International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol.5, No.2, pp 1087-1093, April-June 2013

ICGSEE-2013[14th – 16th March 2013]
International Conference on Global Scenario in Environment and Energy

Combating India's Power Deficit Using Solar Thermal Power

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Abstract: India is a fast developing nation but still faces an acute energy shortage which is a big hindrance in its overall economic growth. The Central Electricity Authority of India estimates an average electrical energy shortage of 9.3% and a peaking power shortage of 10.6% during the 2012-13 fiscal, and the situation does not seem to improve in the coming years. With the depleting reserves and environmental concerns associated with non-renewable conventional sources of electricity, there is a strong need to develop the renewable power sector.Solar thermal power is one such source of energy which has a huge potential in a country like India. However, to achieve grid parity, solar thermal power plants need to be equipped with a Thermal Energy Storage (TES) system. After explaining the concept of a solar thermal power plant, the paper analyses the scope and scalability of this form of power in India, explains the significance and need of TES, and throws light on the current and future projects in this field.
A numerical analysis tries to determine the potential of solar thermal power to act as the primary power source of the country, replacing the conventional thermal power plants.The conclusion reaffirms thatSolar Thermal power plants equipped with proper thermal storage systems can turn India from a power deficient to a self-sufficient power producing nation.
Keywords: solar thermal power; concentrated solar power; India energy deficit; thermal energy storage.

India's Power Deficit Scenario

India stands amidst the pioneering developing nations in the world, but we fall short in generating one of the most basic parameters of development, electricity. With a total installed capacity of 210.951 GW (as of December 2012)[1], India stands 5th in the world in terms of installed power capacity, but its per capita consumption is among the world's lowest (778.71 kilowatt hours a year, against the world average of 2600 kWh/year)[2,3]. The Central Electricity Authority of India, in its Load Generation balance Report 2012-13, pointed out that India would suffer an average electrical energyshortage of 9.3% and a peaking power shortage of 10.6% during the 2012-13 fiscal[4].

The main reasons for this shortage can be summarized as follows:

1. Shortage of coal, which is currently the primary fuel for electricity generation in India.
2. India lacks high quality coal reserves, and our mining processes are not efficient. The gross calorific value of Indian coal is poor, about 4500 Kcal/kg[5].

3. Due to growing environmental concerns and rising awareness amongst the masses, resistance by environment conservation firms and public litigation forums has become very common. Several major power projects have had to be delayed or curtailed due to such oppositions.
4. Reluctance to step into nuclear power after the Fukushima incident.

Introduction To Solar Thermal Power

As the name suggests, solar thermal power is a technique that involves harnessing the sun's heat for various utilization purposes. This can either be done actively, using special instruments to capture and concentrate the sun's heat; or passively, without using dedicated solar heat absorbing and storing media.

The technique that uses special mirrors or lenses to focus the sun's heat on a receiver for generating electricity is called Concentrated Solar Power (CSP) technology. The idea is simply to concentrate the sun's rays using reflectors on a pipe carrying the Heat Transfer Fluid (HTF). HTFs can range from mineral oil to molten salt, or even pressurized steam. The HTF in turn goes through a heat exchanger, transferringits heat to a boiler, where steam is generated. This steam is then used to drive a generator turbine which produces electricity, just like in any other conventional power plant. It is a renewable, green and eco-friendly technique of producing electricity and does not cause any form of pollution.

This concept is different from a solar photovoltaic system, where sunlight is directly converted into electricity using semiconductor panels. In fact, solar thermal power is more efficient and cost effective as compared to solar PV. As per the tariff issued by the Central Electricity Regulatory Commission of India,the cost for solar thermal electricity was Rs. 15.31/kWh,whereas it was Rs. 17.91/kWh for solar PV[6].

Solar energy as received directly from the sun is in dilute form and cannot be used efficiently for power generation. In order to make it a feasible power source, it needs to be concentrated. Various working models have been proposed for the efficient tapping of the sun's heat energy, the major ones being the following:

1. **Parabolic trough design**

   Such solar fields have long rows of parabolic mirrors aligned in the north-south direction. These mirrors track the sun on a single axis as it moves from east to west during the day, and concentrate its rays on a receiver pipe positioned at the focal axis. The HTF flowing within the receiver tube gets heated to temperatures as high as 750 degrees Fahrenheit before delivering this heat into the heat exchanger[7].

