Renewable Energy 75 (2015) 152–164

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Techno-economic assessment of substituting natural gas based heater with thermal energy storage system in parabolic trough concentrated solar power plant

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ARTICLE INFO

Article history:
Received 2 June 2014
Accepted 18 September 2014
Available online

Keywords:
Concentrated solar power
Parabolic trough
Thermal energy storage
System advisor model
Booster heater
Shams

ABSTRACT

Parabolic-trough (PT) concentrated solar power (CSP) plants are very vulnerable to daily fluctuations in solar radiation. This dependence can be mitigated through a hybridization of solar energy with natural gas based heaters that supply thermal energy during the night or whenever solar irradiance level is dimmed. However, there is more sustainable way for CSP plants to avoid power-generation-outages caused by transient weather conditions, i.e. installation of thermal energy storage (TES). Such a system stores surplus thermal energy provided by solar field during sunny hours and discharges it when the sun is not available. Shams-1 PT plant in Madinat-Zayed, United-Arab-Emirates (UAE) has two natural gas based components, i.e. steam-booster heater and heat transfer fluid (HTF) heater. In the current study, model of Shams-1 was developed and analyzed in the System Advisor Model (SAM) software. It has been attempted to replace the HTF heater with TES. A parametric study has been conducted to determine the size of the TES as well as the solar field such that the specified power target demand would be satisfied. The results of the parametric analysis showed that TES can't completely replace the HTF heater, within reasonable sizes. Nevertheless, consequent simulations depicts that TES increases the capacity factor on one hand and decreases fuel consumption on the other hand.

1. Introduction

There are two main technologies that convert sun energy to electricity, namely photovoltaic (PV) systems and CSP. CSP technology is not a new concept as humankind has used the concentration of sunlight as a heat source since ancient times. However the first large-scale commercial CSP plants for electricity generation were only built in the mid-1980s [14].

The fact that CSP systems implement the technique of sunlight concentration means that CSP can only capture direct component of global irradiance called direct normal irradiance (DNI). The presence of intense DNI as a requirement of effective operation restricts the geographical feasibility of CSP systems to Sun Belt regions where DNI is quite high (Fig. 1).

There is a wide range of CSP systems [15] and four main categories of such technologies are presented in Fig. 2.

PT CSP technology is the most mature and low cost large-scale system among all CSP technologies available today, primarily because it accounts for about 90% of the CSP base currently installed worldwide [1].

The PT power plant consists of two general components: solar field and power cycle. Solar field is the heat collection element of the plant and power cycle is the part of the plant where collected heat is utilized to generate electricity. The general principle of PT plant functioning is the following: heat carrier circulates in the solar field and collects solar thermal energy which is then transferred to the power cycle, where it is used to produce steam and utilize it in the conventional Rankine thermodynamic cycle to generate electricity [15].

PT power plants, as any other solar energy based technology, have one essential disadvantage, i.e. energy generation for such systems is subject to daily fluctuations in solar radiation. In order to mitigate the dependence of PT plants operation on transient weather conditions, the unique ability of CSP plants to work in combination with fossil fuel based energy applications was used in numerous PT plants. Fig. 3 depicts an example of such a combination where fossil fuel heater heats up HTF when there is not enough sun energy available to satisfy the thermal energy demand of the power cycle [19].

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http://dx.doi.org/10.1016/j.renene.2014.09.025
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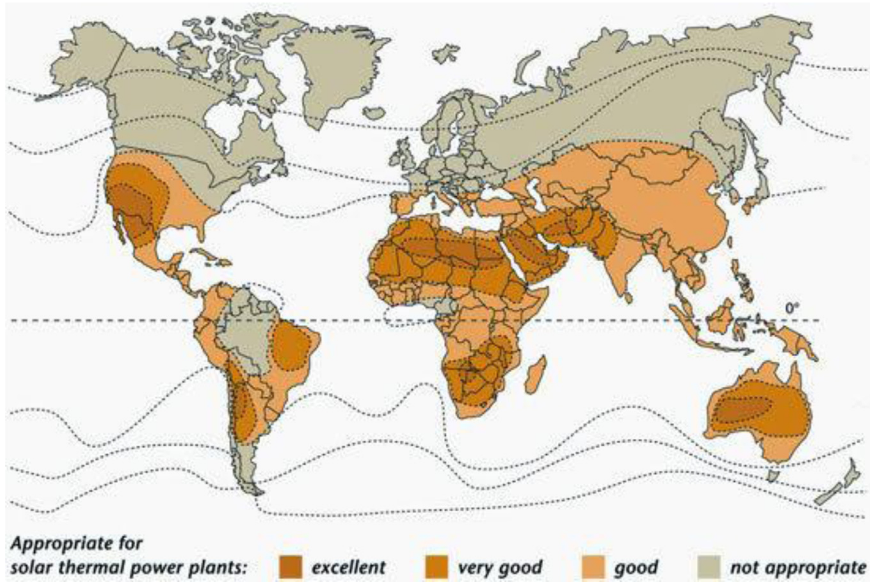

