Making solar thermal power generation in India a reality – Overview of technologies, opportunities and challenges

Shirish Garud, Fellow and Ishan Purohit, Research Associate
The Energy and Resources Institute (TERI), India[1]
Emails - shirishg@teri.res.in and ishanp@teri.res.in

Preamble

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. Limited fossil resources and environmental problems associated with them have emphasized the need for new sustainable energy supply options that use renewable energies. Solar thermal power generation systems also known as Solar Thermal Electricity (STE) generating systems are emerging renewable energy technologies and can be developed as viable option for electricity generation in future. This paper discusses the technology options, their current status and opportunities and challenges in developing solar thermal power plants in the context of India.

India's power scenario

India's current electricity installed capacity is 135 401.63MW. Currently there is peak power shortage of about 10 % and overall power shortage of 7.5 %.

The 11th plan target is to add 100 000 MW by 2012 and MNRE has set up target to add 14500 MW by 2012 from new and renewable energy resources out of which 50 MW would be from solar energy. The Integrated Energy Policy of India envisages electricity generation installed capacity of 800 000 MW by 2030 and a substantial contribution would be from renewable energy. This indicates that India's future energy requirements are going to be very high and solar energy can be one of the efficient and eco-friendly ways to meet the same.

Solar energy potential

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. The India Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. Figure 1 shows map of India with solar radiation levels in different parts of the country. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where development and deployment of solar technologies is maximum.

[1] The Energy and Resources Institute (TERI), Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110003, India

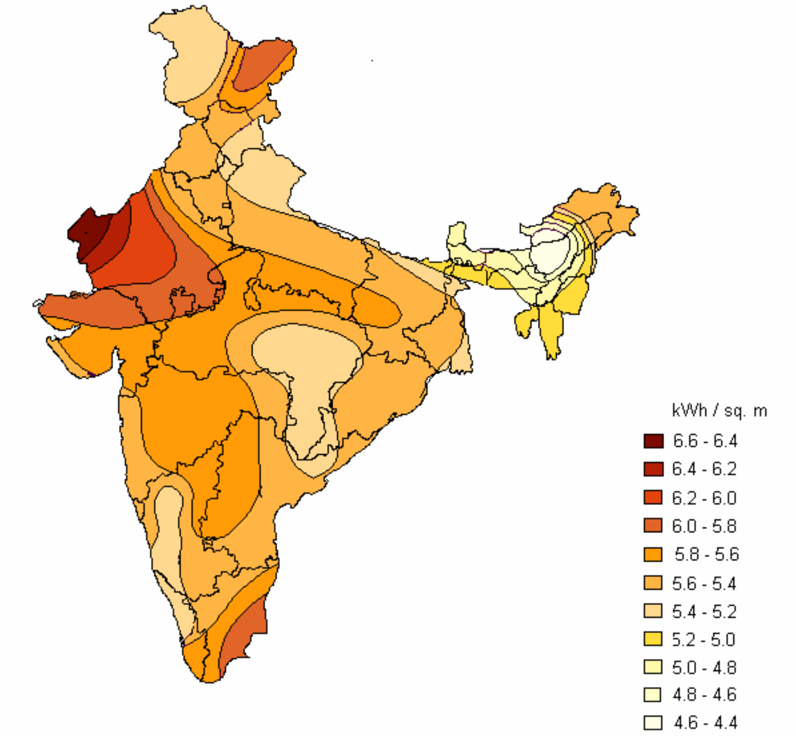

Figure 1 Solar radiation on India

Source: TERI

Solar thermal power generation technologies

Solar Thermal Power systems, also known as Concentrating Solar Power systems, use concentrated solar radiation as a high temperature energy source to produce electricity using thermal route. Since the average operating temperature of stationary non-concentrating collectors is low (max up to 120^{0}C) as compared to the desirable input temperatures of heat engines (above 300^{0}C), the concentrating collectors are used for such applications. These technologies are appropriate for applications where direct solar radiation is high. The mechanism of conversion of solar to electricity is fundamentally similar to the traditional thermal power plants except use of solar energy as source of heat.

