher temperatures. So the evacuated solar collectors are widely used to supply the domestic hot water or heating, including heat pipe evacuated solar collectors and U-tube glass evacuated tube solar collectors. ETC use liquid–vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum sealed tube. The pipe, which is a sealed copper pipe, attached to a black copper fin that fills the tube (absorber plate) is a metal tip attached to the sealed pipe (condenser). The heat pipe contains a small amount of fluid that undergoes an evaporating-condensing cycle. In this cycle, solar heat evaporates the liquid, and the vapor travels to the heat sink region where it condenses and releases its latent heat. The condensed fluid return back to the solar collector and the process is repeated. When these tubes are mounted, the metal tips up, into a heat exchanger (manifold). A schematic diagram of an evacuated tube collector is given in Fig.1.3

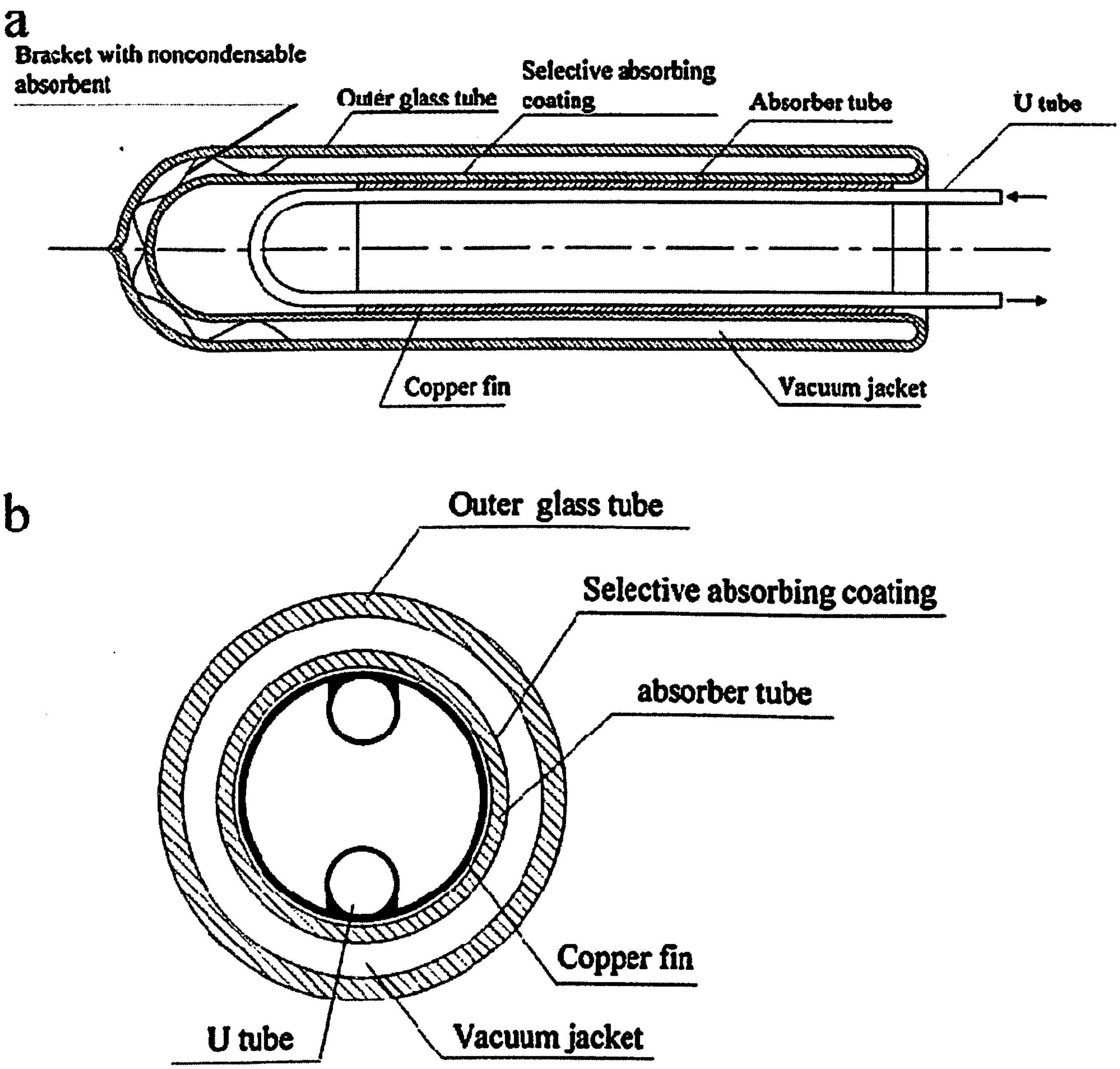


Figure:1.3 Glass evacuated tube solar collector with U-tube. (a) Illustration of the glass evacuated tube and (b) cross section

1.3.13 Concentrating collectors

Concentrating collectors provide energy at temperatures higher than those of flat plate and ETC collectors. They re-direct solar radiation passing through an aperture into an absorber and usually require tracking of the sun. In concentrating collectors solar energy is optically concentrated before being transferred into heat. Concentration can be obtained by reflection or refraction of solar radiation by the use of mirrors or lens.

Concentrating collectors can also be classified into non-imaging and imaging depending on whether the image of the sun is focused at the receiver or not. The concentrator belonging in the first category is the CPC whereas all the other types of concentrators belong to the imaging type.

The collectors falling in this category are:

- Parabolic trough collector.
- Linear Fresnel reflector.
- Central receiver.
- Parabolic dish.

Parabolic trough collector (PTC)

The first practical experience with parabolic trough collector (PTC) goes back to 1870, when a successful engineer, John Ericsson, a Swedish immigrant to the United States, designed and built a 3.25- m2-aperture collector which drove a small 373-W engine. Steam was produced directly inside the solar collector (today called direct steam generation or DSG). From 1872 to 1875, he built seven similar systems, but with air as the working fluid. Nowadays, PTC target application in which a solar field can be successfully integrated for supplying thermal energy at temperatures up to 250^0C (Fig.1.4.1). Nevertheless, there are other applications, such as heat-driven refrigeration and cooling, low-temperature heat demand with high consumption rates, irrigation water pumping, desalination and detoxification. On the one hand, these temperature requirements cannot be achieved by conventional low-temperature collectors (flat plate collectors and evacuated tubes). On the other hand, use of solar concentrating systems with high concentration ratios and high-temperature absorbers would be unnecessarily expensive.

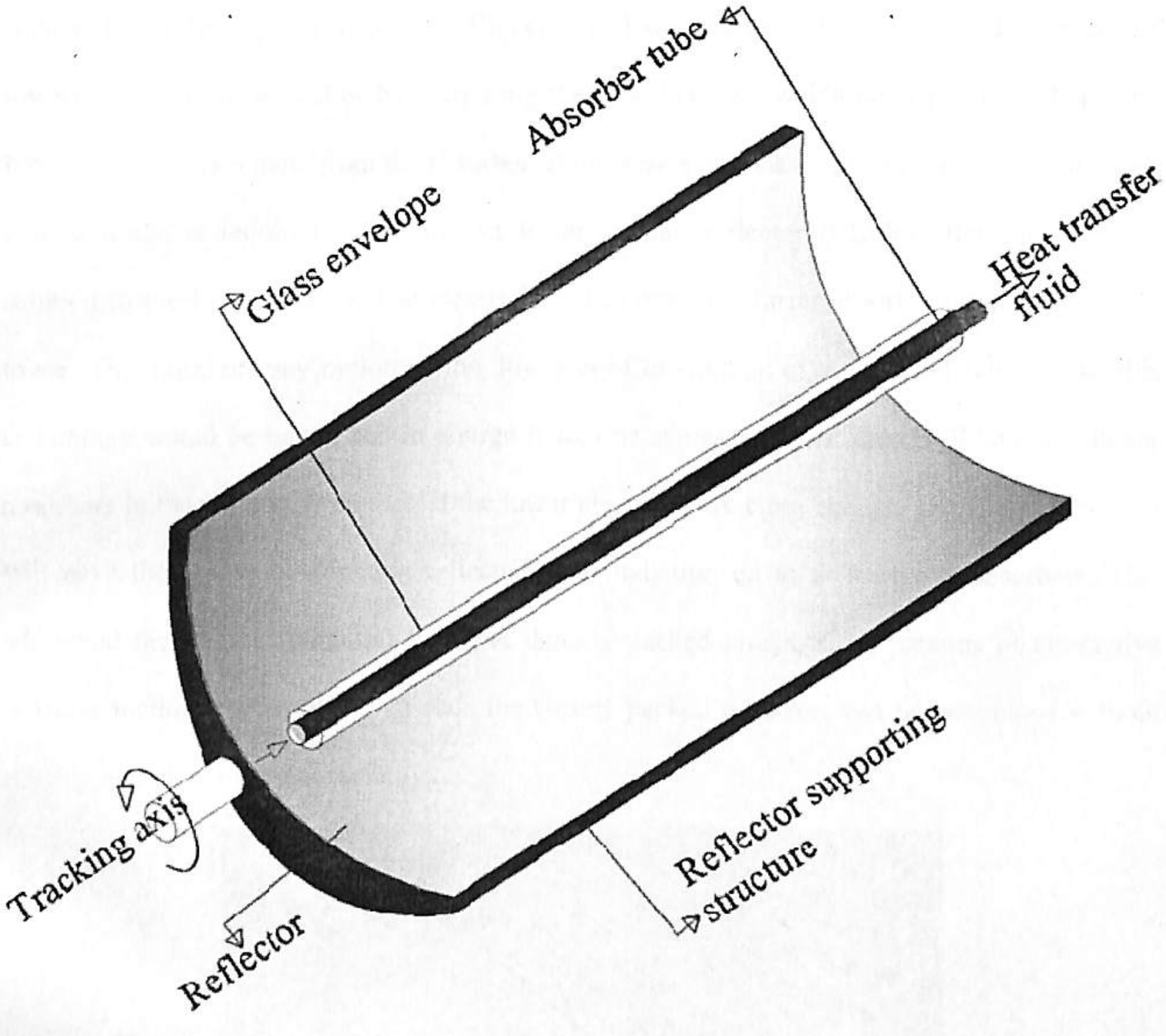


Figure:1.4.1 Parabolic trough collector (PTC)

Linear Fresnel reflector (LFR)

The linear Fresnel reflector (LFR) differs from that of the parabolic trough collectors in that the absorber is fixed in space above the mirror field (Fig 1.4.2). Also, the reflector is composed of many low row segments, which focus collectively on an elevated long tower receiver running parallel to the reflector rotational axis. This system offers a lower cost solution as the absorber row is shared among several rows of mirrors. However, one fundamental difficulty with the LFR technology is the avoidance of shading of incoming solar radiation and blocking of reflected solar radiation by adjacent reflectors. Blocking and shading can be reduced by using absorber towers elevated higher and/or by increasing the absorber size, which allows increased spacing between reflectors remote from the absorber. Both these solutions increase costs, besides a larger ground usage is required. The compact linear Fresnel reflector (CLFR) offers an alternate solution to the LFR problem. The classic LFR has only one linear absorber on a single linear tower. This prohibits any option of the direction of orientation of a given reflector. Since this technology would be introduced in a large field, one can assume that there will be many linear absorbers in the system. Therefore, if the linear absorbers are close enough, individual reflectors will have the option of directing reflected solar radiation on to at least two absorbers. This additional factor gives potential for more densely packed arrays, since patterns of alternative reflector inclination can be set up such the closely packed reflectors can be positioned without shading and blocking solar radiation.

