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A study of the effect of design parameters on the performance of linear solar concentrator based thermal power plants in India

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ABSTRACT

The sizing of a solar thermal power plant directly affects its cost and also the annual electricity output and hence its financial attractiveness. It involves deciding appropriate values of design DNI, solar multiple and hours of thermal storage to achieve high annual capacity utilization factor (CUF) with the least cost of electricity delivered. An analysis of the impact of these design parameters on the performance of parabolic trough concentrator (PTC) and linear Fresnel reflector (LFR) based solar thermal power plants is presented using System Advisor Model for eight locations in India. Annual electricity output is estimated using radiation data source of SEC-NREL. Levelized unit cost of electricity (LUCE) is estimated using benchmark capital cost and other financial conditions specified by the Central Electricity Regulatory Commission of Government of India. For a design DNI of 950 W/m^2, LUCE is minimum in solar multiple range of 1.4–1.6 for PTC based plants and of 1.8–2.0 for LFR based plants. With a solar multiple of 1.0, LUCE is minimum in design DNI range of 550–700 W/m^2 for PTC based plants and 450–550 W/m^2 for LFR based plants.

1. Introduction

Electricity generation using renewable energy technologies is being promoted on a global scale to satisfy increasing demand in a sustainable manner. Solar thermal power generation is one of the important renewable energy technologies for electricity generation that has minimal adverse impacts on the environment. Moreover, it is possible to establish megawatt scale grid connected solar thermal power plants that can provide electricity with high dispatch ability. By the end of the year 2014, CSP plants of cumulative capacity of 4429 MW were operational across the world and plants of about 5684 MW capacity are under construction/development [1]. In India, with the launch of Jawaharlal Nehru National Solar Mission in 2010, activities towards large scale dissemination of solar thermal power plants have attained considerable momentum. The country has huge potential for solar thermal power generation [2–4]. Three solar thermal power generation technologies have attained a significant level of commercial maturity namely, parabolic trough collector (PTC), central receiver system (CRS) and linear Fresnel reflector (LFR). Designing a solar thermal power plant based on any of these technologies involves designing an appropriate solar field as it costs approximately 40–50% of the total project cost [5,6]. Typical cost breakup of a 50 MW PTC based plant in India is presented in Fig. 1 [7].

Optimal sizing of solar field is also important as it directly affects annual electricity output of the power plant and hence the financial attractiveness. While an oversized solar field, by selecting a lower design value of direct normal irradiance (DNI) and/or higher solar multiple, may produce more thermal energy than the amount that can be used by the power block, a plant with undersized solar field is likely to produce power at its nominal capacity only for a limited period during the year and consequently have low annual capacity utilization factor. Optimal sizing of solar field necessarily involves deciding appropriate values of design DNI and solar multiple. The solar multiple is defined as the ratio between the thermal power produced by the solar field at the design DNI and the thermal power required by the power block at nominal conditions. The challenge of designing an optimal solar field for a solar thermal power plant is that the plant should operate at its nominal capacity for the maximum possible duration in a year and at the same time produce electricity at minimum possible prices.

Some studies have attempted to analyze the effect of design and operational parameters on the performance of PTC and LFR based power plants. A comparison of the cost of electricity produced by

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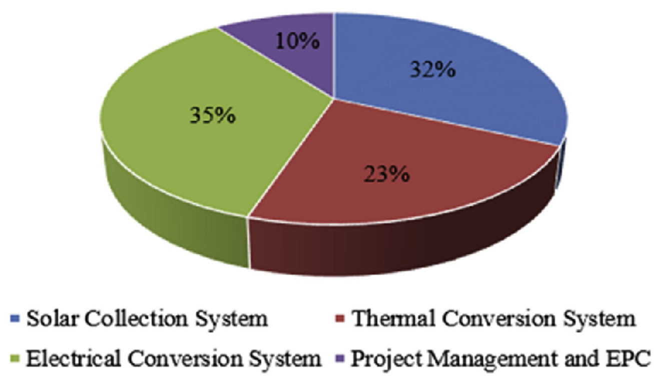

Fig. 1. Typical cost breakup of a 50 MW PTC based plant.