In the basic process of conversion of solar into heat energy, an incident solar irradiance is collected and concentrated by concentrating solar collectors or mirrors, and generated heat is used to heat the thermic fluids such as heat transfer oils, air or water/steam, depending on the plant design, acts as heat carrier and/or as storage media. The hot thermic fluid is used to generated steam or hot gases, which are then used to operate a heat engine. In these systems, the efficiency of the collector reduces marginally as its operating temperature increases, whereas the efficiency of the heat engine increases with the increase in its operating temperature.

Concentrating solar collectors

Solar collectors are used to produce heat from solar radiation. High temperature solar energy collectors are basically of three types;

a. **Parabolic trough system:** at the receiver can reach 400° C and produce steam for generating electricity.
b. **Power tower system:** The reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000° C can be reached.
c. **Parabolic dish systems:** Parabolic dish systems can reach 1000° C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity.

Parabolic trough collector system

Parabolic trough power plants are line-focusing STE (solar thermal electric) power plants. Trough systems use the mirrored surface of a linear parabolic concentrator to focus direct solar radiation on an absorber pipe running along the focal line of the parabola. The HTF (heat transfer fluid) inside the absorber pipe is heated and pumped to the steam generator, which, in turn, is connected to a steam turbine. A natural gas burner is normally used to produce steam at times of insufficient insolation. The collectors rotate about horizontal north–south axes, an arrangement which results in slightly less energy incident on them over the year but favors summertime operation when peak power is needed.

The major components in the system are collectors, fluid transfer pumps, power generation system and the controls. This power generation system usually consists of a conventional Rankine cycle reheat turbine with feedwater heaters deaerators, etc. and the condenser cooling water is cooled in forced draft cooling towers. These type of power plants can have energy storage system comprising these collectors usually have the energy storage facilities. Instead they are couple to natural gas fired back up systems. A typical configuration of such systems is shown in Figure 2.

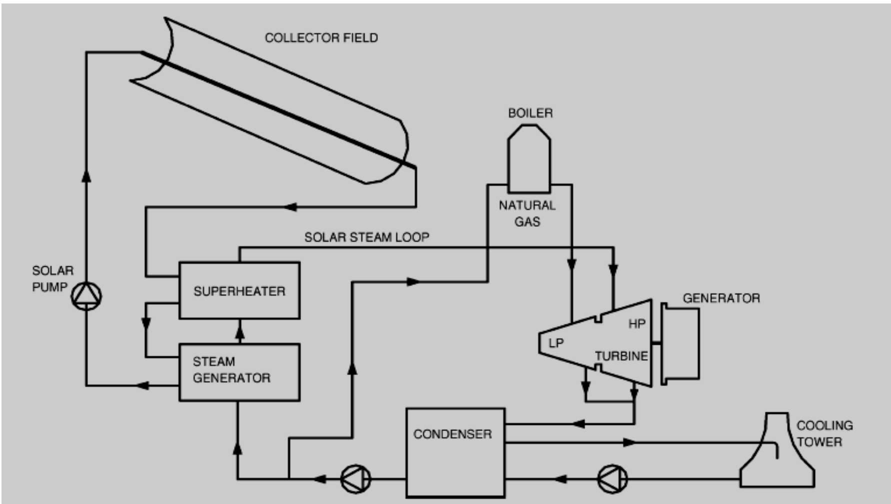

Figure 2 Configuration of PTC solar thermal power plant

These systems were commercialized in 1980's in California in the United States. LUZ Company installed nine such plants between 1980–1989 totaling to 350 MWe capacity. These plants are commonly known as SEGS (solar electric generator systems). SEGS uses oil to take the heat away: the oil then passes through a heat exchanger, creating steam which runs a steam turbine (Figure 3).

