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Improvements, new innovations and status of solar thermal power plants in India

A high solar radiation available in India is a factor to encourage the full development of solar power plants for thermal and electrical energy productions. Most parts of India, Asia experience a clear sunny weather for about 250 to 300 days a year, because of its location in the equatorial sun belt of the earth, receiving 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. Photovoltaic (PV) and solar thermal technologies are two main ways of generating energy from the sun, which is considered the inexhaustible source of energy. PV converts sunlight directly into electricity whereas in solar thermal technology, heat from the sun's rays is concentrated to heat a fluid, whose steam powers a generator that produces electricity. Solar thermal technology is more pollution free energy than solar photovoltaic energy.

In this paper, a brief description and working principles of the solar thermal technology are studied. Besides, the paper points out the solar energy potential, the current state of electricity generation and the future of solar thermal power projects in the country. Special attention is drawn to the Indian government initiatives and support for the use of solar energy. In the end, the future prospects of solar projects development with the worldwide competitive technologies by considering the existing obstacles that should be removed by the Indian governments and energy planners in the future of energy production are presented.

Keywords: *Solar thermal power plant, solar thermal energy storage, concentrating solar power, heat transfer fluid (HTF), thermal energy storage (TES), phase change material (PCM).*

1. Introduction

India is situated north of the equator between 8°4' to 37°6' north latitude and 68°7' to 97°25' east longitude. India's solar power potential at about 750GW, a recently released document by the Ministry of New and Renewable Energy (MNRE) shows the solar power potential has been estimated using the wasteland availability data in every state and jurisdiction of India. The total installed capacity of India has reached 310 GW with generation mix of thermal (69.4%), hydro (13.9%), renewable (14.8%) and nuclear (1.9%) [1]. It is evident that the renewable power has secured 2nd position after thermal and is spreading its wings rapidly in India. The renewable energy (RE) resources along with the energy conservation technologies would lead to energy sustainable development. This is while that the potential of these resources within the country, especially solar PV and wind energies is higher than many leading countries in this field.

The Government of India has up-scaled the target of renewable power capacity to 175 GW which includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydropower to be achieved by 2022 [1]. The Ministry is implementing a wide range of schemes with fiscal and financial support and conducts policies to achieve this target. Largest ever wind power capacity addition of 3423MW, exceeding target by 43% and solar power capacity addition of 3,019MW, exceeding target by 116% was made in 2015-16. For the first time the largest solar power projects capacity of 20,904MW was tendered and 31,472 solar pumps were installed which is higher than total number of pumps installed during last 24 years in 2015-16 (Fig.1).

The other significant initiatives are launching of improved cook-stoves initiatives; initiating coordinated research and development activities in solar PV and thermal; second generation bio-fuels, hydrogen energy and fuel cells, etc.

The research and development efforts of the ministry are directed towards technology development and demonstration, leading to commercialization, apart from strengthening the capacity of R&D/academic institutions and industry for taking up advanced research for technology development.

The ultimate goal is to reduce the cost and improve efficiency in the near future. The prominent projects taken up include advanced research and demonstration of higher efficiency solar cells, solar thermal power generation, hydrogen energy storage and fuel cells development, development and deployment of improved biomass cook

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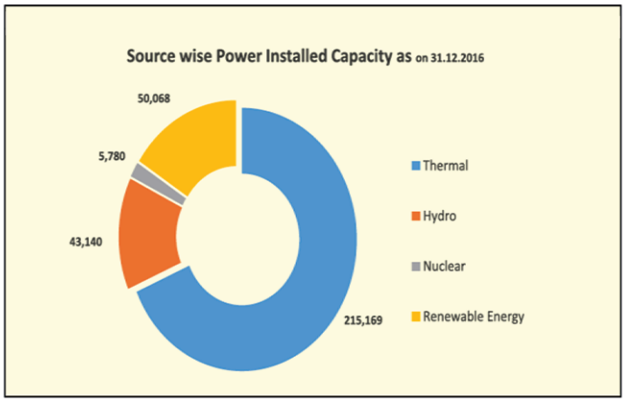