PTC and LFR based plants has been made by Morin et al. [8]. Giostri et al. [9] compared commercial Fresnel technology for direct steam generation with conventional parabolic trough technology based on synthetic oil heat transfer fluid and found that the optical efficiency of Fresnel technology is less as compared to that of parabolic trough technology. The suitability of using a weighted average of incident solar radiation at a location for designing collector field of PTC based solar thermal power plants is presented by Wirz et al. [10]. Influence of varying the value of design DNI on the size of the collector field of PTC based plants has been studied by Quaschning et al. [11]. Montes et al. [12] have presented a study pertaining to economic optimization of the solar multiple for a solar only PTC based plant using oil as heat transfer fluid. The effect of solar multiple on the performance of a direct steam generation solar thermal power plant has been presented by Montes et al. [13]. Izquierdo et al. [14] studied the effect of solar multiple, capacity factor and storage capacity on the cost of electricity delivered by solar thermal plants. A methodology to determine cost optimum design radiation for solar thermal power plants without hybridization and storage has been proposed by Desai et al. [15]. Feasibility analysis of solar thermal power plants for large scale dissemination was undertaken by Reddy et al. [16]. The study analyzed the performance and levelized electricity cost for PTC, LFR and power tower technology. Very few studies have been reported in the Indian context that deal with the analysis of the impact of design parameters on the performance of PTC and LFR based power generation systems. An attempt to identify combinations of design DNI, solar multiple and hours of thermal storage for the least cost of electricity generation by PTC based solar thermal power plants has been reported by Sundaray and Kandpal [17]. This study used the cost and other data inbuilt in System Advisor Model, although the selected locations were in India. There is no study available in the published literature that compares both the linear solar concentrator technologies viz. PTC and LFR for niche locations in India. This paper presents the results of an analysis undertaken to study the effect of the design DNI and solar multiple on the performance of PTC and LFR based solar thermal power plants for 8 potential locations in India. Besides, effect of hours of thermal storage on the annual electricity output and levelized unit cost of electricity (LUCE) for a parabolic trough based power plant has also been analyzed.

2. Methodology

This study essentially involves estimation of annual electricity output as well as the levelized unit cost of electricity (LUCE) for different likely combinations of the values of solar multiple and design DNI. To decide the values of solar multiple and design DNI, 50 MW solar thermal power plants based on PTC and LFR technology have been analyzed. To obtain annual electricity output and the value of another performance metric, i.e. the amount of thermal energy dumped, the System Advisor Model (SAM) [18] software developed by the National Renewable Energy Laboratory (NREL) USA has been used. SAM predicts performance and financial metrics for power plants based on various renewable energy technologies according to the weather data of the proposed location. A schematic of the methodology adopted in the case of solar thermal power plants is presented in Fig. 2 and each of the steps are described in the following paragraphs.

2.1. Selection of potential locations to be considered for analysis

In a recent study, Sharma et al. [4] have presented estimates of solar thermal power generation potential in India and identified considerable potential in the states of Rajasthan, Gujarat, Andhra Pradesh and Maharashtra. Based on the above mentioned study, 8 districts have been selected for the present analysis. These districts satisfy two conditions for the installation of MW scale grid connected solar thermal power plants: (a) sufficient wastelands in the suitable categories and (b) high DNI. Details of the locations along with annual DNI are shown in Table 1.

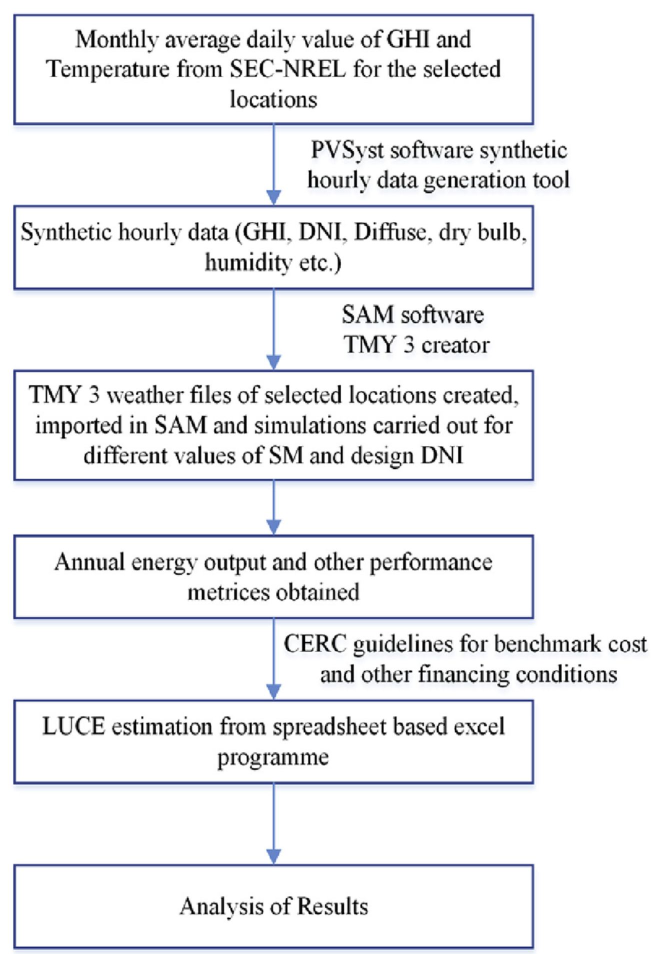

Fig. 2. Methodology adopted for deciding values of solar multiple and design DNI.