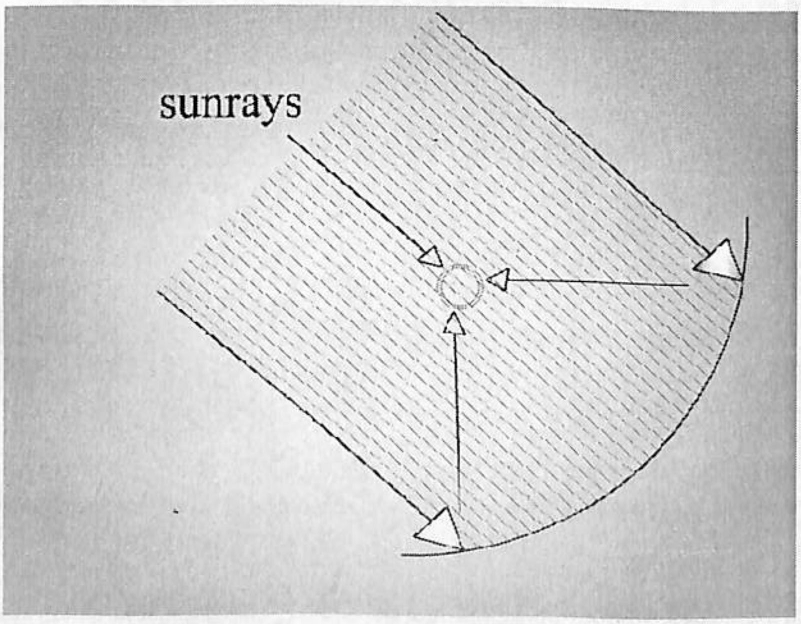


Figure:1.4.2 Linear Fresnel reflector (LFR) collector

Central receiver system

The central receiver systems (Fig.1.4.3) are considered to have a large potential for mid-term cost reduction of electricity compared to parabolic trough technology since they allow many intermediate steps between the integration in a conventional Rankine cycle up to the higher energy cycles using gas turbines at temperatures above 1000 °C, and this subsequently leads to higher efficiencies and huge outputs. Another alternative is to use Brayton cycle (gas, turbines, which require higher temperature than the ones employed in Rankine cycle). There are three general configurations for the collector and receiver systems. In the first, heliostats completely surround the receiver tower, and the receiver, which is cylindrical, has an exterior heat-transfer surface. In the second, the heliostats are located north of the receiver tower (in the northern hemisphere), and the receiver has an enclosed heat-transfer surface. In the third, the heliostats are located north of the receiver tower, and the receiver, which is a vertical plane, has a north-facing heat-transfer surface.

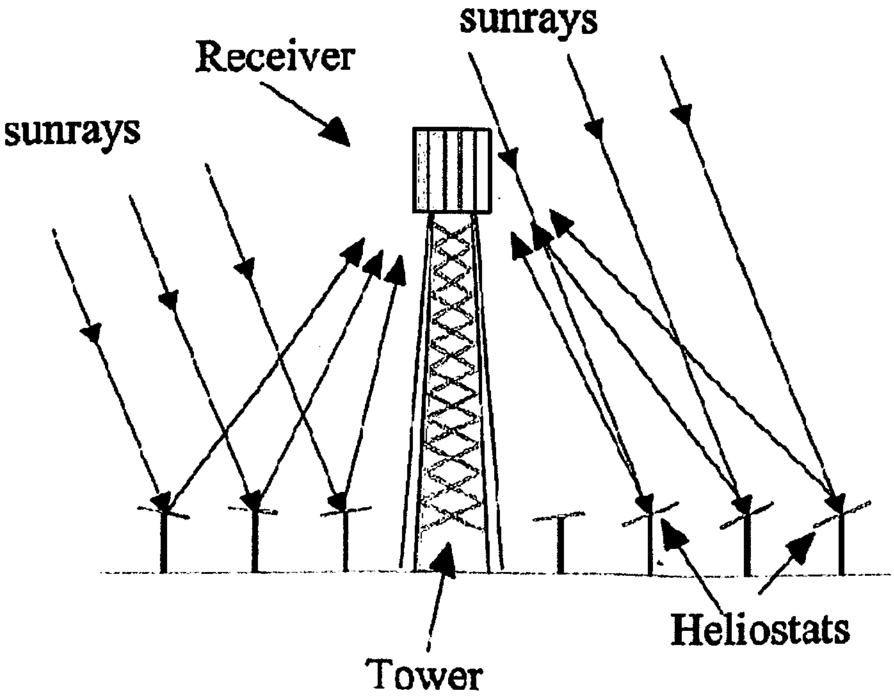


Figure:1.4.3 Central receiver system.

Parabolic dish

A parabolic dish reflector, shown schematically in Fig.1.4.4 is a point-focusing collector. Concentrating solar energy onto a receiver located at the focal point of the dish, it tracks the sun in two axes. The dish structure must track fully the sun to reflect the beam into the thermal receiver. Parabolic-dish systems can achieve temperatures in excess of 1500 ◦C. Because the receivers are distributed throughout a collector field, like parabolic troughs, parabolic dishes are often called distributed-receiver systems. Parabolic-dish systems that generate electricity from a central power converter collect the absorbed sunlight from individual receivers and deliver it via a heat-transfer fluid to the power conversion systems.

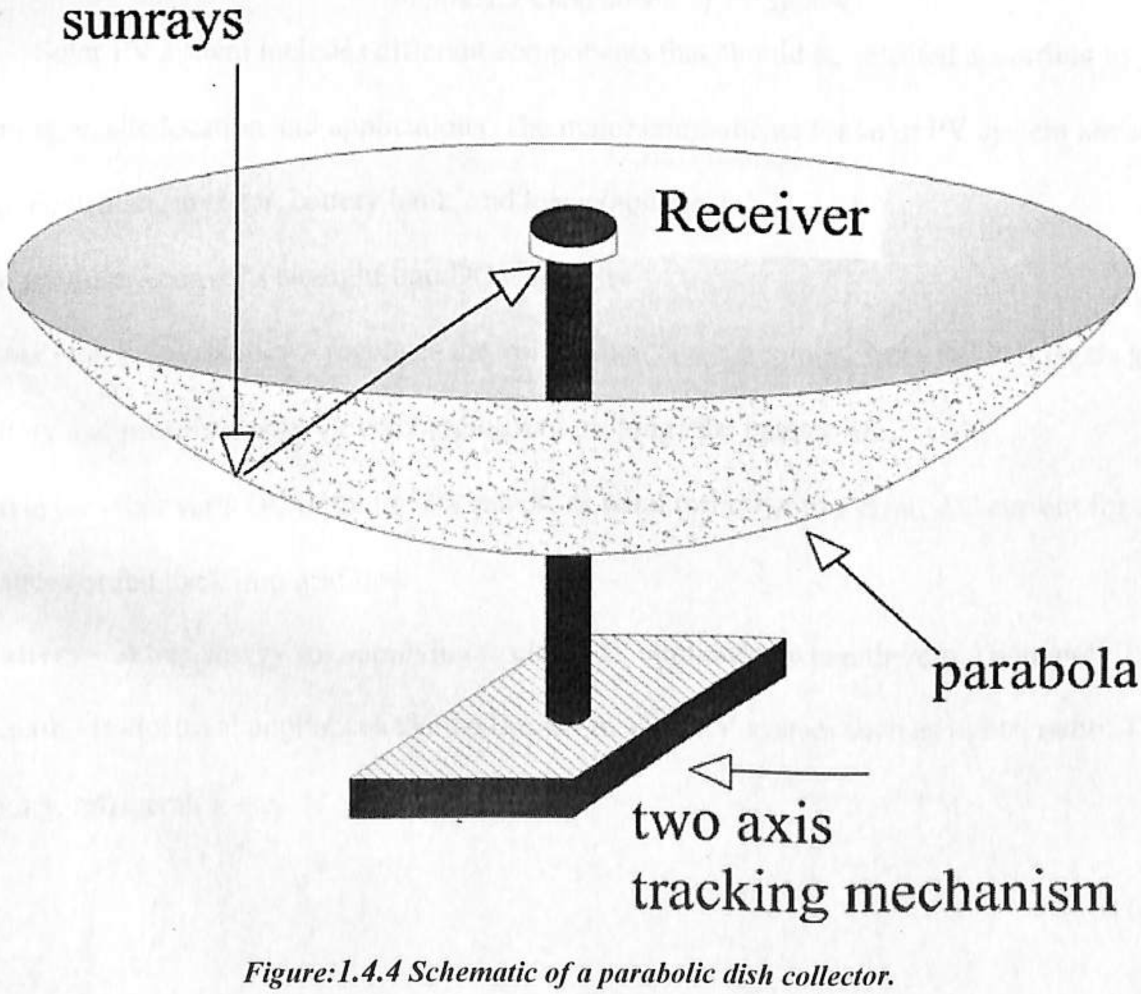


Figure:1.4.4 Schematic of a parabolic dish collector.

1.4 MAJOR COMPONENTS OF SOLAR PV SYSTEM

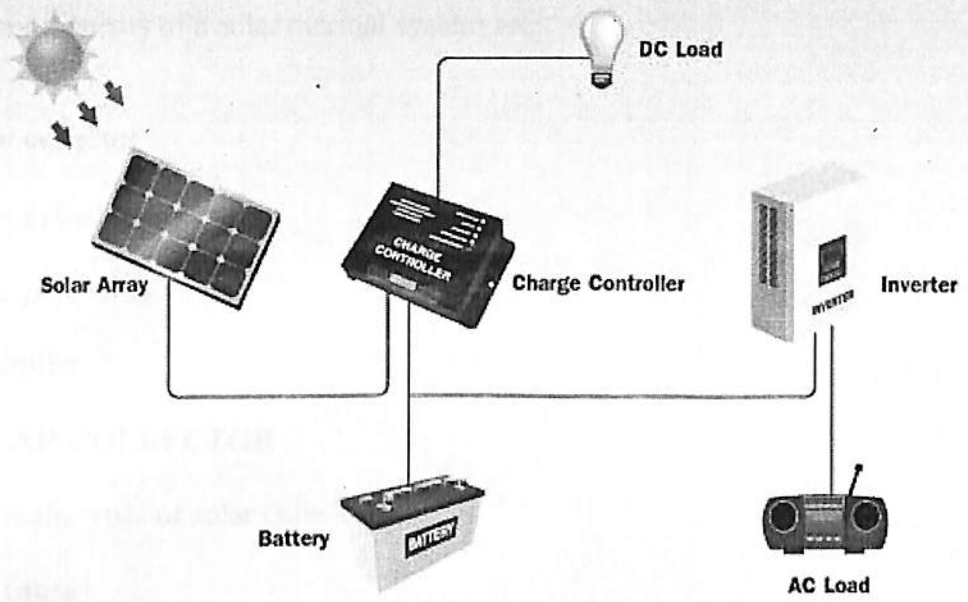


Figure:1.5 Components of PV system

Solar PV system includes different components that should be selected according to your system type, site location and applications. The major components for solar PV system are solar charge controller, inverter, battery bank, and loads (appliances).

- **PV module** – converts sunlight into DC electricity.
- **Solar charge controller** – regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.
- **Inverter** – converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or fed back into grid line.
- **Battery** – stores energy for supplying to electrical appliances when there is a demand.
- **Load** – is electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.