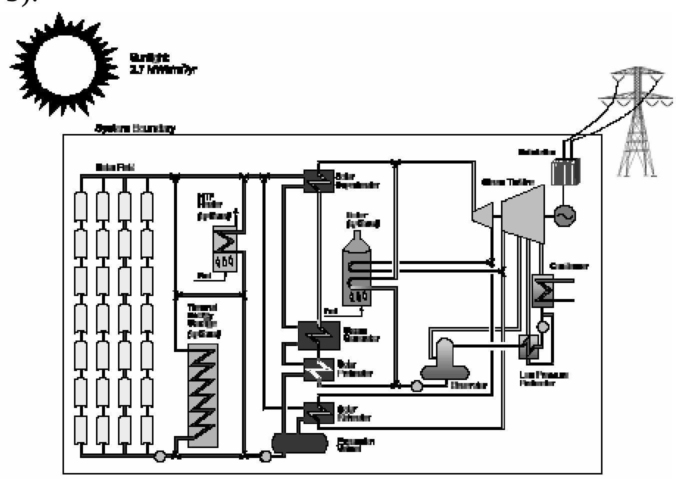

Figure 3 Schematic of solar electric generator system (SEGS)

Besides research and development in components and materials, two major technological developments are under way; 1.Integration of parabolic trough power plants in Combined Cycle plants and, 2. Direct steam generation in the collectors' absorber tubes. Using direct solar steam generation the HTF and water heat exchanger will no longer be required resulting in improvement of the efficiency conditions can be achieved which increases overall efficiency of cycle.

Plataforma Solar de Almería's SSPS-DCS plant in Spain is also another example of this technology.

Power tower system

In power tower systems, heliostats (A Heliostat is a device that tracks the movement of the sun which is used to orient a mirror of field of mirrors, throughout the day, to reflect sunlight onto a target-receiver) reflect and concentrate sunlight onto a central tower-mounted receiver where the energy is transferred to a HTF. This energy is then passed either to the storage or to power-conversion systems, which convert the thermal energy into electricity. Heliostat field, the heliostat controls, the receiver, the storage system, and the heat engine, which drives the generator, are the major components of the system.

For a large heliostat field a cylindrical receiver has advantages when used with Rankine cycle engines, particularly for radiation from heliostats at the far edges of the field. Cavity receivers with larger tower height to heliostat field area ratios are used for higher temperatures required for the operation of Brayton cycle turbines (Figure 4).

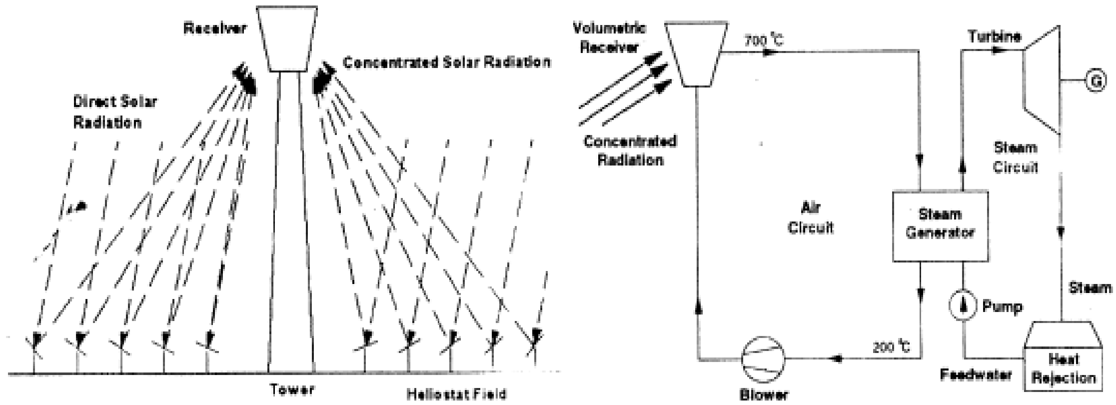

Figure 4 Schematic of power tower system

These plants are defined by the options chosen for a HTF, for the thermal storage medium and for the power-conversion cycle. HTF may be water/steam, molten nitrate salt, liquid metals or air and the thermal storage may be provided by PCM (phase change materials). Power tower systems usually achieves concentration ratios of 300–1500, can operate at temperatures up to 1500^{o} C. To maintain constant steam parameters even at varying solar irradiation, two methods can be used:

- Integration of a fossil back-up burner; or
- Utilization of a thermal storage as a buffer

By the use of thermal storage, the heat can be stored for few hours to allow electricity production during periods of peak need, even if the solar radiation is not available. The modern R&D efforts have focused on polymer reflectors and stretched-membrane heliostats. A stretched-membrane heliostat consists of a metal ring, across which two thin metal membranes are stretched. A focus control system adjusts the curvature of the front membrane, which is laminated with a silvered-polymer reflector, usually by adjusting the pressure in the plenum between the two membranes.