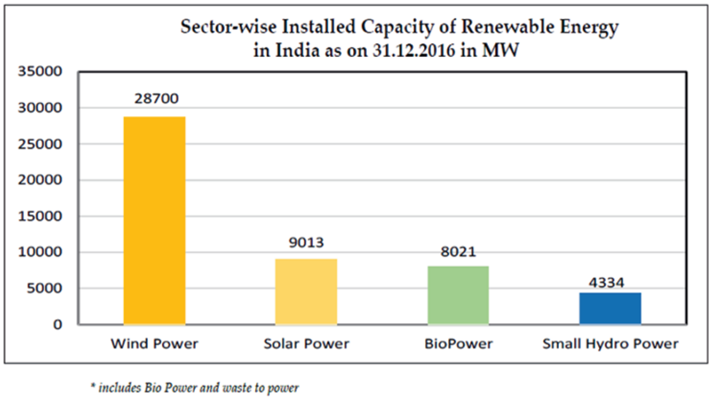


Fig.1

stoves, etc. Research and development activities have been taken up with national laboratories, universities, scientific and educational institutions and industry for improvements in the renewable energy systems and products. The focus is on improved efficiency, cost reduction and technology transfer and demonstration for their commercialization. A national laboratory policy for renewable energy sector is under finalization. Continued emphasis was laid on research and development in various areas of solar energy technologies and application. The focus was on indigenization of technology, product development and resource assessment. At present, 24 number of R&D projects are under implementation in the area of solar photovoltaic (SPV) and solar thermal (ST).

The potential environmental impacts associated with solar power – land use and habitat loss, water use, and the use of hazardous materials in manufacturing – can vary greatly depending on the technology, which includes two broad categories: photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP). The scale of the system – ranging from small, distributed rooftop PV arrays to large utility-scale PV and CSP projects – also plays a significant role in the level of environmental impact.

The whole world is tremendously trending towards solar photovoltaic power generation but the disposal of solar photovoltaic module technology is not fully developed so far; it is a heavy electronic waste, is one of the main cause to go for solar thermal power generation.

2. Solar thermal technology

2.1 Introduction

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. A solar energy is not a high intensive radiant energy and it is not a consistent source of heat energy. To mitigate the above problems, we need go for:

1. Concentrate the solar energy to intensify solar energy.
2. Thermal energy storage (TES) to maintain consistently constant heat energy in absence of solar energy.
3. Sun tracking system required to raise performance of the solar system.

2.2. Concentration of solar thermal energy

Concentrated solar energy systems generate solar power by using principals of physical optics (reflection and refraction) to concentrate a large area of solar radiation, onto a small focal receiver area. The ratio of reflection/refraction area of mirror/lenses to radiation concentrating on receiver area is called concentration ratio (CR) or number of suns.

2.2.1 Solar parabolic trough concentrator

Parabolic trough type collector with line focus raised temperature of working fluid up to 350°C and concentrating ratio varies from 2 to 100. Parabolic trough shaped mirrors reflect the beam radiation on axial pipe; it is a line focus on central axis so pipe on axis absorbs heat energy and transfer to working fluid. PTC tracking is in one plane for daily movement of the sun, adjustment of orientation for seasonal variation and moderate cost.

Although many solar technologies have been demonstrated, parabolic trough solar thermal electric power plant technology proves to be one of the major renewable energy success stories of the last two decades. Among all the solar energy systems, parabolic troughs are one of the lowest cost solar electric power options available today and have significant potential for further cost reduction.

2.2.2 Paraboloidal dish concentrator and Fresnel lens dish concentrator

Paraboloidal dish concentrator (PDC) and Fresnel lens dish concentrator with point focus distributed collector will raise high temperature of working fluid up to 1000°C and concentrating ratio varies from 200 to 1000. Paraboloid dish shaped reflectors focus the reflected high rays on the center of the focal point of Paraboloid, where receiver collects heat energy and transferred to working fluid. PDC track in two

