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State-of-the-art of solar thermal power plants—A review

V. Siva Reddy [a,*], S.C. Kaushik [b], K.R. Ranjan [b], S.K. Tyagi [c]

[a] Sardar Patel Renewable Energy Research Institute, Vallabh Vidhyanagar 388120, Gujarat, India
[b] Centre for Energy Studies, Indian Institute of Technology Delhi, Hauz Khas 110016, New Delhi, India
[c] Sardar Swaran Singh National Institute of Renewable Energy, Jalandhar–Kapurthala Road, Wadala Kalan, Kapurthala 144601, Punjab, India

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ABSTRACT

The solar thermal power plant is one of the promising renewable energy options to substitute the increasing demand of conventional energy. The cost per kW of solar power is higher and the overall efficiency of the system is lower. In the present communication, a comprehensive literature review on the scenario of solar thermal power plants and its up-to-date technologies all over the world is presented. Results of the technical and economical feasibility studies by researchers are reported in brief for further reference. It is observed that the solar thermal power plants have come out of the experimental stage to commercial applications. Case studies of typical 50 MW solar thermal power plants in the Indian climatic conditions at locations such as Jodhpur and Delhi is highlighted with the help of techno-economic model. Different solar concentrator technologies (parabolic trough, parabolic dish and central power tower) for solar thermal power plants are compared economically. It has been found that the parabolic dish concentrating solar Stirling engine power plant generate electricity at a lower unit cost than the other two solar technologies considering 30 years lifespan and 10% interest rate on investment.

Contents

1. Introduction

The ever increasing demand of energy for development of the society is fulfilled by a variety of energy sources. Large scale energy utilization has led to a better quality of life and faster all round development; it has also generated many critical problems [1]. The most prominent of these is the harmful effect on the environment in various forms leading to global warming and climate change [2]. At the same time, the fossil fuel resources are also fast depleting due to over exploitation. Therefore, it is worth to explore the alternative energy sources, systems and technologies for sustainable development, if not fully but at least to substitute an appreciable amount of conventional energy to mitigate the harmful effect to some extent.

Other than fossil fuels, nuclear and large hydro-power, there are a number of sources of energy which have started contribution in a small way to the world's present energy demand and supply scenarios. These include energy sources like wind energy, small hydro, photovoltaic conversion, bio-mass, tidal, geothermal energy and solar thermal power plants. Among the renewable energy

* Corresponding author. Mobile: +91 9898 722 118; fax: +91 2692 237 982.
E-mail address: vundelaap@gmail.com (V. Siva Reddy).

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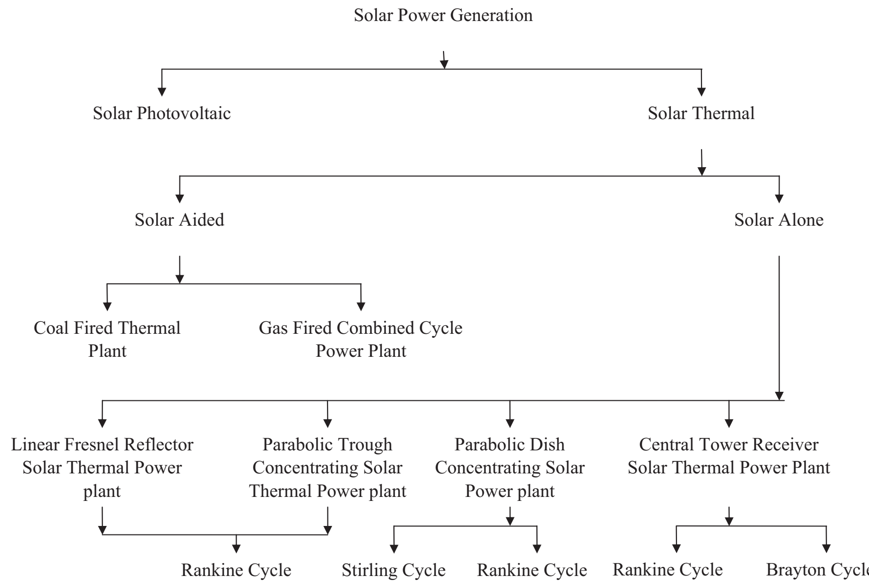

Fig. 1. Schematic view of solar power generation methods.

sources, solar power generation undoubtedly offers the most promising and viable option for electricity generation for the present and future. The schematic views of solar power generation methods are shown in Fig. 1.