   Parabolic trough design is shown in Fig. 1. Though this design does not provide incredibly high values of efficiency, parabolic troughs have been successfully employed in CSP plants across the globe, and by far remain the most used and best proven CSP technology, with an annual efficiency of about 15-20%.

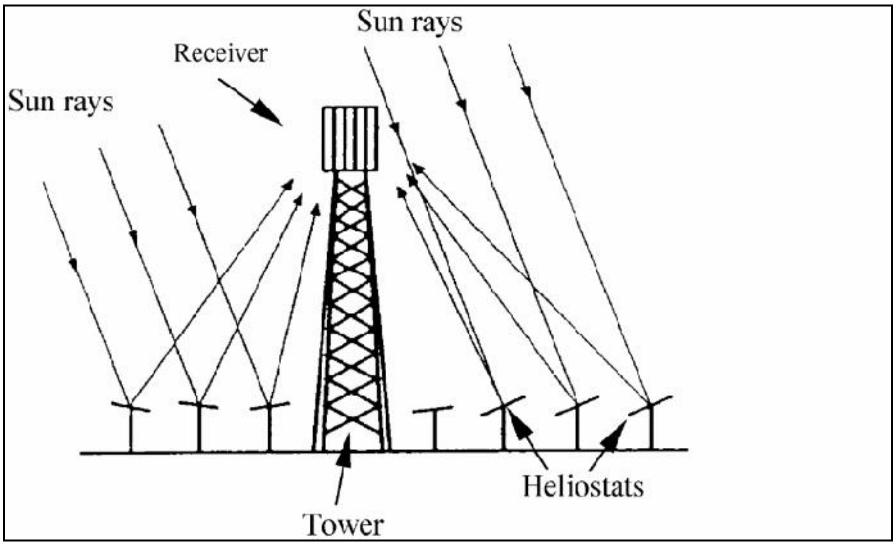

Figure 2: Power Tower Design

2. Power Tower design

This type of CSP field has a central tower on which the heat receiver is mounted. Thousands of flat mirrors, known as heliostats, reflect the sun's rays and focus them on the central receiver. (Fig. 2) The HTF inside the receiver gets heated to temperatures over 1,000 degrees Fahrenheit. Since higher temperature is achieved in Power Tower design, its efficiency is more as compared to parabolic troughs (20-25%). In a study done by the National Renewable Energy Laboratory (NREL), the capacity factor for power towers was estimated to be 72.9%, against 56.2% for parabolic troughs[8].

However, this design requires dual axis control of heliostats, thus increasing the cost of the alignment system.