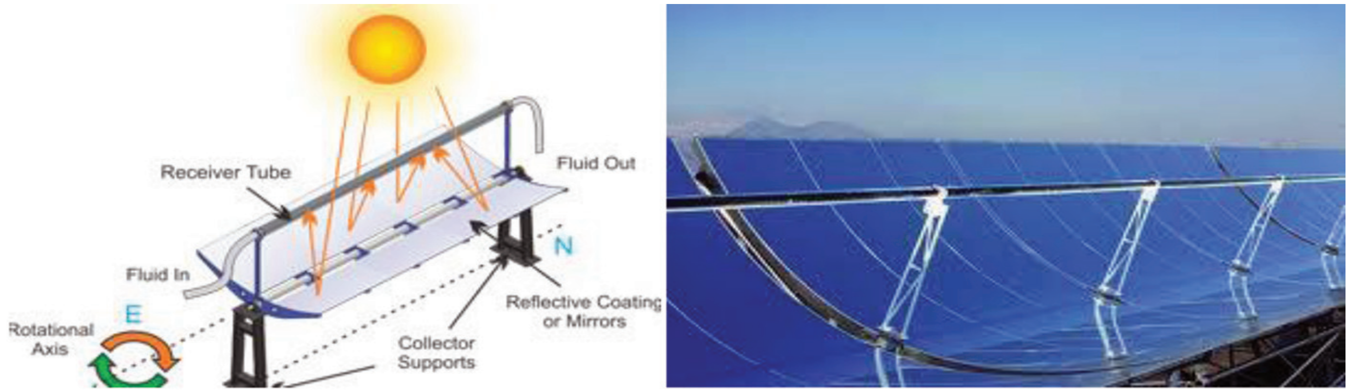


Fig.2

Fig.3

planes for daily movement and seasonal orientation of the sun and its costly equipment (Fig.3).

2.2.3 Central receiver power plant

It is also known as a power tower. It is a solar power facility that uses a field of two-axis tracking mirrors known as heliostats (devices that track the movement of the sun). Each heliostat is individually positioned by a computer control system to reflect the sun‘s rays to a tower mounted thermal receiver. The effect of many heliostats reflecting to a common point creates the combined energy of many suns, which produces high temperature thermal energy. In the receiver, molten nitrate salts absorb the heat energy. The hot salt is then used to boil water to steam, which is sent to a conventional steam turbine-generator to produce electricity.

2.2.4 Solar chimney power plant

Basically solar chimney power plant is the combination of solar and wind energy, in which solar energy is used to heat the air and making air less dense, moves up with particular velocity and rotates the wind turbine. Ambient air is drawn into the glass collector. This is warmed by solar energy and rises up the chimney. The current of rising warm air drives a turbine and the turbine is set at the base of chimney and drives the electrical generator. The solar chimney power plant (SCPP) is part of the solar thermal group of indirect solar conversion technologies i.e. involving more than one transformation to reach a usable form. More specifically, a natural phenomenon concerning the utilization of the thermal solar energy involves the earth surface heating and consequently the adjacent air heating by the sun light. This warm air expands causing an upward buoyancy force promoting the flow of air that composes the earth atmosphere. The amount of energy available due to the upward buoyancy force associated with the planet revolution is so vast that can generate catastrophic tropical cyclones with disastrous consequences. Thus, the SCPP is a device developed with the purpose to take advantage of such buoyancy streams converting them into electricity. For that, a greenhouse – the collector – is used to improve the air heating process, a tall tube – the chimney – promotes the connection between the warm air nearby the surface and the fresh air present in higher atmosphere layers and a system to convert the kinetic energy into electricity.

2.2.5 Solar pond power plant

A solar pond is a pool of salt water which acts as a large-scale solar thermal energy collector with integral heat storage