Examples of heliostat based power plants were the 10 MWe Solar One and Solar Two demonstration projects in the Mojave Desert, which have now been decommissioned. The 15 MW Solar Tres Power Tower in Spain builds on these projects. In Spain the 11 MW PS10 Solar Power Tower was recently completed. In South Africa, a solar power plant is planned with 4000 to 5000 heliostat mirrors, each having an area of 140 m^2.

Parabolic dish system

The parabolic dish system uses a parabolic dish shaped mirror or a modular mirror system that approximates a parabola and incorporates two-axis tracking to focus the sunlight onto receivers located at the focal point of the dish, which absorbs the energy and converts it into thermal energy. This can be used directly as heat for thermal application or for power generation. The thermal energy can either be transported to a central generator for conversion, or it can be converted directly into electricity at a local generator coupled to the receiver (Figure 5).

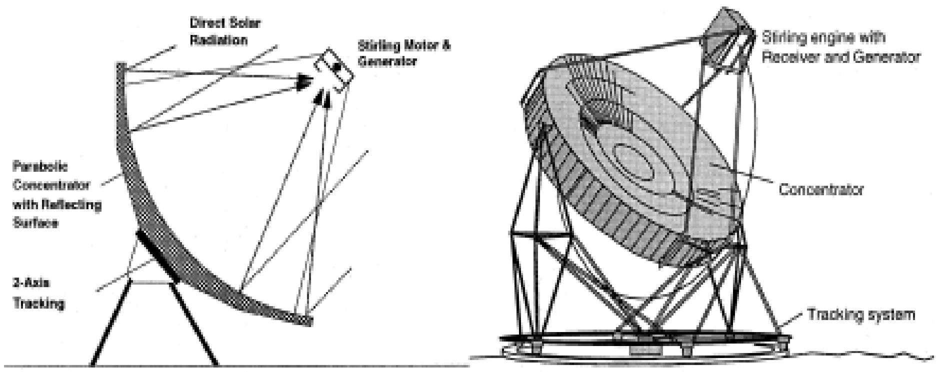

Figure 5 Schematic of Parabolic dish system

The mirror system typically is made from a number of mirror facets, either glass or polymer mirror, or can consist of a single stretched membrane using a polymer mirror of thin metal stretched membrane.

The PDCs (parabolic dish collector) track the sun on two axes, and thus they are the most efficient collector systems. Their concentration ratios usually range from 600 to 2000, and they can achieve temperatures in excess of 1500^o C. Rankine-cycle engines, Brayton-cycle engines, and sodium-heat engines have been considered for systems using dish-mounted engines the greatest attention though was given to Stirling-engine systems.

The main challenge facing distributed-dish systems is developing a power-conversion unit, which would have low capital and maintenance costs, long life, high conversion efficiency, and the ability to operate automatically. Several different engines, such as gas turbines, reciprocating steam engines, and organic Rankine engines, have been explored, but in recent years, most attention has been focused on Stirling-cycle engines. These are externally heated piston engines in which heat is continuously added to a gas (normally hydrogen or helium at high pressure) that is contained in a closed system.

The Stirling Energy Systems (SES) and Science Applications International Corporation (SAIC) dishes at UNLV and the Big Dish in Canberra, Australia are representatives of this technology. Annexure–I presents the technical details of some existing solar thermal power plants globally.