1.5 MAJOR COMPONENTS OF SOLAR THERMAL SYSTEM

The major components of a solar thermal system are:

1. Solar collector
2. Solar cylinder
3. Solar pipe work
4. Controller

1. SOLAR COLLECTOR

There are 2 main types of solar collectors

Evacuated tubes

These contain a dark-coloured absorber component enclosed within an evacuated glass tube, shaped to reflect and concentrate radiation into a central receiver. The collector comprises a series of glass tubes mounted in rows and plugged into a manifold box at the top. The vacuum insulates the system and prevents almost all heat loss. This is especially ideal in winter when wind-chill would otherwise cause heat loss, and also in conditions of extreme cold or high humidity. We utilise either of two evacuated tube technologies:

- **Heat pipe**

  The heat is transferred to a heat pipe, which has a partial vacuum. Here an evaporating-condensing cycle operates using a volatile fluid, which has a low boiling point. The resultant vapour rises up the heat pipe to the condenser, which fits into the manifold. Here the latent heat is released by reverse transformation (condensation), and is transferred in the solar fluid to the cylinder. This cycle repeats continuously.

- **Direct flow**

  In this version the solar fluid is circulated in a coaxial manner through the manifold and tubes. The heat exchange fluid passes through the manifold and transports the heat away through pipe work to the solar cylinder.

Flat plate collectors

These collectors are usually constructed using flat sheets of absorber material and flat glazing. The absorber contains pipes, which in turn contain the fluid that transports the heat away. The surface of the collector resembles a Velux window and can be mounted in-roof or on-roof.

2. SOLAR CYLINDER

The ***twin-coil solar cylinder*** acts as a heat store for the solar gains, and is sized to hold 30% - 50% extra water than your current cylinder. It therefore acts as a 'thermal battery' and storing the energy generated. There are 2 main types of cylinders –

- **Vented**

  Vented solar cylinders utilize the existing cold water storage cistern above. They will be bigger than the existing hot water cylinder to ensure there is a sufficient solar volume. We can have them made to measure to better fit within the allocated space available.

- **Unvented**

  Unvented solar cylinders will deliver mains pressure hot water around the property. Therefore shower booster pumps are not required. Hot and cold supplies will be balanced. The cold water storage cistern can be removed so making more space available in the loft. The cylinder can be located anywhere in the property. However, it is important to ensure that mains pressure is high enough with a good flow rate. Some extra safety controls are required and some annual checks need to be performed.

In a twin-coil cylinder there are two heat exchangers; the upper heat exchanger is connected to the boiler circuit, while the lower heat exchanger is connected to the solar circuit. The cylinder is tall and narrow to encourage stratification (temperature increases towards the top), and is well insulated (~50mm thickness) to prevent heat loss.

3. SOLAR PIPEWORK

The ***heat transfer fluid*** transports the heat produced in the collector to the solar cylinder. It is 40% propylene glycol with water and inhibitor. This ensures freeze protection down to –28°C and ensures thermal stability at high temperatures with an increase in the boiling point to 150°C depending on the pressure. This solar liquid is also non-corrosive, non-toxic, non-irritant and biologically degradable.

The ***solar circuit*** is pressurised to approximately 1.5 bar and comprises insulated copper pipework in which are various components such as pump, expansion vessel, flow meter, pressure relief valve, air vent, non-return valve, fill-and-flush valves, pressure gauge. The automatic air vent releases any air trapped in the system.

The ***expansion vessel*** is designed to incorporate expansion of the heat transfer fluid due to heating and increase in pressure. It is an enclosed metal container in which there is a flexible membrane. On one side is nitrogen under pressure and on the other side is the solar fluid.

The ***pump*** circulates the heat transfer fluid round the system when activated by the controller. A low speed setting will normally optimise efficient heat transfer.

The ***flow meter*** displays and permits the control of the volumetric flow of the heat transfer fluid. A flow rate of 2-3 litres per minute is recommended, i.e. around 1 litre per minute per square meter of collector.

The ***pressure relief valve*** is for safety and is designed to operate should there be a high-pressure build-up. However, the system pressure will rarely exceed 3 bar.

The ***pressure gauge*** indicates the pressure within the system. It will vary slightly depending on the temperature of the fluid. Normally it will be between 1 – 3 bar. The minimum operating pressure that should be maintained is 1 bar.

The ***non-return valve*** prevents reverse circulation in the solar circuit.

The ***fill-and-flush valves*** are for filling the system with heat transfer fluid.

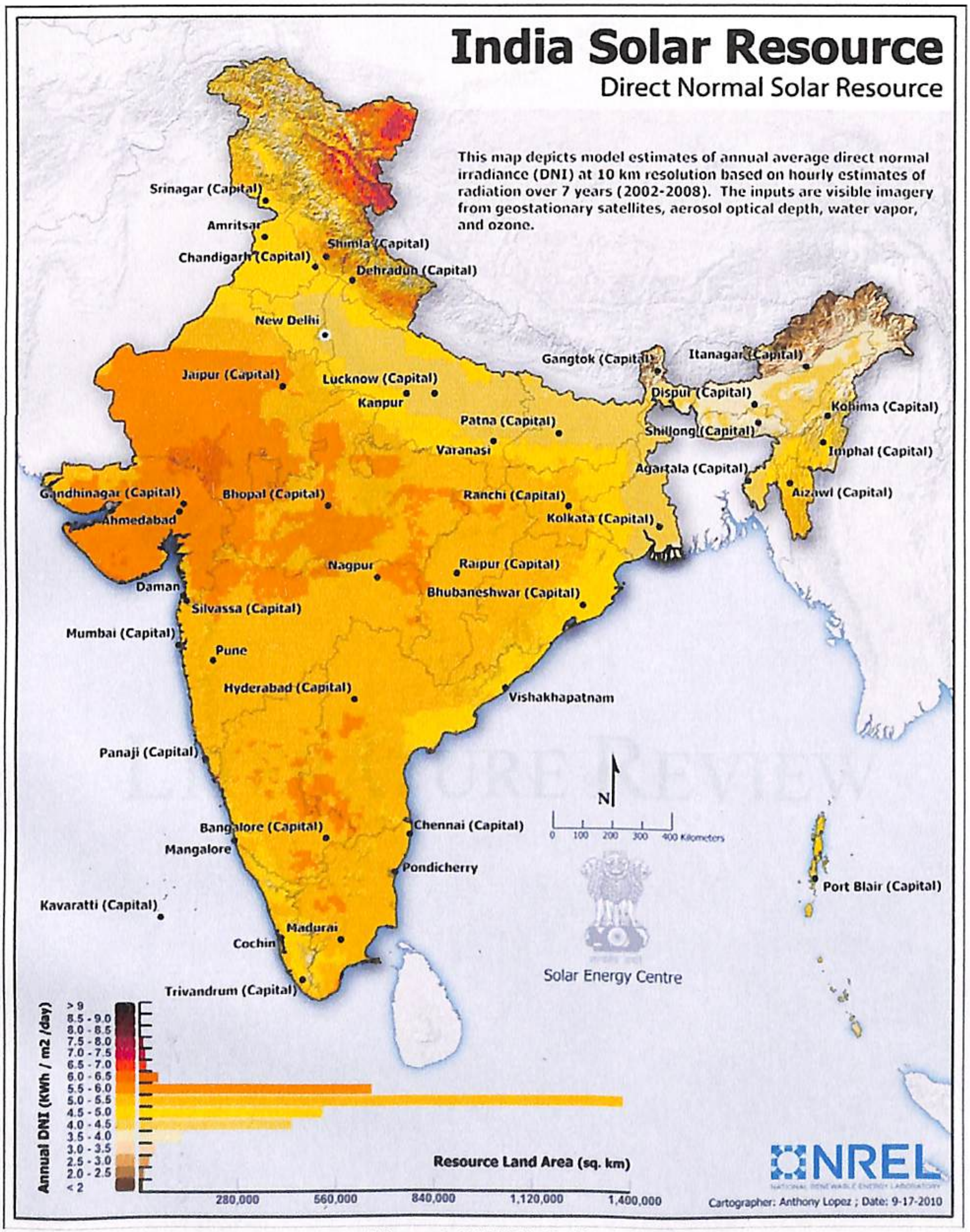
It is possible to include a PV (photo-voltaic) solar panel to generate enough power (DC) to drive the pump so that the entire solar system is independent of mains electricity.

4. CONTROLLER

The controller must control the pump so that the sun's energy is harvested in the best way. This is achieved by temperature difference regulation. Sensors are located on the collector and at the top and bottom of the solar cylinder. The pump switch-on temperature difference is normally 6°C, (i.e. the collector is at least 6°C greater than the water temperature at the bottom of the cylinder). The controller will display all sensor temperatures and produce data on kWh produced as well as cope with potential freezing and overheating situations.

1.6 SOLAR ENERGY AND INDIA

India is located in the sunny belt of the earth, thereby receiving abundant radiant energy from the sun. Its equivalent energy potential is about 6,000 million GWh of energy per year. India being a tropical country is blessed with good sunshine over most parts, and the number of clear sunny days in a year also being quite high. India is in the sunny belt of the world. The country receives solar energy equivalent to more than 5,000trillion kWh per year. The daily average global radiation is around 5 .0 kWh/m2 in north-eastern and hilly areas to about7.0 kWh/m2 in western regions and cold dessert areas with the sunshine hours ranging between 2300 and 3200 per year. In most parts of India, clear sunny weather is experienced for 250to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m2. The direct normal insolation*l* (DNI) over Andhra Pradesh varies from 1800 kWh/m2 to 2600 kWh/m2. India is blessed with plenty of sun as is evident from high solar irradiation, technically termed as insolation. Yield of energy from solar photo-voltaic (SPV) system varies from 4-7 kwhr/day per kW of installation at different places on average throughout the year. In Andhra Pradesh, Punjab, Haryana, Andhra Pradesh and Leh in Kashmir, insulation is very good to signify high-energy output. Experts foresee that within ten years, the price of solar energy will be very close to that of conventional power. In India, adverse elements are exerting high pressure on growth of renewable energy and amongst them solar power potential is highest to ensure energy security.



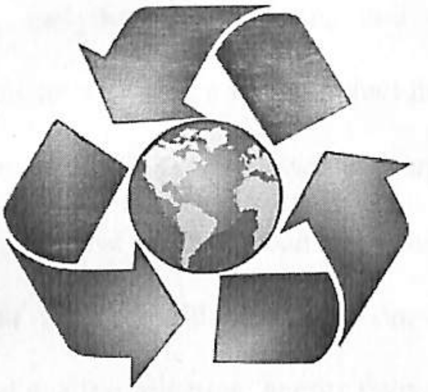
India Solar Resource

Direct Normal Solar Resource

This map depicts model estimates of annual average direct normal irradiance (DNI) at 10 km resolution based on hourly estimates of radiation over 7 years (2002-2008). The inputs are visible imagery from geostationary satellites, aerosol optical depth, water vapor, and ozone.

Cartographer: Anthony Lopez ; Date: 9-17-2010

Figure:1.6 DNI in India



LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

T.T. Chow in his paper on photovoltaic/thermal hybrid solar technology says the numbers of commercially available collectors and systems are still very limited. Major barriers like product reliability and costs remain to breakthrough. Collaborations have been underway among institutions or countries, helping to identify the suitable product materials, manufacturing techniques, analytical tools, testing and training requirements, potential customers, market strength, and so on. Since a PVT product has a much shorter economic payback period than the PV counterpart, PVT as a renewable energy technology (rather than PV) is expected to first become competitive with the conventional power generation. At this stage, the research and development work should be carried on, including thermal absorber design and fabrication, material and coating selection, energy conversion and effectiveness, performance testing, system optimization, control and reliability. Product quality and ease of delivery and installation are important, so are the aesthetics, green image and business concerns. PVT is expected to have significant market expansion potential in the near future [1].

