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Research paper

Modeling and performance simulation of 100 MW LFR based solar thermal power plant in Udaipur India ☆

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ABSTRACT

Solar energy is the most abundant source of energy on the earth and considered as an important alternative to fossil fuels. Solar energy can be converted into electric energy by using two different processes: photovoltaic conversion and the thermodynamic cycles. Lifetime and efficiency of PV power plant is lesser as compared to the CSP technology. CSP technology is viewed as one of the most promising alternative technology in the field of solar energy utilization. A 100 MW Linear Fresnel Reflector solar thermal power plant design with 6 hours of thermal energy storage has been evaluated for thermal performance using NREL SAM. A location receiving an annual DNI of 2248.17 kWh/m^2/year in Rajasthan is chosen for the technical feasibility of hypothetical CSP plant. The plant design consists of 16 numbers of solar collector modules in a loop. HITEC solar salt is chosen as an HTF due to its excellent thermodynamic properties. The designed plant can generate annual electricity of 263,973,360 kWh with the plant efficiency of 18.3 %. The capacity utilization of the proposed LFR plant is found to be 30.2%. The LFR solar thermal power plant performance results encourage further innovation and development of CSP plants in India.

1. Introduction

Power generation using solar energy is one of the most promising options in reduction of fossil fuel consumption and related CO_2 emissions. In India, Solar PV based power generation is given more importance so as to increase the share of electricity production from renewable energy quickly. It is envisaged by the government of India to generate 175 GW electricity from the renewable energy sources by 2022 under Jawaharlal Nehru National Solar Mission [1]. The proposed target is five times the current electricity production from the renewable energy sources. Out of 175 GW target, 100 GW of electricity is to be generated from solar energy alone, and the remaining will be from wind, biomass and small hydro. Solar PV based energy generation is land intensive as well as less efficient. Presently installed capacity of Solar PV based power plant is 8.7 GW [1]. In the current scenario, 97.6% of solar based energy is obtained from solar PV. The contribution of Concentrated Solar Power (CSP) is only 2.4% of the total solar based power generation [2]. In India, the population density (382 persons/km^2) is so high that land should be used judiciously. Since PV based power generation requires more land, there can be a shortage of the land, especially for housing and agriculture in the future. On the other hand, desert land (320,000 km^2) in the states of Rajasthan, Gujarat, and Haryana can be effectively used for solar-based technologies. Rajasthan has more desert area among Indian states. The desert areas are marked as barren lands as they are not suitable for living as well as agriculture. These regions are not preferred for solar PV applications because of high temperature and high DNI [3]. Also after 25 years of expected lifetime, the PV modules will be categorized as e-waste.

Concentrating solar power (CSP) technology is considered as one of the most alternative solutions of power generation from solar energy. In this technology, sunrays are focused onto a solar receiver with the help of mirrors. The energy captured by the receiver is converted to heat or electricity through a series of process. It can operate continuously for up to 100 years. For

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a CSP plant, higher DNI corresponds to higher electricity generation. As a rule of thumb, regions with low annual cloud shading and Direct Normal Incidence (DNI) exceeding 2000 kWh/m^2/year (5.5 kWh/m^2/day) can generate more units of electricity per area.

The linear Fresnel Reflector based CSP power plant is considered as one of the most promising technologies for arid and semi-arid regions. This technology is capable of producing power ranging from few kilowatts (remote power systems) to hundreds of megawatts (grid-connected power plants). Linear Fresnel reflector solar thermal power plants (LFRSTPP) mostly consist of a solar field and power blocks. TES (thermal energy storage) system can be used to enhance the system potential [4]. Presently installed capacity of CSP plant in India is about 503.5 MW [5].

Simplest application of LFR technology is for the direct steam generation eliminating the need of expensive thermo-oil and complex heat exchangers. The superheated steam can be generated directly in the absorber of the concentrating collector.

Mills and Morrison [6] presented the first results from the linear Fresnel solar concentrating collector installation of 1MWth at the Liddell power station. Direct steam generation with the solar array was achieved and optical performance met the design specifications.

Horn et al. presented an investment evaluation, determining the NPV and the LEC of an integrated solar combined-cycle system in Egypt [7].

Hosseini et al. performed a comparative study of different traditional and solar power plants using the levelized electricity cost as the reference metric [8].

A comparison in terms of the LEC between linear Fresnel and parabolic trough collector power plants was performed by Morin et al. [9].

Comparative analyses using the LEC among different renewable electricity generation technologies have been developed by Varun et al. [10] and by Giuliano et al. [3].

