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Comparative Study of Parabolic Trough Collector and Solar Power Tower Technology

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ABSTRACT

The concentrated solar power technology (CSPT) is being looked upon as solution of increasing energy requirement of the world of today. The current non-conventional sources of energy are satisfying only 6.9% of the total potential of the renewable sources in India (i.e. 5594MW out of the total 81,200 MW) [1] This is mainly due to the huge expenses associated with manufacture and installment of solar cell panels and their lesser efficiency than the conventional sources of energy.[1] The presented technology claims to convert the solar heat directly into electricity, without using photovoltaic cells. It is also acclaimed to be the cheapest and the cleanest source of energy ever available on earth. However, the technology is still in its formative phase in many parts of the world. The present paper gives a detailed overview of structure and working of two main types of CSPT plants, i.e. the parabolic trough collectors and the solar power tower technology with focus on their merits and limitations. It further intends to compare them on the bases of their structure, efficiency and deployment.

KEY WORDS

Steam cycle, Direct Normal Irradiation, solar furnace, parabolic trough, heat transfer fluid, heliostat

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INTRODUCTION

A boom in technological growth and industrial development is certainly accompanied with rising galore of increased demand and subsequent energy crisis[1]. So far coal has been majorly used as fuel in most thermal power stations in India. However, the exploited reserves of coal are heading towards a state of exhaustion. This is evident from the fact that 5.5 million tonnes of coal were imported from outside in order to satisfy the rising electricity demands**[2]**. The country is already confronted with a state of power deficit owing to the above stated factors.

CSPT has the potential to cater to the energy requirements of not only India, but the entire world as the cheapest energy source available. This is owing to the fact revealed by Trans Mediterranean Renewable Energy Cooperation (MREC) that 1 square kilometer of a hot desert receives equivalent solar energy to 1.5 million barrels of oil, and such desert of 25000 square miles, i.e. only 1% area of the Sahara desert, covered completely with CSPT, could generate electricity equivalent to that required by the whole world**[1]**.

The basic principle behind CSP plant is exactly the same as that of a conventional coal driven thermal power plant. The only difference is that the steam required to run the turbine for electricity generation is obtained using solar Direct Normal Irradiation (DNI) instead of coal combustion.[2] This is indeed a plus point over the conventional power plants as no carbon dioxide is produced as by-product, the gas chiefly accountable for green house effect.

CSPT is in its beginning phases and many countries of the world are yet to exploit this technology in commercially viable form. The biggest CSPT plants have been successfully erected in USA (Nevada Solar 1) and Spain (PS10)[3]. Other countries of the world getting involved with the technology for generation of electricity are Algeria, China, India, South Africa, Morocco etc.[4,5] Some countries such as France have even used CSP to run solar furnaces. This solar furnace has a broad spectrum of applications at industrial level such as extraction of metals from their ores.

Four major technologies have been evolved to generate steam using concentrated solar power. These include-

- Parabolic trough having multiple parallel arrays of solar collectors with receiver tubes containing heat exchange tubes along their focal lines to absorb reflected heat.

- Fresnel mirrors having long flat mirror strips aligned at different angles to reflect solar rays on HTF tubes mounted above the mirrors. The mirrors are so orientated so that the sunlight remains concentrated on the tubes.
- Power tower surrounded by a heliostat field to reflect the rays of sun to the receiver positioned at the top of the tower. The receiver contains molten salt for thermal storage.
- Dish/Stirling engine which is a field of dish shaped concentrators which reflect the solar radiation to the receiver (PV panel or generator and Stirling engine) at their focal points.

A detailed account and technological comparison of the first two of the above stated technologies is presented below.

EXPERIMENTAL SECTION

The experimental design for the following study has been an investigatory approach with thorough literature review using magazines and the electronic media. The facts were compiled together and then analysed to compare the above stated technologies.

Concentrated Solar Power is basically an application of the simple principles of optics and electromagnetic induction. For example, when sun’s rays are concentrated at the focus of a magnifying glass, the temperature of the paper rises dramatically and reaches temperature as high as 451^0F.[2] This results in combustion of the paper within a very short span of time.

