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Concentrating or non-concentrating solar collectors for solar Aided Power Generation?

Jiyun Qin, Eric Hu*, Graham J. Nathan, Lei Chen

School of Mechanical Engineering, The University of Adelaide, Adelaide, SA 5005, Australia

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ABSTRACT

The preheating of the feedwater in a Regenerative Rankine Cycle power plant with solar thermal energy, termed Solar Aided Power Generation, is an efficient method to use low to medium temperature solar thermal energy. Here, we compared the use of medium temperature (200–300 °C) energy from concentrating solar collectors (e.g. parabolic trough collectors) to displace the extraction steam to high temperature/pressure feedwater heaters with that from low temperature (100–200 °C) non-concentrating solar collectors (e.g. evacuated tube collectors) to displace the extraction steam to low temperature/pressure feedwater heaters of the power plant. In this paper, the in terms of net land based solar to power efficiency and annual solar power output per collector capital cost of a Solar Aided Power Generation using concentrating and non-concentrating solar collectors has been comparted using the annual hourly solar radiation data in three locations (Singapore; Multan, Pakistan and St. Petersburg, Russia). It was found that such a power system using non-concentrating solar collectors is superior to concentrating collectors in terms of net land based solar to power efficiency. In some low latitude locations e.g. Singapore, using non-concentrating solar collectors even have advantages of lower solar power output per collector capital cost over using the concentrating solar collectors in an SAPG plant.

1. Introduction

Due to the environmental effects of the conventional fossil-fired power plants, the utilisation of renewable energy (e.g., solar energy) is attracting growing attention [1]. Although solar thermal energy has the advantages of being clean and having low greenhouse emissions, and has a trajectory of cost reduction, solar thermal power presently suffers from high costs where no carbon price has been established [2]. On the other hand, conventional fossil-fired power plants are the backbone of current electricity production. Therefore, integrating solar thermal energy with combustion power plant can be an attractive option [2]. It has been found that hybrid power systems has lower Levelized Cost of Electricity (LCOE) than stand-alone solar power plants [3]. There are two operations in integrating solar thermal energy into a Rankine power plant. One is to integrate the solar heat into the boiler and the other is to preheat the feedwater to the boiler [4,5]. The second operation has the advantages of being easy to control and lower capital costs, which the former has advantage of a higher solar share [4].

Solar Aided Power Generation (SAPG) plant uses solar thermal energy to preheat the feedwater of a Regenerative Rankine Cycle (RRC) power plant [6]. In this technology, the heat of the extraction steam from the steam turbine is displaced by the solar thermal energy to generate additional power in the steam turbine. This means that the thermodynamic benefit of an SAPG plant comes from the displaced high quality heat of the extraction steam [7,8]. Therefore, an SAPG plant can achieve higher solar thermal to power efficiency and thermo-economic benefits than a stand-alone solar power plant [9,10] and also reduce the exergy losses of an RRC power plant [11,12].

The utilisation of medium temperature (200–300 °C) concentrating solar collectors (e.g., parabolic trough collectors) to displace the extraction steam to high temperature/pressure feedwater heaters (FWHs) of an RRC power plant is the most common target for an SAPG plant. However, the system can be configured with the solar thermal energy displace the heat of the extraction steam at various alternative temperature stages. It has been found that the displacement of the extraction steam at higher temperature stages leads to higher solar thermal to power efficiency than at a lower temperature stage [13,14]. For an SAPG plant operated for fuel saving purposes, displacement of the extraction steam at a higher temperature stage also leads to more fossil fuel savings [9]. Considering the impact of overloading the steam turbine, with the same solar thermal input, displacement of the extraction steam to all high pressure/temperature FWHs can achieve highest solar share and solar thermal to power efficiency [15,16]. Therefore, most previous studies about SAPG plants are based on the assumption that

* Corresponding author.
E-mail address: eric.hu@adelaide.edu.au (E. Hu).

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Nomenclature

$C_{Initial}$	initial capital cost of the solar collectors, $
W_{Solar}	power output from the solar thermal energy in a time interval, kW
$\dot{Q}_{Land}$	solar radiation (global horizontal radiation) falling on the land of the solar field in a time interval, kW
x	annual solar power output per collector capital cost, kWh/$
η_{Net}	net solar to power efficiency, %
Δt	time interval (i.e. 1 h)

Abbreviation

DEA	Deaerator
ET	Evacuated tube
FWHs	Feedwater heaters
HTF	Heat transfer fluid
HPFWH	High temperature/pressure FWHs
LPFWH	Low temperature/pressure FWHs
LCOE	Levelized Cost of Electricity
PT	Parabolic trough
RRC	Regenerative Rankine Cycle
SAPG	Solar Aided Power Generation
SP	Solar Preheater

high pressure/temperature FWHs are displaced by the solar thermal energy [17–22]. As the feedwater outlet temperature of the high pressure/temperature FWHs is about 250–300 °C, medium temperature (200–300 °C) concentrating solar collectors (e.g. parabolic trough collectors) are often used to produce the heat transfer fluid (HTF) [17–22]. However, in these studies, only parabolic trough (PT) collectors are analysed as solar collectors to provide the HTF at a required temperature. The layout of collectors over a given piece of land has not been considered.