Ashish Shukla, Dan Nchelatebe Nkwetta, Y.J. Cho presented a paper on performance of transpired solar collector. As the performance of transpired solar collector depends significantly on specific location and application, it is difficult to compare different cases. Heat exchange for holes nearly contribute 28% of the overall temperature rise of air whereas it is also reported that heat exchange effectiveness changes marginally while changing the porosity of the collector. But the case may be different for different thickness of the collector. It is found that TSCs are ideal to be used in the buildings. Literature review, theory, experimental analysis has shown that high efficiency can be achieved using TSC. The TSCs can also be integrated with other technologies, e.g. heat pump and PV. The literature has shown that the most critical factors affecting TSC efficiency are wind velocity, flow rate, porosity, absorptivity and porosity [2].

V.V. Tyagi, S.C. Kaushik, S.K. Tyagi mentions in Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology that the demand of heat and electricity are needed in industries and different application, i.e. solar cooling, water desalination, solar greenhouse, solar still and solar heat pump. Industries show high demand of energy for both heat and electricity and the hybrid PV/T systems could be used to meet the increasing energy demand for these requirements. This article gives the trends of development and technological advancement for the useful applications of PV/T of hybrid systems, like solar cooling, water desalination, solar greenhouse, solar still, photovoltaic–thermal solar heat pump/air-conditioning system, building integrated photovoltaic/ thermal (BIPVT) solar collector and so on. The work done by different researchers in this area shows that there is a huge potential of new and hybrid solar energy devices for useful and multipurpose applications.

In hot countries, PV cells are suffering to low efficiency due non availability of low ambient temperature for cooling the PVC system. Thus, by placing a solar thermal collector behind a solar photovoltaic (PV) array, the PV cells can be cooled up some extent and at the same time the heat produced by a PVC system. At the same time, the solar collector can harvest most of the energy that passes through the array that would otherwise be lost, recovering it for productive and useful applications. In this scenario, the PV cells can be cooled by circulating fluid like water or air within the solar thermal collector and hence, the heat produced by PVC can be utilized in an optimum operating temperature range by controlling the flow rate of the cooling medium/circulation fluid. It is clear from the literature review that PV/T collectors are very e.g. heat pump and PV. The literature has shown that the most critical factors affecting TSC efficiency are wind velocity, flow rate, porosity, absorptivity and porosity [2].

V.V. Tyagi, S.C. Kaushik, S.K. Tyagi mentions in Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology that the demand of heat and electricity are needed in industries and different application, i.e. solar cooling, water desalination, solar greenhouse, solar still and solar heat pump. Industries show high demand of energy for both heat and electricity and the hybrid PV/T systems could be used to meet the increasing energy demand for these requirements. This article gives the trends of development and technological advancement for the useful applications of PV/T of hybrid systems, like solar cooling, water desalination, solar greenhouse, solar still, photovoltaic–thermal solar heat pump/air-conditioning system, building integrated photovoltaic/ thermal (BIPVT) solar collector and so on. The work done by different researchers in this area shows that there is a huge potential of new and hybrid solar energy devices for useful and multipurpose applications.

In hot countries, PV cells are suffering to low efficiency due non availability of low ambient temperature for cooling the PVC system. Thus, by placing a solar thermal collector behind a solar photovoltaic (PV) array, the PV cells can be cooled up some extent and at the same time the heat produced by a PVC system. At the same time, the solar collector can harvest most of the energy that passes through the array that would otherwise be lost, recovering it for productive and useful applications. In this scenario, the PV cells can be cooled by circulating fluid like water or air within the solar thermal collector and hence, the heat produced by PVC can be utilized in an optimum operating temperature range by controlling the flow rate of the cooling medium/circulation fluid. It is clear from the literature review that PV/T collectors are very promising devices and that no substantial steps have been taken towards reducing their cost and making them more competitive. The overall energy production of the units is increased the hybrid system have better chances of success. Future work should be focus to improvement the efficiency of PV/T collectors and cost reduction, through this achievement, it will be more competitive collector device [3].

Kody M Powell, Thomas F Edgar in Modeling and control of a solar thermal power plant with thermal energy storage have shown that adding thermal energy storage to the energy system provides the invaluable benefit of taking an intermittent energy source and converting it to a constant power source. A simple control scheme was proposed for doing this. However, more advanced control and optimization schemes can be pursued in order to more fully leverage the thermal energy storage. Optimal control schemes can be implemented to mini- mize operating costs or maximize the total benefit that solar energy provides to the system. For example, on cloudy days, it may be optimal to provide heat at lower temperatures and allow the system to rely partially on supplemental fossil fuel, thereby reducing the energy losses to the environment. When optimal control schemes are considered, energy storage provides the system with extra degrees of freedom that can be used to enhance the system's overall performance. Solar thermal power faces many economic and technical hurdles, which must be overcome to be truly competitive with fossil fuel energy. Thermal energy storage allows these systems to overcome many of the problems associated with solar power intermittency. Advanced control and optimization techniques are still needed to help these plants operate more efficiently, thereby making them more technically and economically viable [4].

Yabei Zhang, Steven J Smith, G.PageKyle, Paul W Stackhouse in Modeling the potential for thermal concentrating solar power technologies examined three potential applications of CSP electric generation technologies: (1) CSP as intermediate and peak (I&P) load power plants without thermal storage, (2) CSP as I&P load power plants with thermal storage, and (3) CSP as base load power plants with thermal storage. We find that, for the capital cost assumptions used here, CSP plants without thermal storage can be competitive as I&P load plants in prime locations. Either policy incentives, lower capital costs or high natural gas prices could result in electricity generation that is competitive with natural gas turbines.

The increase in generation cost after a certain threshold is partly due to the increasing need for operation of the auxiliary backup system and partly due to the loss of CSP output from the solar component when there is excess supply. Because of this increased use of natural-gas backup, the usefulness of CSP plants to reduce carbon emissions from I&P generation decreases at high penetration levels. Operation in backup mode, however, increases revenues and would allow capacity payments to the CSP plant operator. Thermal storage systems can only supply firm power for specified periods, which might include evening hours, short cloudy periods during a day, or overnight in the case of base load systems. Thermal storage cannot fulfill the role of supplying backup power for days in which direct irradiance is not sufficient to operate the CSP solar field [5].

Yuxiang Chen , A.K. Athienitis, Khaled Galal in Modeling, design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house presented a detailed study of the modeling and design of a BIPV/T system implemented in a near net-zero-energy house in a cold climate, the integrated energy concept of the house, and an analysis of the measured thermal performance of the BIPV/T system. The integrated concept of the house combines three technologies to approach net-zero energy consumption over a year: direct gain passive system, an active BIPV/T system and a ground source heat pump. It also uses a combination of passive and active thermal storage integrated in the floors of the house.

The study shows that a BIPV/T system can be implemented in near net-zero energy houses in a cold climate, and provide significant potential for reducing their space heating energy consumption. The full-scale monitored data presented in the paper indicate that the BIPV/T heat recovery system can lower the PV panels' operating temperature significantly and can collect a considerable amount of solar thermal energy [6].

Adnan Ibrahim, Mohd Yusof Othman, Mohd Hafidz Ruslan, Sohif Mat in recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors tells about a comprehensive review on the description on design configurations of flat plate PV/T collector systems. This paper also convoluted the principle classifications of flat plate PVT collector systems. This classification provides clearly how this flat plate PV/T collector system designed can be grouped systematically according on the type of working fluid used such as water or air. Moreover, the flat plate PV/T collector system can be further distinguished according to the flow pattern of the absorber collector underneath the flat plate module. For flat plate PV/T water type, it can be distinguished by the water flow pattern usually installed underneath the flat plate and can be in sheet and tube, square/rectangular or round shape. For flat plate PVT air type, it can be distinguished according to the air flow pattern and can be installed above, below or on both sides of the absorber collectors. The flat plate PV/T air type can also be combined with water type. The flat plate PVT collector systems inherit the benefits of PV module. It works on noiseless environment; do not produce any unwanted waste such as radioactive materials, highly credibility system with life span expectation is between 20 and 30 years and very low maintenance cost and suitable for the application of building integrated photovoltaic/thermal system [7].

L.A. Chidambaram, A.S. Ramana, G. Kamaraj, R. Velraj in solar cooling methods and thermal storage options presented review of the technologies related to the better utilization of solar energy for the production of cool energy. It is understood from the review that thermal storage is essential in the solar circuit, in order to take maximum advantage of the solar resource and control differences between the cooling/heating demand and solar radiation availability. Thermal storage integrated solar cooling systems increase the cooling availability, capacity and improve the overall performance [8].

S. Mekhilef, R. Saidur, A. Safari in the review on solar energy use in industries mentions the Applications, developments and forecasts of solar energy used in industries were presented in this paper. It was discussed how the solar energy utilization can improve the quality and quantity of products while reducing the greenhouse gas emissions. It has been found that both solar thermal and PV systems are suitable for various industrial process applications. However, the overall efficiency of the system depends on appropriate integration of systems and proper design of the solar collectors. Solar energy systems can be considered either as the power supply or applied directly to a process. Large scale solar thermal systems with large collector fields are economically viable due to the usage of stationary collectors. In addition, they need less initial investment cost compared to small plants. Feasibility of integrating solar energy systems into conventional applications depend on industries' energy systems, heating and cooling demand analysis and advantages over existing technologies. Solar PV systems are reliable substitutes to be considered as an innovative power source in building, processes industries and water desalination systems. The economic outlook for these systems is more viable when the system is operating in remote regions where there is no access to a public grid [9].

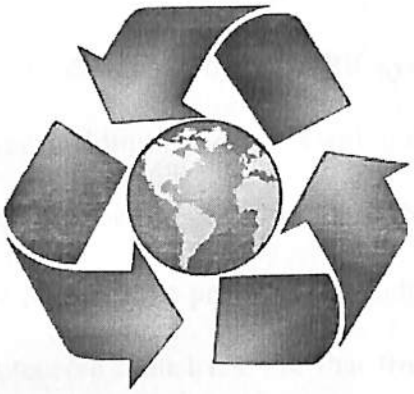
Agustin M. Delgado-Torres Solar thermal heat engines for water pumping: An update shares the Knowledge about solar thermal heat engines for water pumping. New conventional designs have been added to previous known systems, some of them corresponding to solar thermal driven reverse osmosis desalination systems. It is pointed out the intensive activity on conventional designs in the 1970s and 1980s in the 20th century. In almost cases, these conventional systems are low power output and low efficiency systems: below 20 kW with the exception of the 150 kW solar Coolidge irrigation plant and below 5% respectively. In general, Rankine cycle with water or an organic substance as working fluid is used as power cycle to convert solar thermal energy into work [10].

Mirunalini Thirugnanasambandam, S. Iniyan, Ranko Goic in the review of solar thermal technologies presented major solar thermal technologies comprising of solar water heaters, solar cookers, solar driers, solar ponds, solar architecture, solar conditioning, solar chimneys, solar power plants and solar stills was performed. The review gives a brief overview of the developments in each of these key areas of technology in view to either raise the performance of the presently used systemor to build a new system which employs a great deal of innovation and gives better results than the present ones, both at the same time. Thus the paper explicitly points out the areas in solar thermal technologies where there is scope for future research [11].

OBJECTIVES

CHAPTER 3: OBJECTIVES

1. To design a solar PV system for the replacement of all the lighting system for an institute in Bengaluru.
2. To study the various solar thermal technologies to which it can be incorporated in different industries so that to improve the efficency and to reduce the usage of fossil fuels.
3. To suggest a possible solution for the case study of solar steam cooking system.