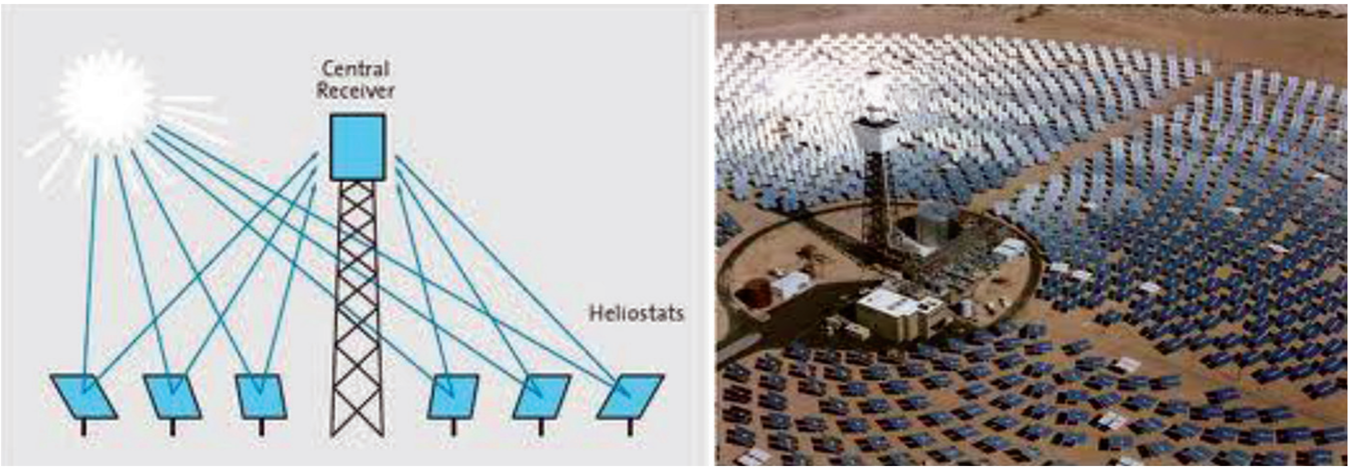
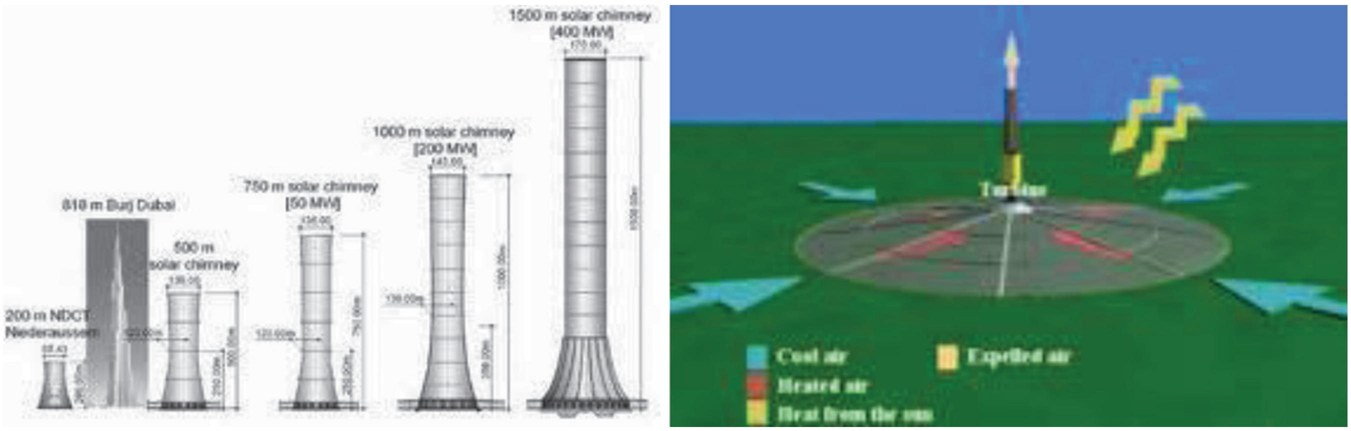


Fig.4



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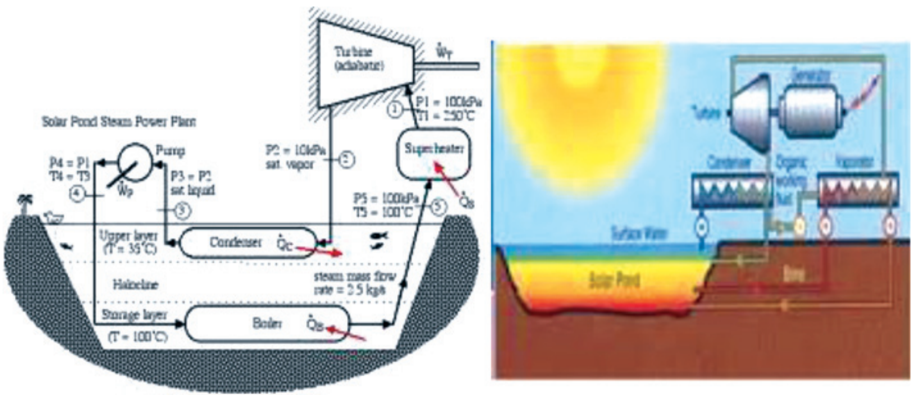

Fig.6

for supplying thermal energy. A solar pond can be used for various applications, such as process heating, desalination, refrigeration, drying and solar power generation.

2.3 Solar thermal enrgy storage

In most of the systems, there is a mismatch between the solar energy supply and energy demand. The energy storage can even out this imbalance and thereby help in saving of capital cost. In peak load excess solar thermal energy is stored into thermal energy storage unit and in absence of solar radiations thermal energy storage unit supplies thermal energy to demanding equipment. Energy storage in the form of the thermal energy is generally employed when it is to be used in the same form. Thermal energy (TE) can be stored in well insulated fluids or solids. It is generally stored either

1. Sensible heat – by virtue of the heat capacity of the storage medium, or as
2. Latent heat – by virtue of the latent heat of change of phase of the medium

Latent heat storage system via phase change material (PCM) was preferred. PCMs can store large amount of heat by changing the phase from solid to liquid. In a latent heat TES system, selection of the PCM plays important role in

