



Contents lists available at ScienceDirect

Applied Energy

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

Performance of a solar aided power plant in fuel saving mode[☆]

Hongjuan Hou^a, Junjie Wu^a, Yongping Yang^{a,*}, Eric Hu^b, Si Chen^c

^a National Thermal Power Engineering & Research Center, North China Electric Power University, Changping District, Beijing 102206, China

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

^c University of Kentucky, Power and Energy Institute of Kentucky, Lexington, KY 40506, United States

HIGHLIGHTS

- A coupling analysis about solar aided power generation (SAPG) system is made.
- The off-design performances of turbine and boiler are considered in SAPG system.
- Matrix Thermal Balance Equation is used in SAPG system models.

ARTICLE INFO

Article history:

Received 27 September 2014

Received in revised form 19 December 2014

Accepted 22 January 2015

Available online xxx

Keywords:

Solar aided power generation

Feedwater heating

Thermal performance

Matrix Thermal Balance Equation

ABSTRACT

Integrating solar energy into conventional fossil-fuel fired power plant has been proven to be an efficient way to use solar energy for power generation purpose. In a solar-aided power generation (SAPG) system without storage system, owing to the instability of solar radiation, the turbine and the boiler work under off-design conditions most of time. In this paper, a modified simulation model is established to analyze the off-design performance of SAPG system. In order to speed up the calculations of the model, improved Matrix Thermal Balance Equation (MTBE) approach is used. A solar-aided feedwater heating of a 330 MW coal-fired power generation unit in fuel-saving operation mode is discussed as a case study. The results show that, in a SAPG system, when HP extraction steam is partly replaced, with the increasing solar energy being introduced, the temperature of exhaust flue gas decreases; boiler efficiency improves and standard coal consumption rate decreases. With more solar heat introduced the temperature of superheated and reheated steam keep constant at first and then decrease rapidly. However, in real project, the temperature drop should be no more the permissible limits, which should be considered. The results obtained in the current study could provide a promising approach to find the balance between coal saving and safe operation of the SAPG system.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

With the shortage of fossil fuels and its negative effects on the environment, green energy has attracted increasing attention both socially and politically. As a clean, free and non-depleting resource, solar energy has become more and more popular. However, its inherent shortcomings, such as low intensity, instability and high

initial investment limit the development of industrialization of solar thermal energy. Integrating solar energy into a conventional coal fired power station through so-called solar aided power generation (SAPG) technology could overcome the problems of a solar-only power station. Another advantage of SAPG is the flexible operation modes, which are (1) power boosting mode when power demand is high, and (2) fuel saving mode when power demand is low [1].

The early works in this field include Zoschak and Wu in 1975 [2], who assessed seven methods of integrating solar thermal energy into a 800 MW fossil fueled steam power plant. Using solar heat for feedwater pre-heating (i.e. SAPG) was one of the methods, which was proven to be a desirable option in terms of capital costs, technical design and operating aspects. Hu et al. [1] made an analysis on the advantages of solar aided power generation using both the first and the second laws of thermodynamics, based on a hypothetical case. Ying and Hu [3] presented the advantages of

Abbreviations: DNI, direct normal irradiance; HP, high-pressure; LP, low-pressure; MTBE, Matrix Thermal Balance Equation; RH, reheater; SAPG, solar-aided power generation; SH, superheater; SPP, simple payback period.

[☆] This article is based on a short proceedings paper in Energy Procedia Volume 161 (2014). It has been substantially modified and extended, and has been subject to the normal peer review and revision process of the journal. This paper is included in the Special Issue of ICAE2014 edited by Prof. J Yan, Prof. DJ Lee, Prof. SK Chou, and Prof. U Desideri.

* Corresponding author. Tel./fax: +86 10 61772011.

E-mail address: yypncepu@163.com.cn (Y. Yang).