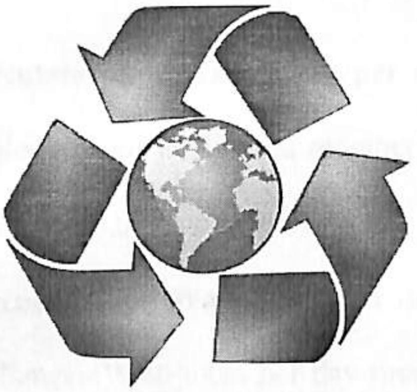
METHODOLOGY

CHAPTER 4: METHODOLOGY

First of all the literature survey has been done and different research papers from science direct, Elsevier publications and renewable and sustainable energy reviews is collected and studied.

For the designing of solar PV system, place is to be decided to design the solar PV system , after deciding the place, visiting the site and surveying of number of lights needed and load required is to be calculated and then the designing is to be done as per the procedure.

Next phase of the project is to study and analyse the incoporation of solar thermal energy in energy intensive industries. For that from the literature, previously incorporated systems has been studied, analysed and suggestions are given if any, to improve the effeciency and to save the fuel.



SOLAR PV SYSTEM DESIGNING

CHAPTER 5: SOLAR PV SYSTEM DESIGNING

5.1 PROCEDURE

1. Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

- **Calculate total Watt-hours per day for each appliance used:** Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.
- **Calculate total Watt-hours per day needed from the PV modules:** Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

2. Size the PV modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced needs. The peak watt (Wp) produced depends on size of the PV module and climate of site location. We have to consider "panel generation factor" which is different in each site location. For Bangalore, the panel generation factor is 2.86. To determine the sizing of PV modules, calculate as follows:

- **Calculate the total Watt-peak rating needed for PV modules**: Divide the total Watt-hours per day needed from the PV modules (from item 1.2) by 2.86 to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.
- **Calculate the number of PV panels for the system**: Divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to you. Increase any

fractional part of result to the next highest full number and that will be the number of PV modules required.

Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened.

3. Inverter sizing

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting.

For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation.

4. Battery sizing

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculate as follows:

- Calculate total Watt-hours per day used by appliances.
- Divide the total Watt-hours per day used by 0.85 for battery loss.
- Divide the answer obtained in item 4.2 by 0.6 for depth of discharge.
- Divide the answer obtained in item 4.3 by the nominal battery voltage.
- Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.

$$\textbf{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances}}{(0.85 \times 0.6 \times \text{nominal battery voltage})} \times \text{Days of autonomy}$$

5.2 CALCULATIONS:

Place: Sri Ramakrishna Vidyarthi Mandiram, Bengaluru.

Institution type: Hostel

Work: Replacement of all lighting systems of the hostel with 15W CFL using Solar PV systems.

Total number of lighting systems required

Rooms	60
Kitchen	15
Shrine	15
Auditorium	25
Library	15
others	20
TOTAL	**150**

Load Estimation:

SL.NO	EQUIPMENT	QTY	WATTAGE	DURATION	LOAD
1	Light	150	12W	6hrs	10800 Wh
				TOTAL	10800 Wh

Power consumption demand:

Total PV panels energy demand = 10800 * 1.3

(1.3 is the measure of energy lost in the system)

= **14040 Wh**

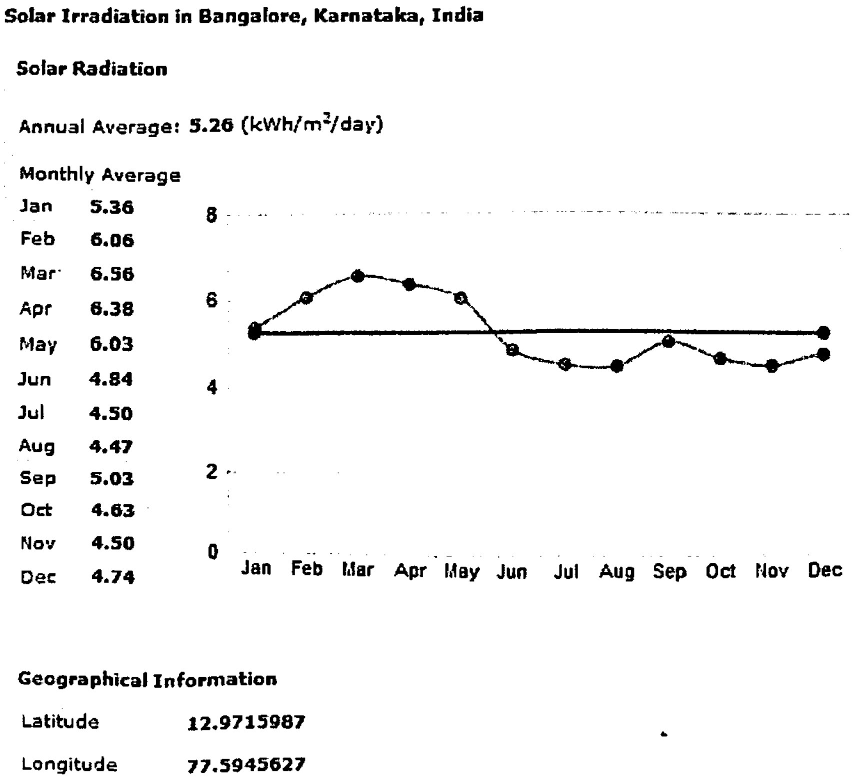
Sizing of PV panel:

$$\text{Wp of PV panel capacity needed} = \frac{\text{Total PV panels energy demand}}{\text{Panel generation factor}}$$

Panel generation factor = collection efficiency * average solar radiation in least sunny month

collection efficiency = 1-0.36 = 0.64 = 64%

(for a typical solar panel collection losses on annualized basis is 36%)



Solar Irradiation in Bangalore, Karnataka, India

Solar Radiation

Annual Average: **5.26 (kWh/m²/day)**

Monthly Average

Jan	**5.36**
Feb	**6.06**
Mar	**6.56**
Apr	**6.38**
May	**6.03**
Jun	**4.84**
Jul	**4.50**
Aug	**4.47**
Sep	**5.03**
Oct	**4.63**
Nov	**4.50**
Dec	**4.74**

Geographical Information

Latitude	**12.9715987**
Longitude	**77.5945627**

Average solar radiation in least sunny month = 4.47

Therefore,

Panel generation factor

= 0.64 * 4.47

= **2.86**

Source: http://www.synergyenviron.com/tools/solar_insolation.asp

.’. Wp of PV panel capacity needed $= \frac{14040}{2.86}$

$$= \mathbf{4909.1\ Wp = 4.9\ kWp}$$

Number of panels needed:

$$= 4909.1/160 = 30.68 = \mathbf{31}$$

.’. System requires atleast 31 panels of 160Wp

Inverter sizing:

Total wattage of all appliances = (150*12)

$$= 1800\ W$$

For safety, Inverter should be considered 25% to 30% bigger size

$$.’.\ 1800 * 1.25 = 2250\ W$$

.’. Inverter should be **2250 W** or greater

Battery sizing:

$$\textbf{Battery Capacity (Ah)} = \frac{\textbf{Total Watt-hours per day used by appliances}}{\textbf{(0.85 x 0.6 x nominal battery voltage)}} \textbf{ x Days of autonomy}$$

Nominal battery voltage = 12 V

Total use = 10,800 Wh/day

Battery loss = 0.85

Depth of discharge = 0.6

Days of autonomy = 2

.’. Battery Capacity $= \frac{10{,}800 * 2}{(0.85 * 0.6 * 12)} = \mathbf{3530\ Ah}$

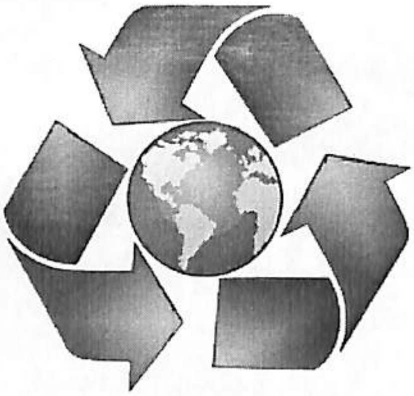
Battery rating = **12 V, 3530 Ah** for **2 days** of autonomy

Cost calculation:

Approximate cost for a 10 kW solar PV plant, it costs around Rs 25,00,000/-

So for a 5 kW plant, cost = 0.49 * 25,00,000

= **Rs 12,25,000/-**



SUBSIDY BY MNRE

5.3 SUBSIDY PROVIDED BY THE MNRE FOR SOLAR PV:

The Ministry of New and Renewable Energy (MNRE) has revised the benchmark cost of the solar PV system and the capital subsidy w.e.f 2011. Under the revised guidelines, From April 1, 2011, the benchmark cost will be Rs. 270/Wp (with battery) and 190/Wp (without battery). The corresponding reduced capital subsidy will be Rs. 81/Wp (with battery) and Rs. 57/Wp (without battery) in general areas.

The simplest form of subsidy is 30% capital subsidy by MNRE.

MNRE's basic guidelines to avail this subsidy is:

1. Project should not exceed 100 kWp installation (single location).
2. Project could be off-grid or grid-synchronized.
3. Power cannot be fed to the grid i.e. it has to be for captive consumption only.
4. Battery backup is optional. The subsidy for projects with and without battery is different - MNRE adjusts subsidy amount for higher project cost due to battery.
5. Project should be preferably executed by MNRE empanelled vendor.

Therefore cost of the system,

Without subsidy: **Rs 12,25,000/-**

With Subsidy: **Rs 8,57,500/-**

5.4 SITE SELECTION

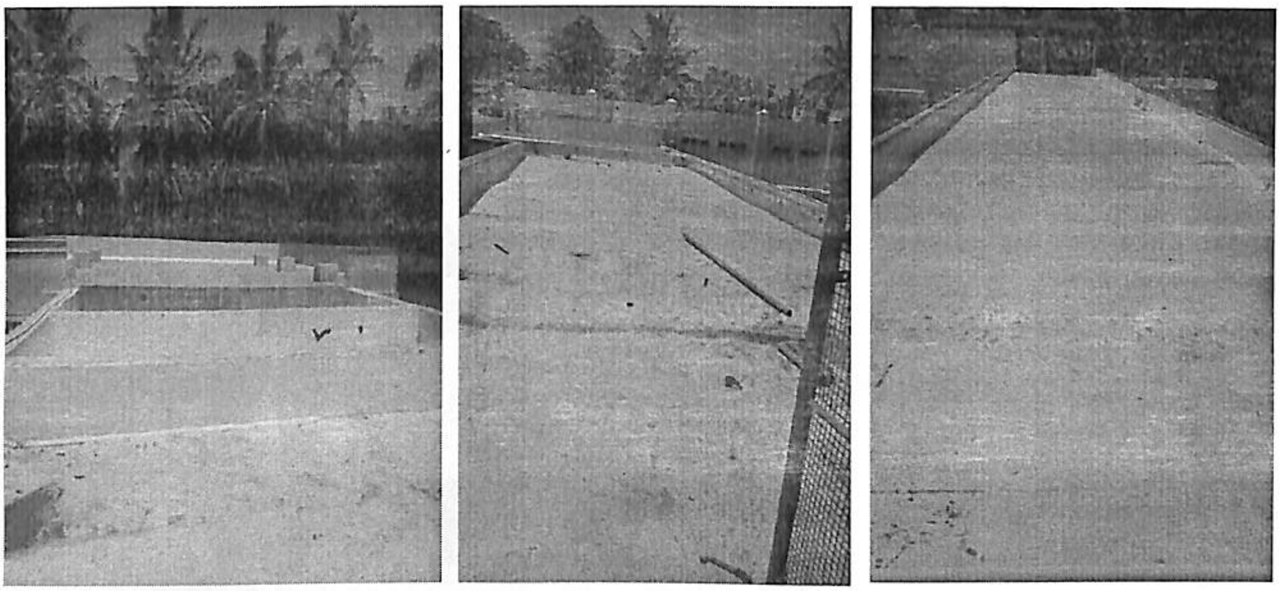
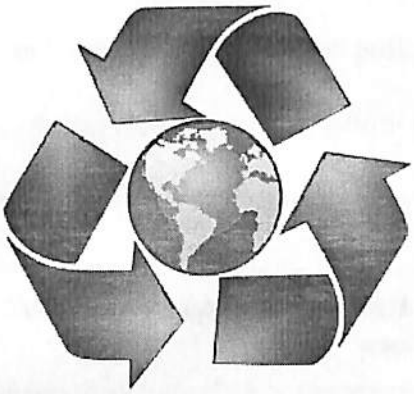


Figure:5.1 Site selected for PV system

SRVM has an area of more than 5000 sq ft on the terrace on which 31 panels of 160Wp can be easily mounted. Though it has an open field next to the building, terrace is the best site to place the PV panels.