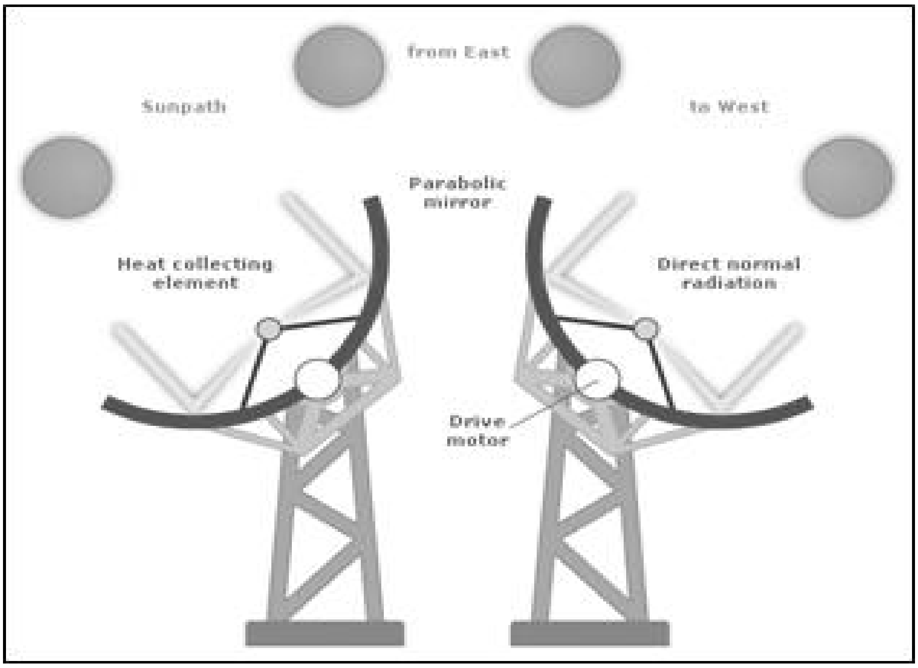

Figure 1: Parabolic Trough Design

3. Solar Dish

This technology involves a dish shaped reflector (pretty similar to TV dishes) fitted with a heat engine on the focal point. The sun's rays falling on the reflector are focused on the engine which converts heat energy into rotational form and drives a generator which produces electricity. Hence, a single solar dish is a self-contained power system. (Fig. 3) The maximum temperature achieved in this system is higher than any other type of CSP mechanism, and hence the efficiency is also high (usually greater than 20%). However, power generated ranges from 3-5 kilowatts.

Like in the Power Tower design, dual axis control of each dish is required in this system. Also, since the engine is mounted on the dish itself, structural complexity and maintenance requirement increases.

4. Fresnel Reflectors

These solar fields contain a series of flat mirrors that focus light on receiver units positioned above them. The overall design is simpler and cheaper as multiple mirrors share a single receiver unit. Also, mirrors need to be aligned only on a single axis. Since the receivers are not mounted on the mirrors, the need for structural maintenance reduces a great deal. (Fig. 4)