Parabolic-trough solar water heating

This is one of the most viable technologies that consist of Solar Collector Assembly (SCA), power block and thermal storage section.

This technology involves the use of parabolic trough shaped single axis mirror field which concentrate DNI onto a receiver tube running along its focal line. The association of trough and receiver tube is known as SCA. The solar field consists of large number of parallel rows of SCA aligned horizontally. The trough collector systems are oriented along either east-west direction or along north-south direction. East-west orientation is preferred during winter season, while north-south orientation is preferred in summer.[6]The reflector is 0.85 mm thick silver coated mirror on back layer and 4mm thick glass on the top for getting high reflectivity.[2] A stainless steel tube of 70mm diameter high absorption coating is used. A heat exchange fluid circulates through the receiver tubes either for direct use or for transfer through a heat exchanger to the end use.

Basically, a parabola is a geometric shape whose curve is such that light travelling parallel to the axis of a parabolic mirror will reflect to a single focal point from any place along the curve. Since light rays coming from a far off source, i.e. sun, are parallel rays, the parabola facing the sun concentrates the sunlight at its focal point. A parabolic trough extends the parabolic shape to three dimensions along a single direction, creating a focal line along which the absorber tube is run. This pressurized tube through which the water and antifreeze solution circulates is coated with a special heat-absorbent surface and encased in a glass tube. An electric tracking system is used in order to keep troughs facing the sun all the time and to turn the collectors upside down at night or during period of high winds to reduce stress on the structure and help keep the mirrors clean. Because they transmit structural stress from wind loading and require large areas for installation, parabolic-trough collectors are usually ground mounted.

The parabolic trough collectors can heat their transfer fluid to as much as 520°F (271°C) or more, but for domestic water supply systems, they typically operate at about 200°F (93°C) to deliver water at about 120°F to 140°F (49°C to 60°C).[4] Efficiency is highest with a temperature difference of about 60°F (33°C) between input to the solar collector field and output from the field.[3]

A mixture of water and antifreeze or ethylene glycol/water solution or other heat transfer fluid (HTF) is pumped through the absorber tube to absorb solar heat and then pass through heat exchanger to heat potable water. In locations with no freeze danger, water can be used instead of antifreeze because it's cheaper and is a better heat transfer fluid.[7] The HTF preheats water, generates steam and also superheats steam. This is then circulated back to the SCA to get heated again. This is where the power block of the station starts functioning.

This assembly consists of a non-pressurized hot-water storage tank, a circulating pump (to drive the fluid from the troughs through a closed-coil heat exchanger in the storage tank to heat that tank), a loop that draws cold intake potable water through a second heat exchanger in the storage tank on its way to the conventional water heater, and various sensors to trigger the proper operation.[8] The system acts as a preheating system for conventional water-heating system. If the solar-heated water is too hot, a tempering valve mixes in cold water. If the water is not hot enough, the conventional system heats it to the proper temperature. As hot water is used from the conventional water heater, incoming cold water flows through a heat exchanger, drawing heat from the hot-water storage tank, and then to the conventional water-heating system. The efficiency of the system is the product of collector efficiency, field efficiency and the steam cycle efficiency. The collector efficiency largely depends upon the angle of incidence of rays of sun and the temperature of tube. The heat loss due to long length of the tubes is estimated to be 10%. The steam cycle efficiency is found to reach a maximum value of 35%. Thus, an altogether efficiency of the parabolic trough solar power plant is 15%.[9]

Parabolic-trough collector systems require somewhat more maintenance than most non-concentrating solar water-heating or other renewable energy or energy efficiency installations. Because high temperature and high-pressure fluid is involved, they should be monitored regularly. Also, the mirror surfaces should be washed every few months. The mirror surfaces will degrade slowly with time and may need replacement after about 15 years.[5] The pumps and tracking equipment should last for the life of the project, but the pump seals will likely need to be replaced after about 10 years and the tracking equipment controls may need replacement as soon as 10 years or as late as 30 years.[9] The technology stands avoided in areas particularly prone to very severe weather—high winds, tornados, hail storms or hurricanes—or to vandalism areas with unusually high dust or dirt loads in the air, mineral-rich water supply (can foul the heat exchanger and the rest of potable loop—less of a problem for troughs than for other solar water-heating systems).[10]

Parabolic-trough collectors can also drive absorption cooling systems or other equipment that runs off a thermal load. A dark surface is positioned to absorb sunlight and convert it to heat. Water or another heat transfer fluid passes along that hot surface to pick up the heat—either for direct use or for transfer through a heat exchanger to the end use.