INCORPORATION OF SOLAR THERMAL IN INDUSTRIES

CHAPTER 6: INCORPORATION OF SOLAR THERMAL ENERGY IN INDUSTRIAL SYSTEMS

As mentioned earlier, solar energy is said to be the most promising renewable source of energy for use in industrial as well as residential purposes. Solar energy is free of cost, available in abundance and does not cause any pollution to the environment. It can be used for many applications. Below table 6.1 shows how solar energy can be used in various applications and also the technologies that are being used by the industries presently.

Table:6.1 Solar energy applications, technologies and the type of systems that are commonly used in industries.

Solar energy application	**Solar system technology**	**Type of system**
SWH	Thermo syphon systems	Passive
	Integrated collector storage	Passive
	Direct circulation	Active
	Indirect water heating systems	Active
	Air systems	Active
Space heating and cooling	Air systems	Active
	Water systems	Active
	Heat pump systems	Active
	Absorption systems	Active
	Adsorption (desiccant) cooling	Active
	Mechanical systems	Active
Solar refrigeration	Adsorption units	Active
	Absorption units	Active

Industrial heat demand process	Industrial air and water systems Steam generation systems	Active Active
Solar desalination	Solar stills Multistage flash (MSF) Multiple effect boiling (MEB) Vapor compression (VC)	Passive Active Active Active
Solar thermal power systems	Parabolic trough collector systems Parabolic tower systems Parabolic dish systems Solar furnaces Solar chemistry systems	Active Active Active Active Active

A basic or a distinctive industrial solar energy system would contain four main parts such as power supply, production plant, energy recovery and cooling systems. Below given figure illustrates a classic industrial energy system.

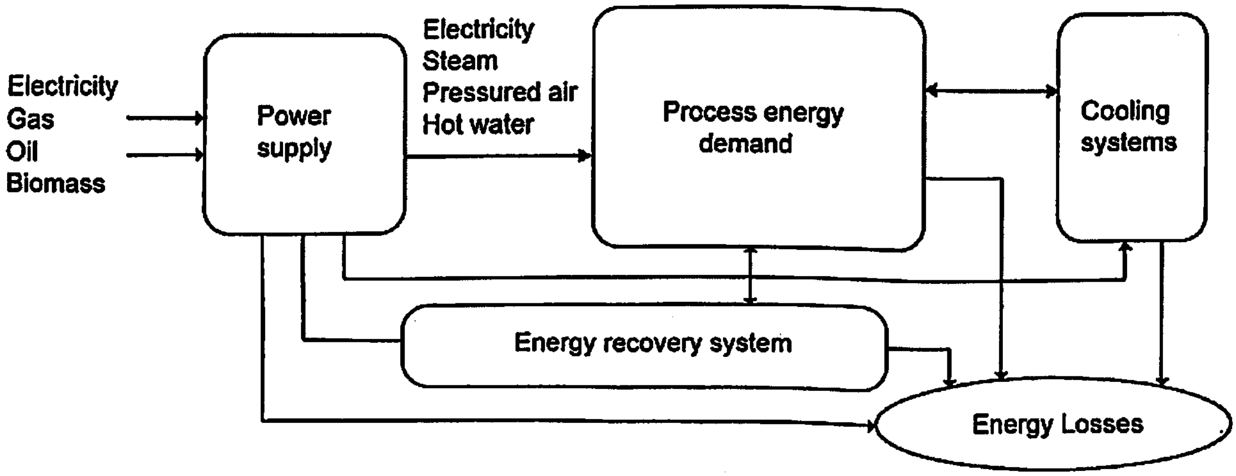


Figure 6.1. Block diagram of a typical industrial energy system

Power supply: It is used to supply the required energy for the system to operate. This is usually electrical energy, heat energy, steam, gas or coal.

Production plant: It is that part of the system which carries out and executes the actions of the production. Here the energy from the power supply is made use of to rum systems, valves and switches.

Solar energy systems can be made use of either way to make use of as a power supply or directly used as to carry out a process. Solar thermal is the process of conversion os solar radiation to heat. Solar thermal is the most economical amongst all the available renewable resources. As mentioned in the earlier part of the report, the solar energy systems would make use of solar collectors or concentrators to collect solar irradiation and then make use of it to heat air or water which can later be used to run turbines to generate power. The heated water can also be used for general residential and industrial purposes. The figure shown below gives a general outline of the solar irradiation conversion to mechanical energy.

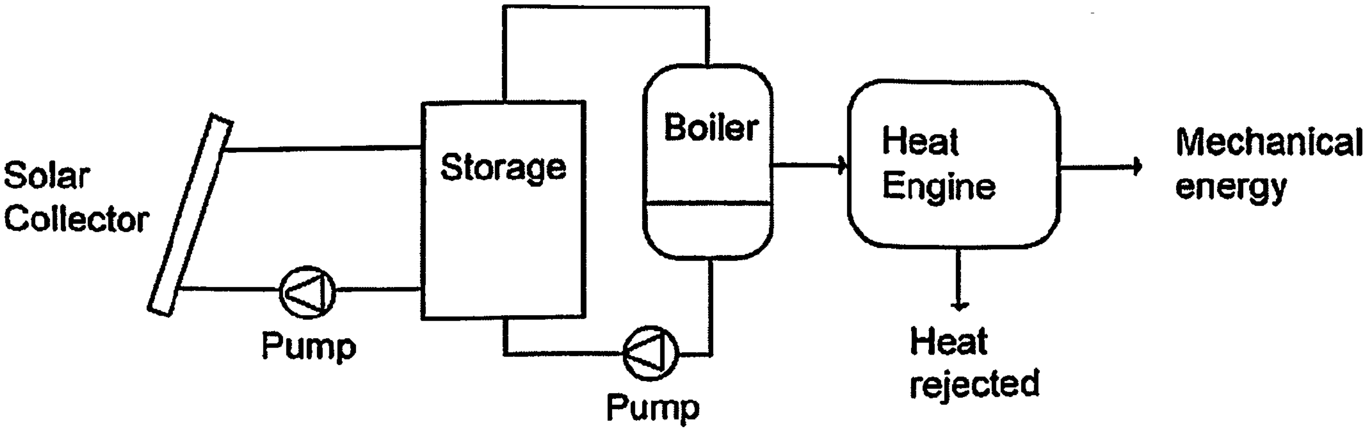


Figure:6.2 Schematic of a solar-thermal conversion system

The size of the heat exchanger and the load factor that need to be considered would be determined on the basis of the system factors such as type of collector, fluid used, storage volume and the location where the system is installed.

In cases such as applications where solar energy is not available continuously throughout the day but required, measures would be taken up so that the solar irradiation is collected and stored in embedded phase transition whenever available during sunny days and then made use of when required by releasing it in a controlled manner. The efficiency of the solar thermal system is increased by applying the heat collected through the collectors to the medium of heat transfer such as water. However different types of plates are used on the basis of the type of application the system would be used for. Flat plate applications are used in applications where the process would be carried out in low temperature, and sun-tracking parabolic trough collectors (PTC) are used in applications dealing with high temperature reaching about 250^0 C and where high efficiency is required, two axis tracking collectors are used in power generation and stationary & one axis collections are made use of in industrial applications.

6.1 SOLAR THERMAL ENERGY FOR INDUSTRIES

Most of the industries working in the energy sector are presently completing and solely dependent on the fossil fuels for power generation. It is seen that about 13% of thermal industrial applications require low temperature thermal energy up to 100^0C, 27% up to 200^0C and the remaining applications need high temperature in steel, glass and ceramic industries. Below given table shows the temperatures at which particular industrial processes takes place.

Table: 6.2 Heat demand industries and range of temperatures

Industry	Process	Temperature (°C)
Dairy	Pressurization	60–80
	Sterilization	100–120
	Drying	120–180
	Concentrates	60–80
	Boiler feed water	60-90
Tinned food	Sterilization	110–120
	Pasteurization	60–80
	Cooking	60–90
	Bleaching	60–90
Textile	Bleaching, dyeing	60–90
	Drying, degreasing	100–130
	Dyeing	70–90
	Fixing	160–180
	Pressing	80–100
Paper	Cooking, drying	60–80
	Boiler feed water	60–90
	Bleaching	130–150
Chemical	Soaps	200–260
	Synthetic rubber	150–200
	Processing heat	120–180
	Pre-heating water	60–90
Meat	Washing, sterilization	60–90
	Cooking	90–100
Beverages	Washing, sterilization	60–80
	Pasteurization	60–70
Flours and by-products	Sterilization	60–80
Timber by-products	Thermo diffusion beams	80–100

	Drying	60–100
	Pre-heating water	60–90
	Preparation pulp	120–170
Bricks and blocks	Curing	60–140
Plastics	Preparation	120–140
	Distillation	140–150
	Separation	200–220
	Extension	140–160
	Drying	180–200
	Blending	120–140

It can be said that almost all or most of the industrial processes require heat energy in some or the other part of the system to carry out a process. There are a large number of industries that are involved in the utilization of heat with temperatures ranging from 80 to 240 degrees Celsius. But according to the industrial analysis, solar thermal energy has massive number of applications working with low temperatures from 20 to 200^0 C, medium and medium high temperature from 80 to 220^0 C. In industrial sector of South European countries almost 15% of the final energy demand is made use of for heating applications. SWH's, space heating, water desalinisation, solar dryers and cooling systems are the most commonly used applications for solar thermal energy. Many industrial applications make use of solar energy as the input power for heat engines.

Sterling engines for their operation make use of any kind of external heat source. These engines are simple in construction but highly reliable. They are also very easy to operate and run on low cost. But the efficiency of this engine is low. By making use of solar irradiation for the heating purpose in stirling engines can reduce the cost much further and also can increase their efficiency. The cheapest alternative would be to generate electricity using the stirling engines.

The generate electricity in the rage of 1 to 100 kW and use compressed fluids lie hydrogen, air, nitrogen, helium or steam. They are also applicable in various applications where there is a need for quite operation and in systems with good cooling source, low speed, constant power output, low pace of changing output power and in systems with multi-fueled characteristics.