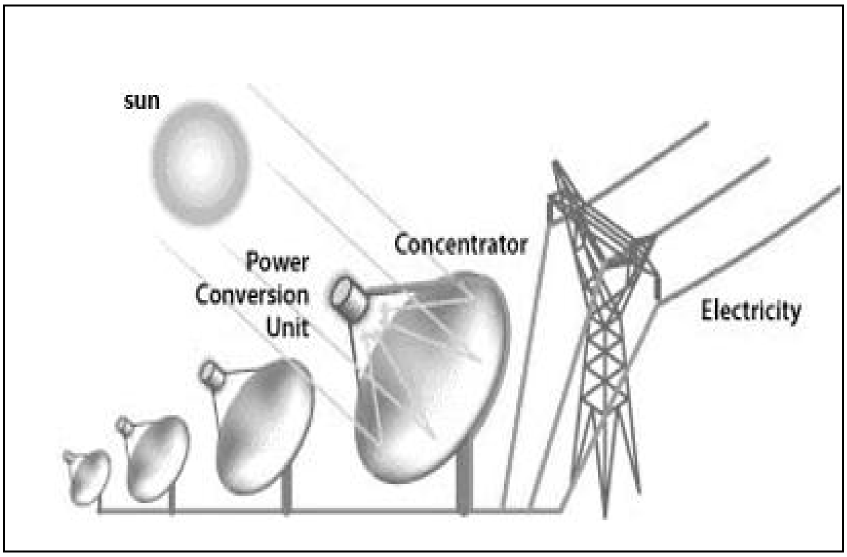

Figure 3: Solar Dish

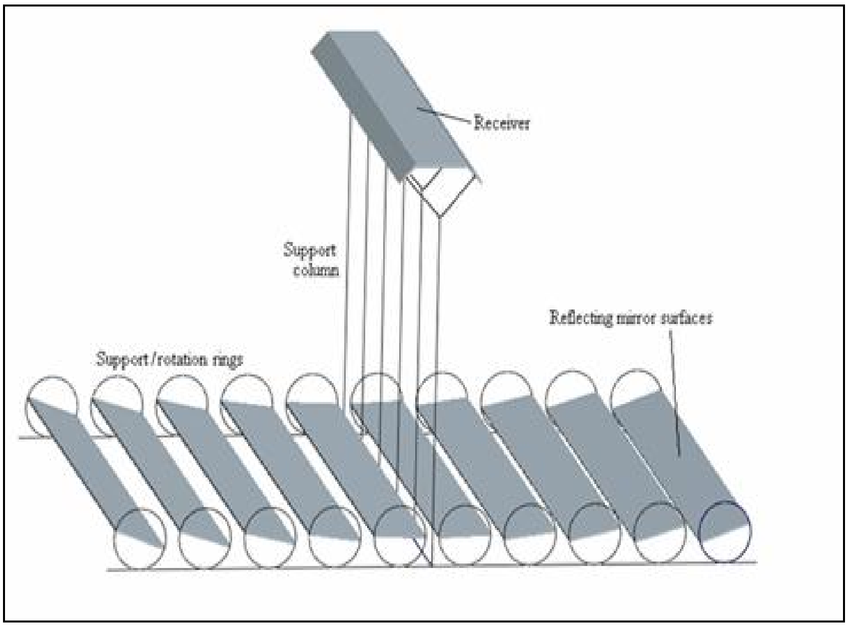

Figure 4: Fresnel Reflectors

Need For Thermal Energy Storage

Solar thermal is a clean and efficient source of power, but there is a major catch. There can be no heat produced in the solar farms during night or under outcast conditions, subjecting this mode of power to a high degree of irregularity. For the integration of solar thermal power in the main supply grid, it is essential that it delivers constant and reliable energy throughout the year. This is ensured by installing adequate Thermal Energy Storage (TES) systems, so that the CSP plant continues to deliver power even in the absence of the sun.

The heat collected by the HTF is transferred to a TES medium where it can be stored for later use[9]. Various materials have been tested for their use as TES media, the ones majorly under research and use are:

1. **Water/Steam:** The concept of Direct Steam Generating (DSG) plants is a topic attracting vast research these days. A DSG plant eliminates the need for HTFs by directly using water/steam in the receiver tubes in the solar fields[10]. This helps bring down the overall capital investment of the plant. Steam is stored in high pressure tanks in condensed form, and vaporizes back into steam as soon as the pressure is lowered. The storage period is approximately an hour.
2. **Molten salt:** This is the most widely used and best proven TES employed in CSP plants. Even before power plants, molten salts were being employed for heat storage in other industries like chemical and

metal. The most commonly used salt is a mixture of sodium nitrate and potassium nitrate, though calcium nitrate salts are also under development.

3. **Phase Change Materials (PCMs):** "A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) units." (Wikipedia) PCMs are considered to be highly efficient TES materials credit to their high heat of phase change, non-toxicity and stability under high temperatures[11].

The mechanism of a TES equipped solar thermal plant is simple; heat up the HTFs in the receiver tubes, partly use this heat to generate electricity in-situ and partly transfer this heat to a TES media using heat exchangers, and finally use the heat in these media to generate electricity at the time of need.Based on the mechanism adopted for thermal storage, TES systems are classified into Two-Tank Direct System, Two-Tank Indirect System and Single-Tank Thermocline System.

The peak electricity demand in India varies monthly. TES measures enable the CSP plant to be used for both peak load and base load. Also, it is cheaper and more efficient to store energy in the form of heat rather than electricity, thus giving TES equipped CSP plants an edge over any other power plant.

Scope Of Solar Thermal Power In India

India is blessed with a varied geography which proves a vast potential for harnessing renewable energy resources, including solar power. In this paper, the feasibility of harnessing India's solar potential for the generation of electricity is being determined under the following key parameters:

1. **Accessibility and Scalability:** Indiareceives a total of 5,000 trillion kWh of solar energy on its land area annually[12]. Such tremendous value of energy means that covering even a small fraction of India's land with solar farms can fulfill the whole country's power needs. On an average we have around 300 sunny days in a year, though the value of solar irradiance varies from region to region. The gestation period of a solar thermal power plant is lesser as compared to the other conventional power plants, and thus a decentralized approach can be applied for power generation. Apart from grid connected power, solar thermal power in India can be effectively used for off-grid purposes like rural electrification and industrial needs on a small scale.
2. **Capital Investment and its feasibility:** An initial investment of about Rs. 15 million/MW is required for building a solar thermal power plant with a lifetime of 25 years. Although this cost is much higher than that required for conventional sources, but what needs to be noted here is that a solar thermal power plant, once set-up, requires minimal running capital, since there are no fuel costs involved. And keeping in mind the decreasing availability and soaring prices of conventional fuel sources, thermal power plants are not going to be a cheap power source for long. As an instance, indigenous B Grade coal in India was available around Rs. 1750 during the period 2006-07, and was reported being sold at Rs. 3350 during 2011-12. This indicates a twofold increase in the price in a mere 5 year period. "Already, faced with crippling electricity shortages, price of electricity traded internally, touched Rs 17.46 per unit during peak periods in the month of July 2012. The situation will also change, as the country moves towards imported coal to meet its energy demand.[6]" **Environmental factors:** Solar thermal power is a completely green and eco-friendly source of power. Every unit of electricity produced from CSP plants saves the emission of 963 grams of carbon-dioxide into the atmosphere[14].