In the present study, the authors have focused on the solar thermal conversion route of power generation only. The basic mechanism of conversion and utilization of solar energy for solar thermal power generation is available in the literature elsewhere. The main differences are found to be in the solar energy collection devices, working fluids, solar thermal energy storage and heat-exchanger, and suitable solar thermal power cycles. Solar thermal power cycles are classified as low (up to 100° C), medium (up to 400° C) and high (above 400° C) temperature cycles [1].

2. Status of low and medium temperature technologies of solar thermal power plants

Low temperature solar thermal power plants use flat-plate collectors, or solar ponds for collection of solar energy. The working fluid of low boiling points; organic fluids like methyl chloride and toluene, and refrigerants like R-11, R-113 and R-114 are normally used in the Rankine cycle. Solar power plants of this type having generation capacities up to about 50 kW were installed in many parts of the world, particularly Africa, in 1970s. The reported Rankine cycle efficiency of 7–8% and efficiency of the solar flat-plate collector system of about 25% lead to an overall efficiency of only 2%. The cost of similar solar thermal power plant of 10 kW installed at IIT Chennai in 1979–1980 were estimated about Rs. 300,000 per kW for 6–8 h of daily operation. In order to reduce the cost, solar ponds have been used instead of flat-plate collectors in Israel for 6 kW and 150 kW capacities. Systems working on the solar chimney concept have also been tried in Manzanares, Spain as an experimental pilot plant [1].

Medium temperature solar power plants use the line focusing parabolic solar collector at a temperature about 400° C. Significant advances have been made in parabolic collector technology as well as organic Rankine cycle technology to improve the performance of parabolic trough concentrating solar thermal power plant (PTCSTPP). A parabolic trough collector consists of long parallel rows of reflectors made by bending a sheet of reflective material (silvered low-iron float glass) into a parabolic shape [3]. At the focal point of the reflector is the absorber tube or receiver. The receiver is a black treated metal tube, covered with a glass tube, the space between the pipe and glass cover is evacuated to reduce heat losses. The rows are arranged along a north–south axis and they can rotate from east to west over each day. Parabolic troughs can achieve concentration ratios (ratio of solar flux on the receiver to that on the mirrors) of between 10 and 100. A heat transfer fluid (HTF) is circulated through the receiver absorber tube to remove the solar heat. The HTF can be heated to temperatures of up to 673 K. The fluid is pumped to a heat exchanger where its heat is transferred to water or steam.

A tracking mechanism is to be used to follow the sun and must be able to track the sun during periods of intermittent cloud cover. Finally, then return the parabolic trough concentrator to its original position at the end of the day or during the night. At present tracking system for the parabolic trough concentrator is based on “virtual” tracking. The traditional sun-tracking unit with sensors that detect the position of the sun has been replaced by a system based on calculation of the sun position using a mathematical algorithm [4]. The biggest application of this type of system is the southern California power plants known as Solar Electric Generating Systems (SEGS), which have a total installed capacity of 354 MW_e [5]. SEGS-I of 14 MW_e capacity was set up in 1984. SEGS-II to VII was of 30 MW_e each, and SEGS-VIII and IX are of 80 MW_e each. The collector array for SEGS-IX has an area of 483,960 m^2. SEGS-VIII which started operation in 1990 is reported to have cost $4000 per kW.

A recent development in cost effective concentrators is the design of the Euro Trough, a new parabolic trough concentrator, in which an advanced lightweight structure is used to achieve cost-efficient solar power generation [6,7]. More details on this development of parabolic concentrator system are given in Table 1.

The parabolic trough solar power plant can collect up to 60–70% of the incident solar radiation and has achieved a peak electrical conversion efficiency of 20–25% (net electricity generation to incident solar radiation). A number of researchers have carried out works on the solar parabolic trough concentrator based solar power system with varied perspectives. Some of the findings are presented in this paper for further reference in the research works with the aim to improve the performance of the solar thermal power generation systems. Treadwell et al. [8] presented the performance of single-axis tracking parabolic trough solar