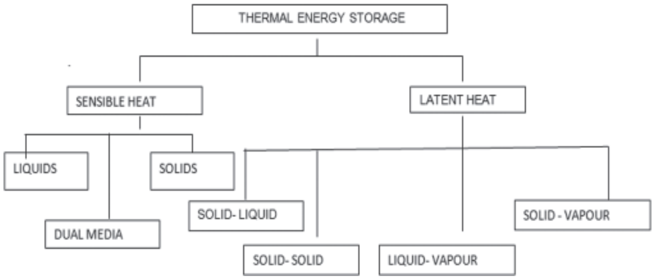

Fig.7

addition to heat transfer mechanisms in the PCM. The most important PCMs include Glauber's salt, calcium chloride hexahydrate, sodium thiosulphate penthydrate, sodium carbonate decahydrate, fatty acid, and paraffin wax. Both fatty acids and paraffins are cheap, readily available, and melt at different temperatures. However, PCMs are good TES from the security point of view of energy supply.

2.4 Sun tracking system

Solar tracking system is a device for orienting a solar panel or concentrating a solar reflector or lens towards the sun. Concentrators, especially in solar cell applications, require a high degree of accuracy to ensure that the concentrated sunlight is directed precisely to the powered device. Precise tracking of the sun is achieved through systems with single or dual axis tracking.

Single-axis solar trackers rotate on one axis moving back and forth in a single direction. Different types of single-axis trackers include horizontal, vertical, tilted, and polar aligned, which rotate as the names imply. Dual-axis trackers continually face the sun because they can move in two different directions. Types include tip-tilt and azimuth-altitude. Dual-axis tracking is typically used to orient a mirror and redirect sunlight along a fixed axis toward a stationary receiver. Because these trackers follow the sun vertically and horizontally they help obtain maximum solar energy generation.

There are also several methods of driving solar trackers. Passive trackers move from a compressed gas fluid driven to one side or the other. Motors and gear trains direct active solar trackers by means of a controller that responds to the sun's direction. Finally, a chronological tracker counteracts the Earth's rotation by turning in the opposite direction.

Selecting a solar tracker depends on system size, electric rates, land constraints, government incentives, latitude and weather. Utility-scale and large projects usually use horizontal single-axis solar trackers, while dual-axis trackers are mostly used in smaller residential applications and locations with high government feed-in-tariffs. Vertical-axis trackers are suitable for high latitudes because of their fixed or adjustable angles.

The use of solar trackers can increase electricity production by around a third, and some claim by as much as 40% in some regions, compared to modules at a fixed angle. In any solar application, the conversion efficiency is improved when the modules are continually adjusted to the optimum angle as the sun traverses the sky. As improved efficiency means improved yield, use of trackers can make quite a difference to the income from a large plant. This is why utility-scale solar installations are increasingly being mounted on tracking systems

There are, however, some disadvantages of solar trackers. Adding a solar tracking system means adding more equipment, moving parts and gears that will require regular maintenance and repair or replacement of broken parts. Also, if the solar tracker system breaks down when the solar panels are at an extreme angle, the loss of production until the system is functional again can be substantial. A solar tracker is also more prone to be damaged in a storm than the actual panels.

Fig.8

Fig.9

3. Solar thermal power plants in world wide and in India

3.1 Solar thermal power plants in World

Concentrating solar thermal power (CSP), also known as solar thermal electricity (STE), bringing global capacity to more than 4.8GW by year end 2016 [3]. This was the lowest annual increase in total global capacity in 10 years, at just over 2%. 2 Even so, CSP remains on a strong growth trajectory, with as much as 900MW expected to enter operation during the course of 2017. Most new CSP plants are being developed with TES, and 2016 marked a decade since the first commercial CSP system with TES was deployed.TES continues to be viewed as central to the competitiveness of CSP by providing the flexibility of dispatchability.

Parabolic trough and tower technologies continued to dominate the market, with parabolic trough systems representing the bulk of capacity that became operational in 2016 as well as most of the capacity expected to come online during 2017. Fresnel and parabolic dish technologies are still largely overshadowed, apart from some smaller plants in the development and construction phases.

Spain remained the global leader in existing CSP capacity, with 2.3GW at year‘s end, followed by the United States with just over 1.7GW. These two countries still accounted for over 80% of global installed capacity. South Africa brought its first commercial tower plant online with the launch of the 50MW (with 2.5 hours of TES; 465 MWh). Khi Solar One facility in early 2016, followed shortly thereafter by the 50MW (9.3 hours; 100MWh) Bokpoort parabolic trough plant. Several additional CSP projects under development faced uncertainty after the state-owned utility, Eskom, delayed the signing of PPAs under the Department of Energy’s Renewable Energy Independent Power Producer Procurement Programme (REIPPPP).