Solar Thermal Power As The Primary Power Source In India: A Numerical Analysis

India's current energy requirement as reported by the CEA in its Load Generation Balance Report (2012-13) is **985317 MU** which is expected to reach **1354874 MU** by the end of the 12th 5 year plan (2016-17) and further increase to **1904861 MU** by the end of the 13th plan (2021-22). India's current energy availability stands at 893371 MU, which includes electricity from conventional sources, non-conventional sources and import from neighbouring countries.

The National Electricity Plan 2012 released by the Ministry of Power, Government of India predicts that a generation capacity addition of **79,690 MW** and **79,200 MW** would be required by the end of the 12th and 13th plans respectively in order to meet the increasing demand for electricity in our country. That brings the total to

15,8890 MW additional power by 2022. Out of this energy, 116986 MW of capacity addition is planned to be obtained from coal and gas.

Though India possesses significant coal reserves, but there always exists a gap between the demand and supply of coal for thermal power stations. "The quality of Run of Mine (ROM) coal from Indian mines is continuously decreasing due to the geographical pattern of coal seams in coal bed.[15]" During the year 2011-12, there was a shortage of 53 Megaton coal in the thermal power plants, which is expected to rise to 238 MT by 2016-17. With depleting worldwide reserves of coal, the option of importing coal from foreign countries would be a highly expensive one in near future. Table 1 below shows the trend of increase in the wholesale price of coal from 2005-2011.

Table 1: Wholesale Prices of Coal

Year	Wholesale price index				
	Coal	Coking Coal	Non Coking Coal	Coke	Lignite
2005-06	117.6	106.7	102.58	152.7	85.7
2006-07	117.71	106.7	102.52	152.7	88.47
2007-08	121.69	111.37	106.53	155.43	99.13
2008-09	151.26	119	112.7	234.4	134.85
2009-10	156.45	126.8	121.16	234.4	134.85
2010-11	184.6	178.7	166.5	219.3	168.9

If we target to replace all coal and gas power by solar thermal power,

India's solar power reception on its land area: 5000 Petawatt-hours per year[12].

India's Total solar energy reception: 5000 Petawatt-hours/8760 hours= 570776255 MW.

Additional energy requirement (only replacing coal and gas): 116986 MW.

Fraction of total land area to be covered for fulfilling additional demand (assuming 1% efficiency and 30% capacity factor): 0.006

That is, assuming 1% efficiency of CSP generation process, covering a mere 0.6% of the total land area of India with solar fields would meet our energy demands, completely eliminating any need of capacity addition from coal and gas based thermal power stations.

The initial investment in setting up solar thermal power plants is typically higher as compared to conventional power plants like thermal and hydro. But keeping in mind the depleting reserves of non-renewable fuels, the increasing environmental concerns regarding greenhouse gas emissions, and the long term reliability of solar power, CSP plants are amidst the best options we have.

Current And Future Projects

India's venture in the solar thermal power sector was negligible until the announcement of the Jawaharlal Nehru National Solar Mission under the National Action Plan on Climate Change on June 30, 2008. The plan is phased in three parts. "The first phase (up to 2013) focused on capturing of the low hanging options in solar; on promoting off-grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country.[6]"

The mission aims at achieving 20 GW of grid connected solar power by 2022. Currently the project has put up 7 CSP plants with a total capacity of 470 MW scheduled to be commissioned by March 2013[6].

Conclusion

With a steadily growing economy and a clear vision of the future, India is on its way to become a major superpower on the world map. But the shortage of electrical energy can prove to be a major hindrance in its path of development. India is already taking strides in developing its renewable power sector. With proper planning and implementation, solar thermal power can go a long way in curing India's power crisis. It has enough potential to replace the conventional sources of energy and become the primary power source of the nation.

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