From the standpoints of technological feasibility, compatibility with existing facilities, conventional energy use reduction, and pollution and climate-change-gas emission reduction, the outlook is quite good. The technology is more limited geographically to areas of high solar resource and to larger facilities than technologies, but the economics are better.

This is largely the reason for the fact that 97% of the total energy generated in the world through CSPT utilizes parabolic trough solar power.[8] In India, Cargo Solar Power project in Kutch (Gujarat) and Corporate Ispat Alloys Limited project in Nokh (Rajasthan) are targeted to be finished by 2013, both being parabolic trough type plants.[9]

Solar power tower

This is based on the focusing of DNI onto a receiver mounted on a tower. Hundreds of sun trackers, known as heliostats are mounted in front of the tower in order to reflect the sunlight directly to the receiver. The receiver contains a heat transfer fluid which is used to produce superheated steam to drive the turbine in power block.

The solar power tower system is a combination of multiple sub-systems. These include collector system, receiver system, steam generation system, thermal storage system, master control system, electric heat tracing system and finally the electric power generating system.

The collector system comprises the heliostat field. Each heliostat is made of 2mm thick float glass mirror having high reflectivity.[6] These flat mirrors are cheaper in contrast to the reflectors used in parabolic trough. Care is taken to maintain low iron content in the heliostat material. Since the heliostat field represents the largest single capital investment in a power tower plant, advancements in technology are needed to improve the ability to manufacture, reduce costs, and increase the service life of heliostats. In particular, a lower cost azimuth drive system is needed (i.e., to rotate the heliostat around an axis that is perpendicular to the ground).[6]
Light rays reflected from the heliostat are focused upon the receiver to raise the temperature of the HTF. The HTF is made of molten salt which contains 60% $NaNO_3$ and 40% KNO_3. The salt melts at 220^0C and is maintained molten in the cold storage tank. Thus, the molten nitrate salt, though an excellent thermal storage medium, can be a troublesome fluid to deal with because of its relatively high freezing point. To keep the salt molten, a fairly complex heat trace system must be employed.[4] (Heat tracing is composed of electric wires attached to the outside surface of pipes. Pipes are kept warm by way of resistance heating.) Molten salt has low viscosity and wets the metal surface well. So it is difficult to contain and transport. Thus identification of pumps, valves, gasket material and valve packing needs to be addressed. Steam is produced directly instead of using a heat exchanger.[11]

The receiver design has been optimized to absorb a maximum amount of solar energy while reducing the heat losses due to convection and radiation. The design, which includes laser-welding, sophisticated tube-nozzle-header connections, a tube clip design that facilitates tube expansion and contraction, and non-contact flux measurement devices, allows the receiver to rapidly change temperature without being damaged. For example, during a cloud passage, the receiver can safely change from 290 to 570ºC (554 to 1,058ºF) in less than one minute.
The steam generation system (SGS) consists of shell and tube super heater, kettle boiler and shell and tube pre-heater. The stainless steel cantilever pump salt from hot tank to cold tank through SGS. Salt in the cold tank is pumped up to the receiver again.

The thermal storage system aids to maintain the power output constant through the phases of solar intensity fluctuations. This process continues till all energy stored in the tank is depleted. The energy storage system provides electricity dispatch during peak hours of demand. The storage efficiency of the molten salt is 99%.[12] Even in the event of salt spill, the salt immediately freezes and can be removed with a shovel, causing insignificant loss to the soil. The electric heat tracing system and the master control system are programmed to coordinate and to work in coordination with the other subsystems.[13]

This technology has high efficiency and requires minimal piping leading to minimized thermal losses during the transfer of HTF through the pipes. Also, the receiver unit is fixed whereas heliostat field set up is flexible. This situation is ideal to set up hybrid plants. Another advantage of the solar tower plant is that it can be built on rough terrain also as the position of each heliostat is independent of the other.