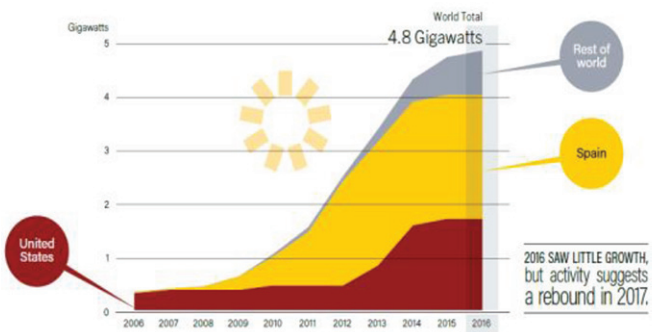

Fig.10

Apart from China, India was the only Asian country with CSP facilities under construction by the end of 2016. India‘s projects included the 25MW Gujarat solar 1 plant (9 hours; 225MWh) and the 14MW National Thermal Power Corporation’s Dadri Integrated Solar Combined-Cycle (ISCC) ii plant.

3.2 Solar thermal power plants in India

Concentrated solar thermal (CST) technologies have wide range of applications across the various industrial sectors in India. These technologies have the potential to play a significant role in achieving India‘s solar mission target and also in achieving India’s Nationally Determined Contributions (NDCs) of reducing GHG emissions as part of Paris agreement on climate change mitigation. MNRE has been promoting solar thermal technologies including CST technologies for the last few years and became a part of the first phase of national solar mission launched in 2010 wherein CST technology based power plants with 500 MW capacity were tendered. Moreover, under the initial phase of NSM for implementation of off grid applications CST technology based systems were promoted for industrial process heating, cooking and similar applications but in subsequent years these technologies became secondary to solar PV technologies due to market conditions. In the current climate, the solar thermal is gaining advantage again due to better efficiencies and smaller space requirements,

TABLE 1

Project Name:	Abhijeet Solar Project	ACME Solar Tower	Dadri ISCC Plant	Dhursar	Diwakar	Godawari Solar Project	Gujarat Solar One	KVK Energy Solar Project	Megha Solar Plant	National Solar Thermal Power Facility
Country:	India	India	India	India	India	India	India	India	India	India
Location:	Phalodi (Rajasthan)	Bikaner (Rajasthan)	Dadri (Uttar Pradesh)	Dhursar (Rajasthan)	Askandra (Rajasthan)	Nokh (Rajhastan)	Kutch (Gujarat)	Askandra (Rajasthan)	Anantapur (Andhra Pradesh)	Gurgaon
Owner(s):	Corporate Ispat Alloys Ltd. (100%)	ACME Group (100%)	NTPC	Reliance Power (100%)	Lanco Infratech (100%)	Godawari Green Energy Limited (100%)	Cargo Solar Power (100%)	KVK Energy Ventures Ltd (100%)	Megha Engineering and Infrastructure (100%)	IIT Bombay (100%)
Technology:	Parabolic trough	Power tower	Linear Fresnel reflector	Linear Fresnel reflector	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough	Parabolic trough
Turbine Capacity:	Net: 50.0 MW Gross: 50.0 MW	Net: 2.5 MW Gross: 2.5 MW	Gross: 14.0 MW	Net: 125.0 MW Gross: 125.0 MW	Net: 100.0 MW Gross: 100.0 MW	Net: 50.0 MW Gross: 50.0 MW	Net: 25.0 MW Gross: 28.0 MW	Net: 100.0 MW Gross: 100.0 MW	Net: 50.0 MW Gross: 50.0 MW	Net: 1.0 MW Gross: 1.0 MW
Status:	Under construction	Operational	Under construction	Operational	Under construction	Operational	Under constructi on	Under constructio n	Operational	Operation al
Start Year:	2015	2011	2017	2014	2013	2013	2014	2013	2014	2012
PPA/Tariff Rate:	12.24 Rs per kWh	------	-------	11.97 INR per kWh	10.5 Rs per kWh	12.2 Rs per kWh	------	11.2 Rs per kWh	11.31 Rs per kWh	--------
Storage Type:	None	None	None	None	2-tank indirect 4 hour 1010 MWht, Molten Salt		2-tank indirect 9 hours Molten Salt	2-tank indirect 4 hours 1010 MWht, Molten Salt	None	None

which MNRE is keen to popularize not only power generation but also for heating, cooling and tri-generation applications. CST technologies and industries are flourishing in India. As on date, there are more than 203 about 115 Nos. on-going projects having total collector/reflector area of 30,000 m^2 area are under execution (Table 1).