Use of solar energy for the purpose of heating and generating thermal energy not only reduces the industrial dependency on fossil fuels but also reduces the emissions like CO2, SO2 and NOx. But there are quite a few challenges that exist for merging solar heat for industrial processes like periodic, dilute and variable nature of solar radiation.

6.2 SOLAR THERMAL IN FOSSIL FUEL FIRED POWER PLANTS

Repowering the steam power plant is not a new suggestion. In order t increase the efficiency and lifetime, gas turbine addition is added to the existing power plant. This way coal fired plants can be converted into combined cycle plant where the input to the steam cycle would be the hot gas turbine's exhaust gas. Similar approach can be functional to the heat from solar thermal generation field located in the vicinity of the plant. The first step in the design process would be determining how to incorporate the solar heat into the already existing conventional steam plant.

A simple option would be to replace the plant's auxiliary steam system with a direct solar steam generation process. The auxiliary steam system usually provides a dependable source of steam to many plant systems such as steam heavy fuel oil heaters, steam air heaters, turbine gland steam, air ejectors, deaerator, burners, soot blowers and thermal seawater desalination system for process and boiler makeup if applicable. Depending on the unit status and boiler pressure, the steam system itself can be supplied from several sources. The system can draw steam from the main steam line, cold reheat steam line or from the next unit's auxiliary team header. Steams from the main steam line and the cold reheat line pass through a pressure controller valve since the pressure would be too high. Some of the typical parameters of steam from the steam header are: pressure – 10 to 15 bar and temperature- up to 230^0 C. And the steam consumption can be 2-3% of the actual steam output of the boiler.

An easier way to incorporate solar heating into the Rankine cycle plane is to replace the boiler either partially or completely with a solar based steam generation facility. The Rankine cycle power plant has steam conditions of 16 MPa and 540 degrees Celsius. Steam with such parameters would be able to be generated through a high temperature solar technology like solar tower or advanced parabolic collectors.

6.2.1 SOLAR HEATED FEED WATER PREHEATING OPTIONS

A conventional power plant would consist of a boiler, either coal or heavy oil that supplies steam to a turbine generator which is exhausting to a condenser of high capacity. The condensate is later pumped through a huge number of water heaters that make use of the steam extracted from higher pressure stages of the turbine. This is done until the water temperature reaches as high as possible reliable with the design of the steam boiler or with the economic contemplation of the cycle. The regenerative feed water heating results in a high cycle efficiency being primarily dependent upon the number of extraction points and feed water heaters that it is economically feasible to utilize.

As shown in the figure below, the feed water cycle consists of two series of heaters namely LP heaters and HP heaters. A set of four heat exchangers make up a group of low pressure heaters. The condensate is degasified after passing through these heaters. The group of high pressure heaters is made up of three heat exchangers fed with high temperature superheated steam which has been let out from the high pressure turbines. The boiler's economizer heat up the feed water further more. To be more practical, there are three different ways by which the solar water heating process can be accomplished in the existing system.

- LP heaters replaced by solar field consisting of water based solar collectors.
- HP heaters replaced by similar solar field.
- HP heaters and economizer replaced by solar field heating.

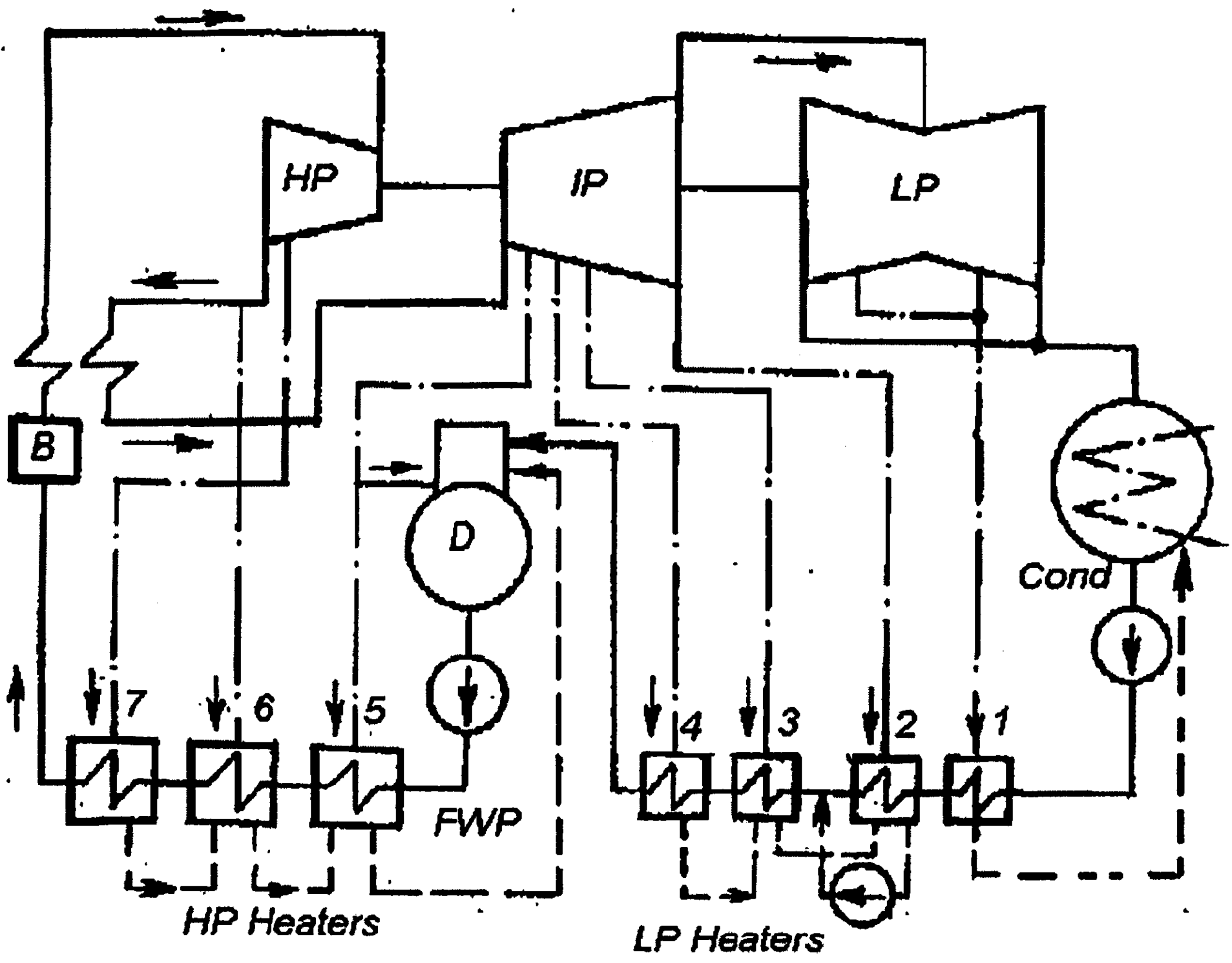


Figure:6.3 Schematic diagram of ordinary steam turbine plant

The result of this replacement there would be considerable amount of reduction or elimination in the steam. This steam would expand in the respective turbines and finally be exhausted to the condenser. Same way turbine stages can be overloaded with left-over steam flow: This is practical especially with the last stages of the LP turbine and such a mode of operation is not new in the working of turbines. It occurs when feed water heaters are out of operation. To avoid any damage in such cases, turbines are imposed with capacity limitations. This simply means that when steam water heaters are out of operation, the steam flow has to be decreased in order to maintain proper functioning of the system. Similar approach has to be applied to a group of feed heaters; they can be switched off whenever required.

Reduction and elimination of steam to feed water heaters results in fuel savings as the boiler steam output will be reduced. The effects can be observed by developing a hybrid power plant.

6.3 SOLAR TEHRMAL IN FOOD INDUSTRY

Solar heat can be widely made use of in the food industry since it requires treatment and storage process involving heat energy that would make the food more durable. Authors [13] have made a study on non concentrating solar collectors which are commonly used by the food industry in Germany. It is evident from the results that the efficiency of the system is comparable to SWH's and solar space heating systems.

Solar thermal can be applied to cooked meat like sausages and salami, milk pasteurizing and also in brewing industries at a medium temperature for sterilizing, pasteurizing, drying, cooking, washing, hydrolyzing, distillation, evaporation, extraction and polymerization. In the brewing industry 80% of the energy consumption is made if the form of thermal energy. This amount of energy is divided in three processes: boiling, washing and pasteurization.

Solar thermal energy can be used in brewing industry for process listed below:

- Low pressure steam generation at temperature 100–110^0 C
- Wort refrigeration; using absorption cooling
- Malting process; for barley drying
- Stop germination of grains after germination
- Conservation with hot air at temperature 60–80^0 C
- Air cooling in the germination process
- Power supplying of washing machines for returned bottles
- The wither and kiln processes

Food industry also makes use of the solar heat for sterilization, pre cooking, sealing, cooling and refrigeration. Dairy industries can also make use of solar heat for various processes such as pasteurization (60-80^0 C), sterilization (130-150^0 C) and to dry milk to produce milk powder. Milk powder industry needs energy constantly with up to 8000 hours per year. The case study mentioned with authors also studied solar thermal applications in food industry in India.

The systems are running on conventional fossil fuels. Solar energy would be a good substitute. Report says that presently 20% of the production cost is spent on energy consumption. These industries are busy working industries and would work most of the days in a year, so it can be said that the use of solar energy for the process carried in these industries would significantly reduce the working cost. To maintain quality of the products and taste, it is recommended to use parabolic concentrators.

6.4 SOLAR THERMAL IN BUILDING INDUSTRY

Building and related industries are the second largest energy consumers in the world. Solar energy is being directly or indirectly being used in this industry. Use of solar energy has a lot of environmental and economic benefits. Conventional solar thermal systems are being developed and used with the integration of solar material, substance and system in buildings. Use of solar energy was restricted only to very few applications in this industry. But with the development of the solar energy technology it is being able to be used as SWH's, solar ventilation, air-conditioning and photo voltaic power systems.

Solar energy in building industry has three main applications. They are:

Passive sunspace: by making use of the physical structure and location of the building, sun radiations are collected.

Active sunspace: solar heating system in used in the building to generate heat or to cool. This usually consists of sun collectors, fans, pumps etc.

Photo voltaic applications: PV power system would be used for electricity, lightening, heating, ventilation and air cooling. Such a building can be called as zero emission building.

6.5 SOLAR THERMAL IN TEXTILE INDUSTRY

It happens in very low cases that the processes which require water preheating have met higher efficiencies because of the nature of solar systems that input temperature. The main reason for this is that simple collectors collect sunlight at temperature required by the load.

The figure given below shows the integration of solar collectors to an industrial system.