In terms of net land based view, an SAPG plant using low temperature (100–200 °C) non-concentrating solar collectors (e.g., evacuated tube collectors) may have net land based technical and economic advantages over using medium temperature (200–300 °C) concentrating solar collectors (e.g., parabolic trough collectors). In an SAPG plant, low temperature (100–200 °C) non-concentrating solar collectors (e.g., evacuated tube collectors) can only be used to displace the extraction steam to low pressure/temperature FWHs. The solar thermal to power efficiencies of an SAPG plant using non-concentrating solar collectors is lower than using concentrating solar collectors due to the low HTF temperature for the displacement [23]. However, Zhou et al. found that using non-concentrating solar collectors (i.e., evacuated tube (ET) collectors) still has higher net land based solar thermal to power efficiencies over using concentrating solar collectors (i.e., parabolic trough (PT) collectors) [24]. One reason for this is that in a given piece of land, the area of the ET collectors could be installed is larger than the PT collectors. Therefore, the annual solar thermal

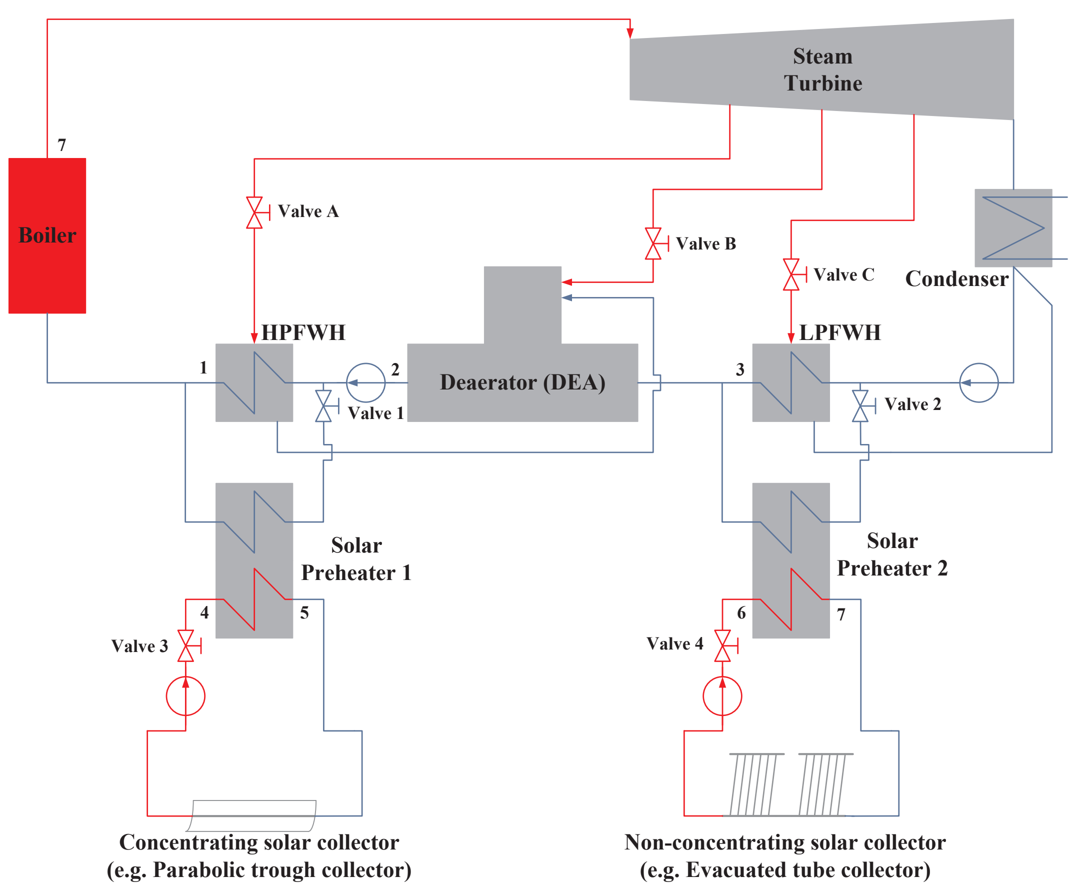

Fig. 1. Schematic diagram of a Solar Aided Power Generation (SAPG) plant. The medium temperature solar collector (i.e. concentrating solar collector is used to displace the extraction steam to high pressure/temperature FWHs, while the low temperature solar collector (i.e. non-concentrating solar collector) is used to displace the extraction steam to low the pressure/temperature FWHs.