Solar chimney

This is a fairly simple concept. As shown in figure 3.0 the solar chimney has a tall chimney at the center of the field, which is covered with glass. The solar heat generates hot air in the gap between the ground and the gall cover which is then passed through the central tower to its upper end due to density difference between relatively cooler air outside the upper end of the tower and hotter air inside tower. While traveling up this air drives wind turbines located inside the tower. These systems need relatively less components and were supposed to be cheaper. However, low operating efficiency, and need for a tall tower of height of the order of 1000m made this technology a challenging one. A pilot solar chimney project was installed in Spain to test the concept. This 50kW capacity plant was successfully operated between 1982 to 1989. Figure 6 shows the picture of this plant. Recently, EnviroMission Limited, an Australian company, has started work on setting up first of its five projects based on solar chimney concept in Australia.

Figure 6 50 kW Solar chimney pilot project , Manzanares, Spain

The Luz Company which developed parabolic trough collector based solar thermal power technology went out of business in 1990's which was a major set back for the development of solar thermal power technology.

Solar thermal power generation program of India

In India the first Solar Thermal Power Plant of 50kW capacity has been installed by MNES following the parabolic trough collector technology (line focussing) at Gwalpahari, Gurgaon, which was commissioned in 1989 and operated till 1990, after which the plant was shut down due to lack of spares. The plant is being revived with development of components such as mirrors, tracking system etc.

A Solar Thermal Power Plant of 140MW at Mathania in Rajasthan, has been proposed and sanctioned by the Government in Rajasthan. The project configuration of 140MW Integrated Solar Combined Cycle Power Plant involves a 35MW solar power generating system and a 105MW conventional power component and the GEF has approved a grant of US$ 40 million for the project. The Government of Germany has agreed to provide a soft loan of DM 116.8 million and a commercial loan of DM 133.2 million for the project.

In addition a commercial power plant based on Solar Chimney technology was also studied in North-Western part of Rajasthan. The project was to be implemented in five stages.

In the 1st stage the power output shall be 1.75MW, which shall be enhanced to 35MW, 70MW, 126.3MW and 200MW in subsequent stages. The height of the solar chimney, which would initially be 300m, shall be increased gradually to 1000m. Cost of electricity through this plant is expected to be Rs. 2.25 / kWh. However, due to security and other reasons the project was dropped.

BHEL limited, an Indian company in power equipments manufacturing, had built a solar dish based power plant in 1990's as a part of research and development program of then the Ministry of Non-conventional Energy Sources. The project was partly funded by the US Government. Six dishes were used in this plant.

Few states like Andhra Pardesh, Gujarat had prepared feasibility studies for solar thermal power plants in 1990's. However, not much work was carried out later on.

Opportunities for solar thermal power generation in India

Solar thermal power generation can play a significant important role in meeting the demand supply gap for electricity. Three types of applications are possible

1. Rural electrification using solar dish collector technology
2. Typically these dishes care of 10 to 25 kW capacity each and use striling engine for power generation. These can be developed for village level distributed generation by hybridizing them with biomass gasifier for hot air generation.
3. Integration of solar thermal power plants with existing industries such as paper, dairy or sugar industry, which has cogeneration units.
   Many industries have steam turbine sets for cogneration. These can be coupled with solar thermal power plants. Typically these units are of 5 to 250 MW capacities and can be coupled with solar thermal power plants. This approach will reduce the capital investment on steam turbines and associated power-house infrastructure thus reducing the cost of generation of solar electricity
4. Integration of solar thermal power generation unit with existing coal thermal power plants. The study shows that savings of upto 24% is possible during periods of high insolation for feed water heating to 241 ^{0}C (4).

Barriers

Solar thermal power plants need detailed feasibility study and technology identification along with proper solar radiation resource assessment. The current status of international technology and its availability and financial and commercial feasibility in the context of India is not clear. The delays in finalizing technology for Mathania plant have created a negative impression about the technology.

Way ahead

Solar thermal power generation technology is coming back as commercially viable technology in many parts of the world. India needs to take fresh initiative to assess the latest technology and its feasibility in the Indian context. These projects can avail benefits like CDM and considering the solar radiation levels in India the se plants can be commercially viable in near future.