The prototypes of tower are functional at Almeria, Spain, California and Israel.[8] However, constructive and fruitful exploration and operation of the technology is still a far goal. So far it has not addressed India successfully. However, since this type of power plant has a bright future owing to its beneficial characteristics as discussed above, it is hoped to root down deep into the energy generating technologies in many parts of the world. The 2010 technology of the solar tower eyes a receiver scaled to a target of 1400 MW with 13 hours of thermal storage with a heliostat field of 2477000 square metres, generating an overall annual capacity factor of 65%.[18]

RESULT AND DISCUSSION

Parabolic trough collector solar plant has been successful in its popularization phase, though technological advancement is still an ongoing process in it. From the stand point of cost of energy generation, the tower plant is much cheaper as compared to the parabolic trough. Also the thermal storage capacity of the molten salt is slightly raised when compared with that of the synthetic oil used in the parabolic trough. This energy storage is then utilized to provide electricity during peak hours of demand. The disadvantage is that each mirror must have its own dual-axis control, while in the parabolic trough design single axis tracking can be shared for a large array of mirrors.

The greatest and the most visible advantage of a solar power tower design above the parabolic trough design is attainment of higher temperature. This helps to convert thermal energy into electricity more efficiently which can be more cheaply stored for later use. Furthermore, there is less need to flatten the ground area. In principle a power tower can be built on the side of a hill. Mirrors can be flat and plumbing is concentrated in the tower.

Despite that, the solar tower is confronted with many challenges prohibiting its widespread deployment. The biggest issue of concern is the handling of HTF safely. Since molten salt operates at high temperature and has abrasive nature, its storage and maintenance of storage chamber is a difficult task. The problem of localized freezing of the salt within the loop has to be addressed separately.

The parabolic trough collectors are generally limited to 150-200 MW of electrical power generation, the associated pumping losses being the major driving factor for that. They use 12-13% of energy in the smaller plants and the efficiency can be scaled higher in larger plants, however, the land requirement for the same also increases proportionally.[7] The thermal losses during the transfer of synthetic oil in the pipes mesh also affects the efficiency of the system, a problem combated in power towers.

Moreover, the deflection and stiffness of the heliostats and their gravitational sag is another problem which needs rectification. Wind also causes a major effect on the tracking and deflection of heliostat. In contrast to this, the reflectors in parabolic trough collectors are much advanced with high reflectivity, but are much costlier than heliostats and require high maintenance. The mirrors need to be washed regularly as any dust accumulation on their surfaces directly affects the overall system efficiency. This is again a challenge in desert areas where these plants are generally set up, because water scarcity is an ever existing problem there.

The life span of reflectors in parabolic trough is really less and they need to be replaced after every 15-20 years to keep the system running. This increases the overall cost of electricity generation substantially. This problem, however, has not been pointed so far with the heliostats. Being plane slanting surfaces, dust accumulation is less and replacement requirement is much less frequent, though washing of the same with deionized water is a requirement. Moreover, the tower erection in desert soil is a challenge. This is because of the fragile landscape of the desert in which sand particles are loosely packed. [24]

CONCLUSION

The content of the major green house effect gas, carbon dioxide in the earth's atmosphere has risen to shocking levels of around 385 ppm, as against the maximum permissible value of 350 ppm. [28] The world has to make a collective effort to combat this situation and save the earth from the extreme effects of this situation. The only solution of this problem, keeping pace with the increasing requirements, is to switch to non-conventional sources of energy, the solar energy being the main component of which.

Though the above mentioned methods are capable of achieving the desired target of reduced carbon emissions, both are confronted with many challenges which need to be positively addressed in order to achieve a better tomorrow. For example, thermal storage and efficient provision of energy in 'no sun' situation can be provided by using back up power using solar storage batteries and inverter system. The sites for setting up of these plants in cities have to be isolated from the vicinity of high rise buildings and projections. Effects of shading and angular deflection of receivers due to changing position of sun have to be automatically altered to track the solar rays.[31]

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