Fig. 1. Regions appropriate for CSP [17].

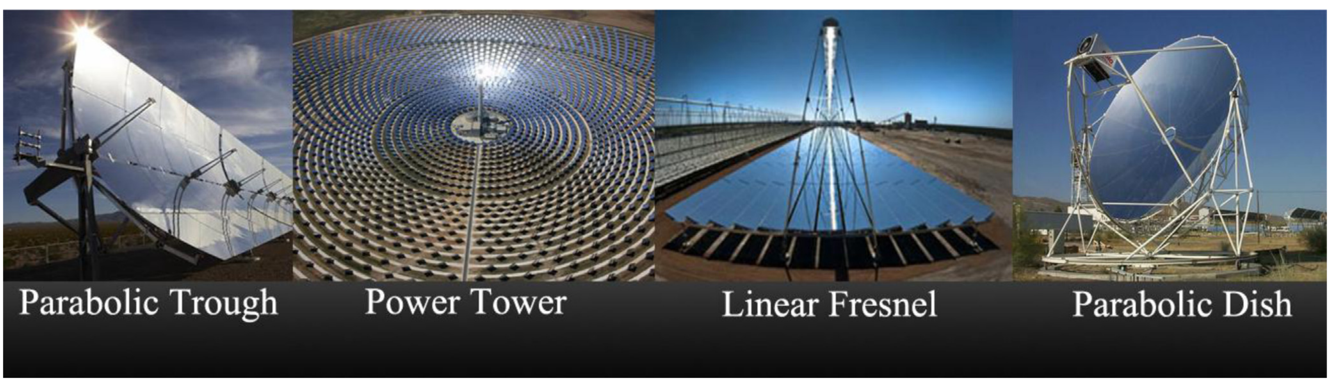

Fig. 2. Four main types of CSP systems [18] (Modified).

In order to eliminate the dependence on fossil fuel without decreasing efficiency and reliability of CSP plants, researchers attempted to store the thermal energy using TES, with the intention of using the stored thermal energy at night time or in case when sunlight is insufficient to drive the power cycle at nominal power output [23].

The presence of TES in a plant will be beneficial in terms of ability to regulate and smooth the power production. Furthermore,

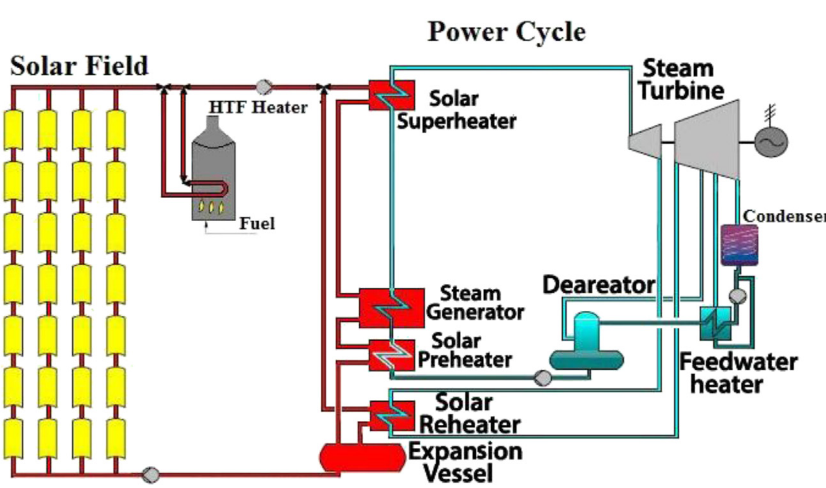

Fig. 3. Sketch of Parabolic Trough Plant combined with fossil fuel heater [19] (Modified).