However, feasibility of large scale CSP Technology in Indian climatic condition has not been reported in the literature till date. This work is just an attempt to address the research gap existing in the field of large scale LFR CSP plants.

The main objectives of the research work are as follows:

1. Propose a suitable design of LFR CSP technology for renewable power generation in the identified sites of India.
2. Simulate the performance of a Linear Fresnel Reflective solar thermal power plant with the help of SAM (system advisor model) software and NREL weather data base.
3. Analyze the thermodynamic aspect and annual energy generation of the proposed Linear Fresnel Reflector solar thermal power plant technology.

2. Methodology

2.1. Thermodynamic cycle

Schematics of solar ORC are presented in Fig. 1. The organic Rankine cycle process is shown in T–S diagram in Fig. 2.

There are four processes in the Rankine cycle. These states are identified by numbers (in color) in the T-s diagram. Processes 1–2 and 3–4 would be represented by vertical lines on the T-s diagram.

- **Process 1–2**: The working fluid (HITEC Solar Salt) is pumped from low to high pressure.
- **Process 2–3**: The high-pressure liquid enters to the boiler, where it is heated at constant pressure by an external heat source to become a dry saturated vapor. The input energy required can be easily calculated using an enthalpy–entropy chart (h-s chart or Mollier diagram), or numerically, using steam tables.

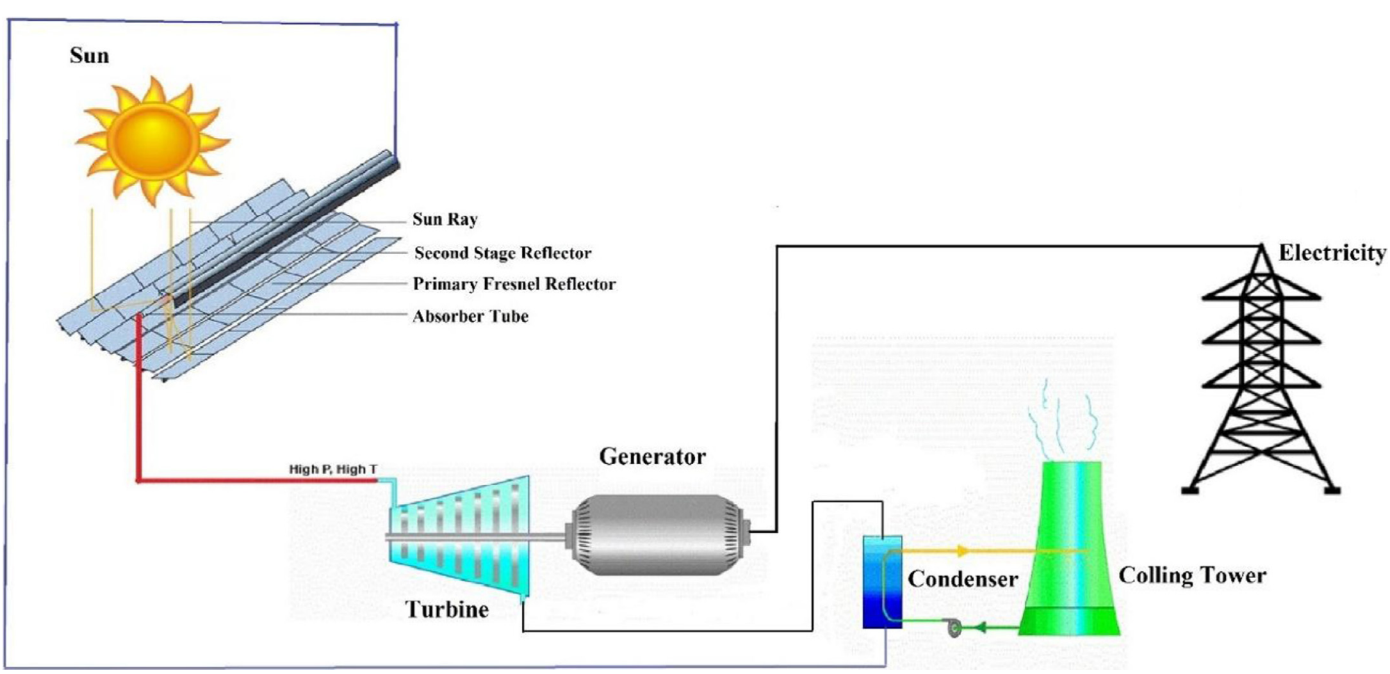

Fig. 1. Schematic diagram of Linear Fresnel Solar Thermal Power Plant.