<http://dx.doi.org/10.1016/j.apenergy.2015.01.092>

0306-2619/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

A_c	aperture area of solar field (m^2)	Q_1	quantity of heat absorbed by the working fluid (kJ)
b_1, b_2, b_3, c_1, c_2	empirical constants	Q_2	heat loss due to exhaust gas (kJ)
b_s	standard coal consumption rate (g/kW h)	Q_3	heat loss due to unburned gaseous combustibles (kJ)
C_I	cash inflow per year (¥)	Q_4	heat loss due to unburned solid combustibles (kJ)
C_O	the increased investment after solar heat can be introduced into power system (¥)	Q_5	heat loss due to radiation and convection (kJ)
c_s	the price of electricity price generated by solar heat (¥/kW h)	Q_6	other heat losses (kJ)
E	electrical energy output (per hour) of the plant (kW h)	Q_{abs}	solar radiation absorbed by the receiver tubes (W)
E_s	electricity generated by solar heat per hour in design point (kW h)	Q_{col}	thermal output of a parabolic trough solar field (W)
f_c	cleanliness factor (–)	$Q_{collector}$	collector heat losses (W)
G_{bn}	the direct normal irradiance (DNI) projected on the collector aperture area (W/m^2)	Q_{loss}	losses of solar field (W)
$h'_{d,i}$	specific enthalpy of drain water from the i th heaters (kJ/kg)	Q_r	the primary energy input from coal (kJ)
h_i	specific enthalpy of extraction steam into the i th heater (kJ/kg)	Q_{solar}	thermal output from solar field (MJ/h)
h_{wi}	inlet specific enthalpy of feedwater in the i th heater (kJ/kg)	Q_{pipe}	pipng system heat losses (W)
$H_{air,in}^0$	the enthalpy of cold air entering the air heater (kJ)	ΔT	difference between the average solar field temperature and the ambient air temperature ($^{\circ}C$)
H_{ex}	the exit flue gas enthalpy (kJ)	$\Delta T_{r,max}$	the maximum superheated and reheated temperature drop allowed ($^{\circ}C$)
k	incidence angle modifier (–)	t_s	the annual peak solar hours (h)
\dot{m}_0	mass flow rate of superheated steam (kg/h)	t_{spp}	simple payback period (year)
\dot{m}_{fw}	mass flow rate of feedwater from deaerator (kg/h)	α_{ac}	the ratio of feedwater through condenser to the mass flow rate through the boiler (–)
\dot{m}_i	mass flow rate of extraction steam for the i th heater (kg/h)	α_{ex}	the excess air ratio at the boiler exit (–)
\dot{m}_{rh}	mass flow of reheated steam (kg/h)	α_{fw}	the ratio of feedwater from deaerator to the mass flow rate through the boiler (–)
m_{sc}	the coal consumption (per hour) converted to the standard coal (kg)	α_i	the ratio of the i th stage of extraction steam ($i = 1, 2, 3 \dots 8$) to the (feedwater) mass flow rate through the boiler (–)
\dot{m}_{solar}	mass flow rate of feedwater heated by solar field (kg/h)	α_{rh}	reheated ratio (–)
\dot{m}_{ti}	mass flow rate of steam of the stage i of turbine under original designed condition (kg/h)	α_{solar}	the ratio of feedwater (heated by solar) through oil-water exchanger to the mass flow rate through the boiler (–)
\dot{m}'_{ti}	mass flow rate of steam of the stage i of turbine under off-design condition (kg/h)	γ_i	specific enthalpy drop of drain water in i th heater ($i = 2, 3, 6, 7, 8$)
p_i	pressure of the stage i of turbine of the original coal-fired power generation unit (MPa)	η_0	the optical efficiency (–)
p'_i	pressure of the stage i of turbine in turbine after the solar energy introduced (MPa)	η_b	efficiency of boiler (%)
q_i	specific enthalpy drop of extraction steam in i th heater ($i = 1, 2, 3, 5, 6, 7, 8$)	$\eta_{SAPG,c}$	coal-based efficiency of SAPG system (%)
q_{sc}	the lower heating value of standard coal (equal to 29,270 kJ/kg)	$\eta_{SAPG,o}$	overall thermal efficiency of SAPG system (%)
		θ	incident angle ($^{\circ}$)
		τ_i	specific enthalpy change of feedwater in the i th heater ($i = 1, 2, 3, 5, 6, 7, 8$) (kJ/kg)

using solar energy as an auxiliary source in regenerative Rankine plant from a thermodynamic viewpoint. However, in previous studies, changes of working fluid (water and/or steam) in terms of flow rate and properties when solar energy is introduced were not considered. Yan et al. [4,5] analyzed the performance of SAPG system with different replacement types and solar collector options under different operating conditions. However, the effect of Direct Normal Irradiation (DNI) was not discussed in the analysis. Yang et al. [6] analyzed the coupling mechanism and performance of SAPG system, which focused on how the turbine system was influenced with the introduction of solar energy, but the influence on boiler was not considered. Based on the THERMOFLEX software, Popov [7] compared the three types of arrangements: (1) the low-pressure (LP) heaters are replaced by solar heat; (2) the high-pressure (HP) heaters are replaced by solar heat and (3) the HP heaters together with economizer are replaced by solar heat. The results showed that the 3rd type was superior to other two for having higher electric efficiency. Suresh et al. [8] proposed the so called 4-E (namely energy, exergy, environment

and economic) analysis for SAPG power plants. The results indicate that it was an economical way to use solar energy to aid coal-fired power plants with the substitution of turbine extraction steam to the feedwater heaters. All the above-mentioned research is based on design conditions. However, owing to the instability of solar radiation, the solar thermal output varies and the SAPG system operates under off-design condition inevitably. Hou et al. [9,10] discussed the performance of solar aided feedwater heating of coal-fired power generation system under different operating conditions. The annual performance of the system and the optimum aperture area of solar field were discussed. Based on the energy-utilization diagram (EUD) method, Hong et al. [11] and Peng et al. [12] did the exergy analysis of the SAPG plant focusing on the exergy destruction and off-design performance respectively. The result indicated that a SAPG plant could achieve better off-design performance and economic performance than a solar-only thermal power plant. But in these literatures, the boiler is regarded as a “black box”. And the off-design condition operation of boiler is ignored.

Download English Version:

<https://daneshyari.com/en/article/6685456>

Download Persian Version:

<https://daneshyari.com/article/6685456>

[Daneshyari.com](https://daneshyari.com)