The MNRE and SEC (Solar Energy Center) should take initiative to study these technologies and develop feasibility reports for suitable applications. Leading research institutes such as TERI can take up these studies.

Conclusion

Resource assessment, technological appropriateness and economic feasibility are the basic requirement of project evaluation. The solar radiation is available sufficiently over the country. The solar tower power and point focusing dish type plants are being popular worldwide. In the pulp and paper industry, the moderate temperature is required for processing; and solar energy can effectively generate this amount of heat. The solar energy based power generating systems can play a major role towards the fulfillment of energy requirements of industry.

Bibliography

1. Annual Report, Ministry of New and Renewable Energy Sources, 2005-06.
2. Beerbaum B. and G. Weinrebe Solar thermal power generation in India: a techno-economic analysis, **Renewable Energy**, 21, 2, 1 2000, 153-174.
3. Duffie J.A., Beckman W.A. Solar engineering of thermal processes. New York: Wiley; 1991.
4. Kalogirou S. A., Solar thermal collectors and applications, **Progress in Energy and Combustion Science**, 30, 3, 2004, 231-295.
5. Kreith F, Kreider J.F. Principles of solar engineering, New York: McGraw-Hill; 1978.
6. Winter C. J., R. L. Sizmann and L.L. Vant-Hull, Solar Power Plants: Fundaments, Technology and System Economics, Springer-Verlag, New York, USA.
7. Status Report on Solar Thermal Power Plants by Pilkington Solar International, Germany
8. National Renewable Energy Laboratory (USDOE), USA
9. http//en.wikipedia.org/wiki/Solar_Thermal_Energy

Annexure – I

TABLE 1. SELECTED SOLAR ELECTRIC GENERATING SYSTEMS (SEGS)			
NAME/SITE	**POWER(MW)**	**OPERATING MODE**	**ON THE GRID**
Coolidge(USA)	0.15	Solar	1980-1982
Sunshine(Japan)	1.0	Solar	1981-1984
IEA-DCS(Spain)	0.5	Solar	1981-1985
Step-100(Australia)	0.1	Solar	1982-85
SEGS I (USA)	14	Hybrid	1985-Present
SEGS II(USA)	30	Hybrid	1986-Present
SEGS III-IV (USA)	30	Hybrid	1987-Present
SEGS V (USA)	30	Hybrid	1988- Present
SEGSVI-VII (USA)	30	Hybrid	1989- Present
SEGS VIII (USA)	80	Hybrid	1990- Present
SEGS IX	80	Hybrid	1991- Present

TABLE 2. STATUS OF CENTRAL RECEIVER SYSTEMS			
NAME/SITE	POWER(MW)	RECEIVER COOLANT	SERVICE PERIOD
Eurelios (Italy)	1.0	Water/Steam	1980-1984
Sunshine(Japan)	1.0	Water/Steam	1981-1984
IEA-CRS(Spain)	0.5	Sodium	1981-1985
Solar one (USA)	10.0	Water/Steam	1982-1988
CESA 1 (Spain)	1.2	Water/Steam	1983-1984
Themis (France)	2.5	Molten Salt	1983-1986
MSEE(USA)	0.75	Molten Salt	1984-1985
SES-5 (USSR)	5.0	Water/ Steam	1985-1989
PHOEBUS-TSA(Spain)	2.5	Air	1992- Present
Solar two (USA)	10.0	Molten Salt	Start in 1995

TABLE 3. CHARACTERISTICS OF SELECTED DISH-STERLING SYSTEMS			
NAME/SITE	POWER(kW)	WORKING GAS	OPERATION PERIOD
Vanguard (USA)	25	Hydrogen	1984-985
Mc Donnel(USA)	25	Hydrogen	1984-1988
SBP(Saudi Arabia)	52.5	Hydrogen	1984-1988
SBP(Spain, Germany)	9	Helium	1991-Present
Cummins CPG(USA)	7.5	Helium	1992-Present
Aisin/Miyako (Japan)	8.5	Helium	1992-Present
STM-PCS(USA)	25	Helium	1993-Present