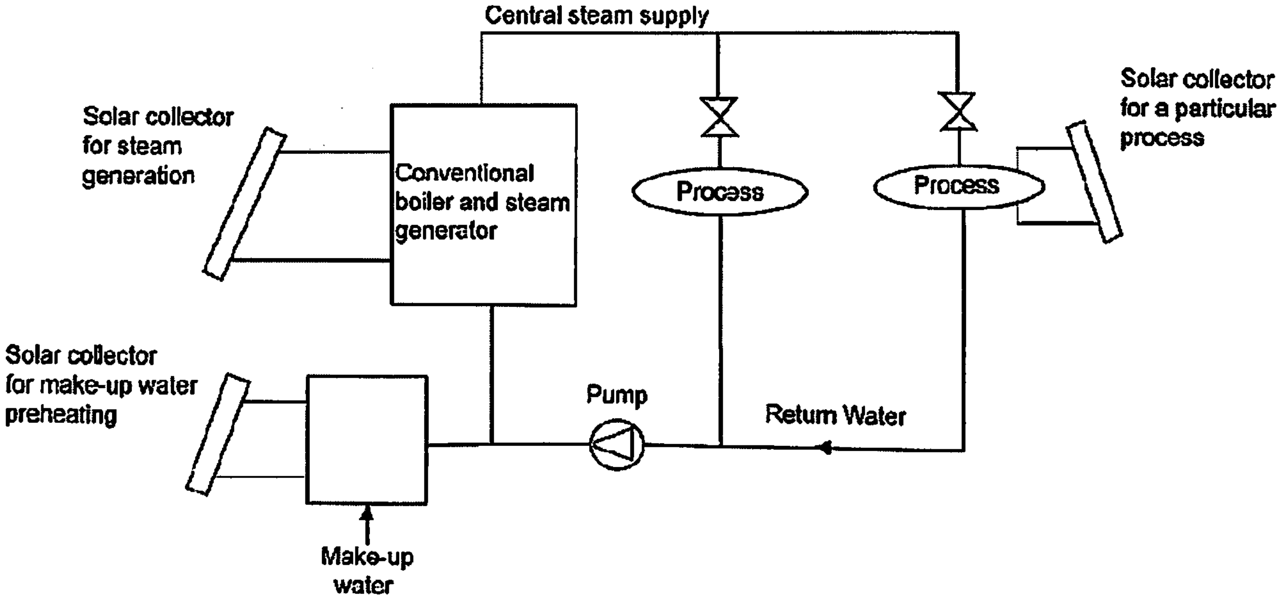
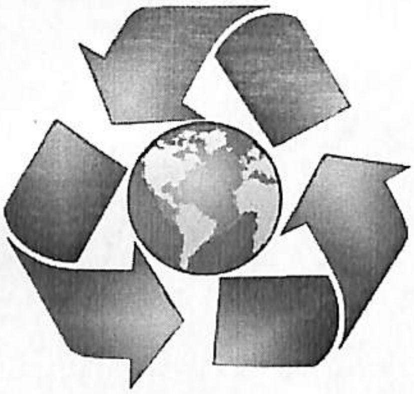


Figure:6.4 Integration of solar collectors to an industrial system

Textile industry makes use of the solar thermal for heating water at temperature nearing to 100 degrees Celsius. This is required to carry out processes such as washing, dyeing and bleaching. Presently this industry is being run on the fossil fuels. SWH's can significantly reduce the problem with the textile industry. Further to increase and improve the performance and stability of the systems, built-in storage water heaters can be used. [12]



CASE STUDY

CHAPTER 7: CASE STUDY

SOLAR STEAM COOKING SYSTEM

Place: Sri Ramakrishna Vidyarthi Mandiram, Bengaluru.

Capacity: 300-330 people/day

System installed: 16 sq-m scheffler's reflector (4 no's)

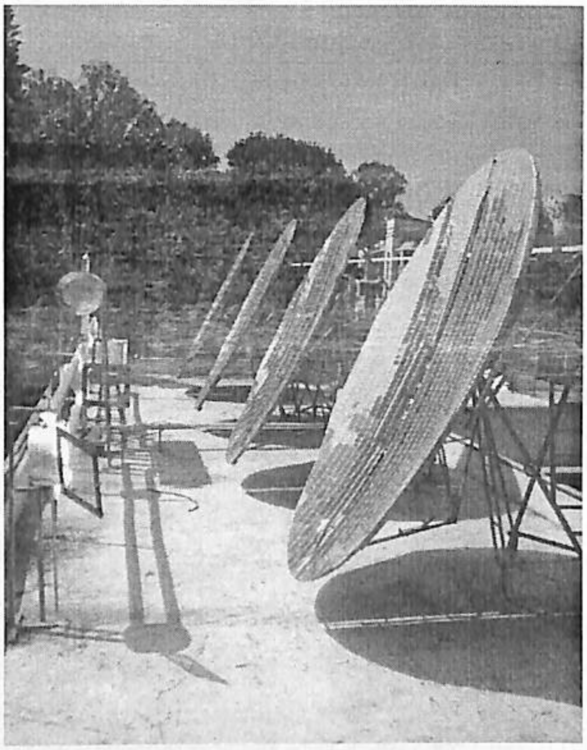


Figure:7.1 Scheffler reflector installed at SRVM

The Scheffler-Reflector

The Idea:

The Basic idea behind development of scheffler-reflectors was to make solar cooking as comfortable as possible and at the same time the device should be built in a way that allows it to be constructed in any rural welding workshop in southern countries after a certain period of training and locally available materials must be adequate enough.

The Technology:

To make cooking as simple and comfortable the cooking place should not have to be moved, even better, it should be inside the house and the concentrating reflector outside in the sun.

The best solution was an eccentric, flexible parabolic reflector, which rotates around an axis parallel to earth's-axis, synchronous with the sun. Additionally the reflector is adjusted to the seasons by flexing it in a simple way.

Technical description

The solar steam cooking plant consists of **solar parabolic concentrator, receiver, Steam header, automatic tracking system, valves and control etc**. The main component of the system is the **16 Sq-m** solar parabolic concentrator. This technology is invented by an Austrian scientist Mr.Wolfgang Scheffler. The parabolic concentrator of 16Sq-m concentrates the sunlight in to 45 cm diameter. Where high temperature around **400^0C** is generated. This temperature is carried in by a circular receiver by means of heat exchange in between the water, which is circulating inside the receiver and the optical temperature. Thus exchanged temperature is transferred to header assembly placed above receiver by thermo siphoning principle (Natural circulation system).

The header assembly needs to be filled with soft water by means of an electrical pump once in a day. Apart from this there is no need of any external power throughout the day. The header assembly works as steam and water preserver. The generated solar steam will be conveyed to the kitchen by necessary safety valves, pressure gauges, temperature gauges etc, solar parabolic concentrators are tracked automatically with help of a photovoltaic panel, light sensor, DC drive, gear box etc.

Observations:

- 10 to 12 kgs of steam is being produced everyday
- Daily utilization is only 4 to 5 kgs of steam

- 5-6 kgs of steam is being wasted daily.

Operating Parameters:

- Steam temperature: up to 400^0 C
- Working pressure: 15 kg/sq-cm
- Average steam flow rate: 8 kg/h

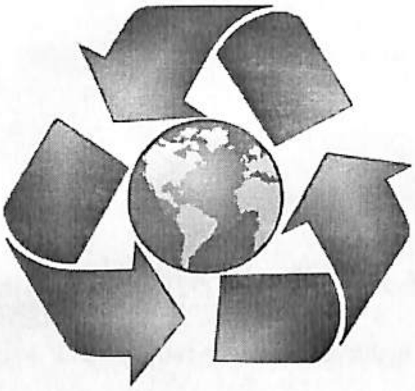
Solution:

The question is how to utilize this steam in the best possible way, there were 2 available options one is for serving hot water purpose for bathing and the other is generation of electricity using a small turbo generator. Since the hot water geyser is located very far from the collectors(500 mtrs) it would not be a feasible option, so we should go for the next option, i.e, generation of electricity using a micro turbo generator.

The above details has been sent to a green turbo generator manufacturer (*Green turbine*), the least available size of the turbo generator was 1 kw, to run this turbine following were the operating conditions provided by the company.

- Temperature of steam: 200-230^0C
- Operating pressure: 20 bar
- Steam flow rate: 15 kg/h

Though it satisfies the temperature of steam and operating pressure requirement, it doesn't satisfy the steam flow rate. The steam flow rate of the installed system is almost half of the required steam flow rate. So it has been understood that the system requires 0.5 to 0.6 kw turbine to generate the electricity which can be stored in battery and use it as a backup power for the institute.



CONCLUSION & SCOPE

CHAPTER 8: CONCLUSION AND SCOPE

- Below are the details of the PV system designed,
  - ✓ Number of panels required: 31 panels of 160Wp
  - ✓ Capacity of the plant: 4.9 kw
  - ✓ Battery Rating: 12V, 3530 Ah for 2 days of autonomy
  - ✓ Inverter size: 2250 W or greater
- Cost of the system,
  - ✓ Without subsidy: Rs 12,25,000/-
  - ✓ With subsidy: Rs 8, 57, 500/-
- Studies shows that the temperature requirement of different industrial processes can be easily met by the solar thermal systems. Applications of solar thermal energy used in industries are shown. It is discussed how the solar energy utilization can improve the quality and quantity of products while reducing the greenhouse gas emissions. It has been found that solar thermal systems are suitable for various industrial process applications. However, the overall efficiency of the system depends on appropriate integration of systems and proper design of the solar collectors.
- For the solar steam cooking system which is discussed in the case study, the system requires a turbo generator of 0.5 to 0.6 kw to generate the electricity.

REFERENCES

Research papers

1. A review on photovoltaic/thermal hybrid solar technology, T.T. Chow, Applied Energy 87 (2010) 365–379.
2. A state of art review on the performance of transpired solar collector, A. Shukla, Dan Nchelatebe Nkwetta, Y.J. Cho, Vicki Stevenson, Phil Jones, Renewable and Sustainable Energy Reviews 16 (2012) 3975–3985.
3. Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology, V.V. Tyagi, S.C. Kaushika, S.K. Tyagi, Renewable and Sustainable Energy Reviews 16 (2012) 1383–1398
4. Modeling and control of a solar thermal powerplant with thermal energy storage, Kody M.Powell, ThomasF.Edgar, Chemical Engineering Science 71 (2012) 138–145
5. Modeling thepotentialforthermalconcentratingsolarpowertechnologies, Yabei Zhang, Steven J Smith, G.PageKyle, PaulW.Stackhouse, Energy Policy 38 (2010) 7884–7897
6. Modeling, design and thermal performance of a BIPV/T system thermally coupled with a ventilated concrete slab in a low energy solar house, Yuxiang Chen , A.K. Athienitis, Khaled Galal, Solar Energy 84 (2010) 1892–1907
7. Recent advances in flat plate photovoltaic/thermal (PV/T) solar collectors, Adnan Ibrahim, Mohd Yusof Othman, Mohd Hafidz Ruslan, Sohif Mat, Kamaruzzaman Sopian, Renewable and Sustainable Energy Reviews 15 (2011) 352–365
8. Review of solar cooling methods and thermal storage options, L.A. Chidambaram, A.S. Ramana, G. Kamaraj, R. Velraj, Renewable and Sustainable Energy Reviews 15 (2011) 3220–3228

9. A review on solar energy use in industries, S. Mekhilef, R. Saidur, A. Safari, Renewable and Sustainable Energy Reviews 15 (2011) 1777–1790

10. Solar thermal heat engines for water pumping: An update, Agustin M. Delgado-Torres, Renewable and Sustainable Energy Reviews 13 (2009) 462–472

11. A review of solar thermal technologies, Mirunalini Thirugnanasambandam, S. Iniyan, Ranko Goic, Renewable and Sustainable Energy Reviews 14 (2010) 312–322

12. An option for solar thermal repowering of fossil fuel fired power plants, Dimityr Popov, Solar Energy 85 (2011) 344–349

13. Solar process heat with non-concentrating collectors for food industry, Benz N, Gut M, Beikircher T, Proceedings of Solar World Congress (1999) 1209–1214

Websites:

1. For Subsidy on solar:
   http://mnre.gov.in/pdf/Revised%20Capital%20Subsidy%20and%20Benchmark%20cost%20of%20the%20SPV%20system.pdf
2. Design of solar PV system:
   http://www.leonics.com/support/article2_12j/articles2_12j_en.php