4. Future of solar thermal technologies

CST technologies are becoming popular; however, the market penetration is still not up to the level where it can become self-sustaining. UNIDO-GEF programme has now successfully laid foundation for CST market development since 2015 through innovative financial mechanisms such as soft loans for CST projects. The solar field can be used to produce process heat that can be used directly or for the steam production. For example, in the food and beverage industry, the solar generated steam can be used in boiling, pasteurisation, sterilisation, drying, cooking/evaporating. The true market potential of CST technologies in the industrial sectors has been assessed as 6.4GW in India in a study recently commissioned by UNIDO. Fourteen industry sectors have been identified – textiles (weaving, finishing), pharmaceuticals, tobacco, breweries, pulp and paper, electroplating, food processing (including dairy and sugar), rubber, chemical and fertilizer, petroleum refineries, desalination, ceramic tile and pottery, plaster of paris, steel rerolling, cement, mining, other industries including tertiary using steam or cooling. By UNIDO where CST technologies make economic and technical sense in terms of ready acceptability for their deployment for a variety of process heat applications in the temperature range up to 350°C.

Major barriers listed in large-scale promotion of CSTs at the start of project are

- Lack of awareness about the technologies and their benefits.
- Information on successful projects not accessible to public.
- Lack of confidence on technologies.
- Lacking in trained manpower of technicians.
- No test standards and test set ups for measuring performance exists.
- Space constraints for installations to beneficiaries.
- Non-availability of solar grade mirrors in required sizes at reasonable prices.
- Non-availability of soft loans to beneficiaries and ESCOs.
- Low returns on investments as compared to SWH.
- Requires higher support, especially for space cooling and standalone systems and also for non-profit making bodies.
- Very few manufacturers. Not much competition. Finding difficult to control cost.

To address these barriers and achieve the set goal of installing 45,000sq.m. of CST-based systems in 90 establishments, various activities were undertaken as per the project components outlined in the documents with outcomes.

At present solar thermal power plants require 5 Ackers land for producing one MWhr power and cost is nearly INR 5 to 7 cores per MWhr. In most of Indian solar thermal power plant PPAs vary from 8 to 11 rupees for unit power. In future solar thermal power will become cheerful, same way like solar PV competitors raise drastically brought down solar PV power become chipper.

5. Integrated solar combined cycle power plant (ISCCPP)

In an ISCCPP, the gas turbine is the same as conventional combined cycle, and the required energy for producing steam can be supplied by both gas turbine exhaust and solar field (Fig.11). In ISCCPP, higher pressure and temperature steam can be produced because of extra solar energy compared to combined cycle. Steam turbine capacity in the conventional combined cycle is 50% of gas turbine capacity, but in ISCC, the solar field increases steam turbine capacity about 50%. In this system, electricity production drop in summer would not occur because, as ambient temperature increases, solar field absorbs more energy.

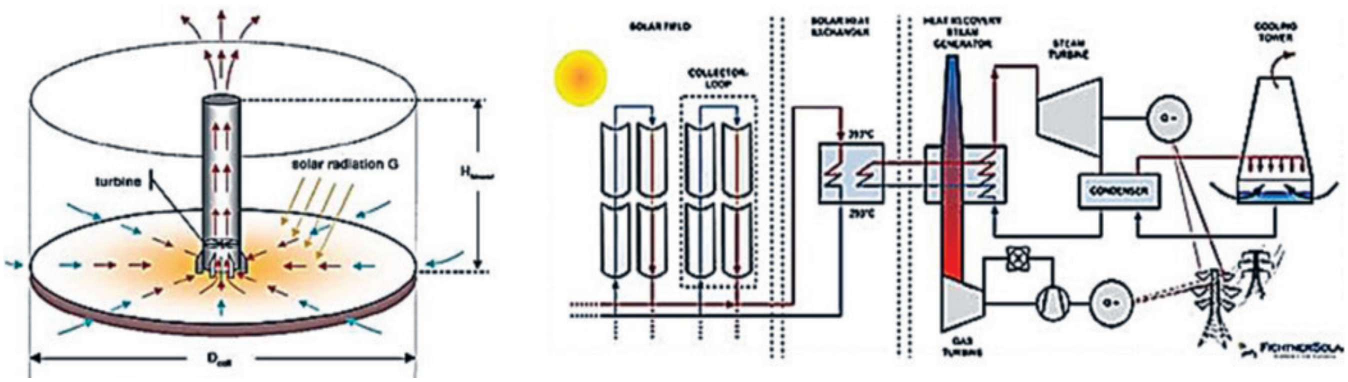

Fig.11

6. Research and development and demonstration (RD&D) in solar thermal energy

Efforts were continued to accelerate R&D activities on different aspects of solar photovoltaic (SPV) and solar thermal (ST) technologies, including multi-disciplinary research, with the objective of improving the efficiency, systems performance and reducing the cost. The details of the ongoing projects, completed and new projects sanctioned during the current year is given below:

- IIT Jodhpur, Rajasthan in solar thermal research and education: A project has been sanctioned to develop IIT-Jodhpur as a center of excellence in solar thermal research and education. Design and installation of solar air tower simulator (SATS) facility is completed. It is being extended for inclusion of solar convective furnace. Developed high temperature solar thermal research laboratory and so far they achieved 360ºC at a concentration of 420 suns and put target 600ºC in the next phase.
- A project "30 kW cross liner-CSP system test unit" sanctioned to Rajiv Gandhi Proudyogiki Vishwavidyalaya, University Institute of Technology, (RGVP) Bhopal in 2014.
- Design, construction and demonstration of zero energy building for solar decathlon Europe 2014 project sanctioned to department of energy science and engineering, IIT Bombay in 2014-15. The IIT Bombay has participated and reassembled the building in IIT campus and performance evaluation is going on.
- Dr. V K Sethi, Ram Krishna Dharmarth Foundation University, Bhopal is implementing a R&D project with USA collaboration (Rensselaer Polytechnic Institute, Troy, New York) entitled energy density thermal energy storage for concentrated solar plant. Design and construction of a prototype 1 kW capacity solar thermal storage has been installed and performance evaluation is going on.
- Development of a monitoring system for the energy reception elements in solar thermal plants by the energy and resources institute (TERI), with co-funding under joint Indo-Spain R&D programme. The broad objective is to develop a reliable, low cost tool that gives a precise and direct evaluation of the energy collection efficiency of each solar collector element including identification of the cause of the error.

The following are the completed solar thermal projects in R&D

- Development and demonstration of 1 MW capacity solar thermal power R&D project with 16-hour thermal storage at Mount Abu, with co-funding from German Ministry and Indian industry. The project is first of its kind to provide thermal storage of 16 hours and will be based on fully indigenously developed solar dish technology. The project has been commissioned and showed some good initial results. This project provides enormous opportunity in terms of product development and energy storage.
- Innovative project "Experimental grid tied solar PV power generation on a water body" sanctioned to IGNOU Community College in 2014. Developed lab scale model, testing equipment, protocol and the standards. A similar floating solar power plant is now being proposed by Kerala Government in line with this R&D project's achievements and a new scheme is under process.

7. 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 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. The country's superiority in terms of solar potential encourages the full development of solar power plants for the thermal and electrical production of energy. Studies show that India can become the major supplier of the solar power generation chain in 2025 to provide the electrical power demand of Asia. However, some obstacles such as lack of required financial supports, contractors and competent observers, highly time consuming for developing of technical and scientific potentials, lessen the process of starting new projects. Besides, the Indian government should support the private sectors to invest in solar installations.

Suggestion to NLC India Limited

Solar thermal energy is emerging technology trough out the world in electrical power generation and process heating and cooling applications in industrial, institutional and residential sectors. Hence I suggest NLC India Limited management to support for solar thermal power generation and co-generation with lignite thermal power plant or biogas power plant to reduce fossil fuel consumption.

- 50 MW solar thermal power plant with parabolic trough concentrator can be set up in the place 50MW boiler of TPS-I with same turbine which is in good condition.
- In NLCIL general hospital concentrating solar thermal water heaters can be implemented for hot water purpose inpatient wards.
- All the offices of NLC India Ltd. solar air condition can be provided.
- In thermal power plant solar thermal energy can used process heating purpose.

References

[1] Ministry of New Renewable Energy of India, Annual report 2016-2017.

[2] IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp. (Chapter 7 & 9).

[3] REN21. 2017. Renewable 2017 Global Status Report (Paris: REN21 Secretariat).ISBN 978-3-9818107-6-9.

[4] Mr. Srinivas Gugulothu1, Dr. Jose K. Kakkassery2, Performance study of Solar Thermal Energy Storage, M.Tech Project work

[5] Thermax Co. Vapour Absorption Machine manuals

[6] Sukhatme S.P., Solar energy – principles of thermal collection and storage, Tata McGraw- Hill, New Delhi, 1996.

[7] Solar energy utilization by G.D. Rai, Khanna Publishers, (1993).