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Solar parallel feed water heating repowering of a steam power plant: A case study in Iran

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ABSTRACT

Currently, the use of renewable energies is put on the agenda of most researchers in the field of energy. On the other hand, in many parts of the world, fossil fuel power plants continue to be the main source of electrical power. Increased efficiency of fossil fuel power plants and the use of solar energy lead to recommendation of merging solar farms with the cycle of these power plants. The statistics indicate that the output of fossil fuel power plants in Iran, which currently supply about 93.9% of electricity of the national network, is experiencing a negative growth. On the other hand, according to government plans, part of the generated electricity should be provided from renewable energy sources in the next few years. In this paper, the use of solar energy for integration with power-plant units of Isfahan is investigated. To do this, preheat project of the feed water is investigated on 7 separate scenarios. The results showed that replacing all high-pressure feed water preheaters with solar farm increases the net energy and exergy efficiencies of the power plant by 18.3% compared to the simple cycle which respectively reaches to 45% and 43.91%. Given the importance of reducing emissions of CO_2 pollutants at power plants, reduction level of gas emissions, as well as some economic aspects of the integration of solar farm with the cycle of this power plant has also been evaluated.

1. Introduction

According to the latest figures announced by Iran's Department of Energy in mid-2016, the capacity of Iran exploited power plants was equivalent to 74,102 MW. Combination of these power plants was as follows: steam power plants: 21.4%, gas turbine power plants: 36.3% and gas turbine combined cycle power plants: 25%, hydro power-plants: 15.2%, nuclear power plants: 1.4%, and diesel wind, and renewable energy power plants: 0.8% [1]. According to this report, during one year ending in March 2016, the share of various power plants of electricity generation in the electricity network was as follows: Fossil fuel power plants: 93.9%, hydroelectric power plants: 5%, nuclear power plants: 1.1%. This is while the diesel, wind, and renewable energy power plants accounted for only 0.1% of electricity generation.

According to research findings, Iran is one of the best locations to build solar power plants and implementing solar repowering program [2]. However, central and southern regions of the country are the most appropriate areas in terms of sunlight radiation and having the potential to build solar power plants [3,4]. The average sunny days in more than 90% of Iran lands is 280 days per year [5]. Isfahan with the latitude of 32.67°N and 51.87° east longitude is one of these appropriate areas [6,7]. However, statistics show that Iran has rich resources of fossil fuels and is not much serious in the use of renewable energies. Therefore, it is one of the largest producers of CO_2 in the world [8]. However, in recent years, we have seen an increase in the rate of using renewable energies in Iran [9]. Among renewable energy sources, Iran has great potential for receiving solar energy [10]. Forecasts suggest an increase in Iran's electricity network capacity of about 139,298 MW until 2030. In this year, it is expected that renewable energies account for about 2% of the total capacity of Iran's installed power plants such that their production capacity reaches about 2800 MW [11].

2. Repowering of steam power plants

One of the solutions for efficiency increase is repowering the existing cycle [11,12]. Repowering means adding gas turbines to the new cycle for increasing generation and efficiency, for which there are several ways [13]:

- Hot wind box (HWB)
- Supply boiler or parallel repowering (SB)

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Nomenclature

A	Area (m^2)
B	Boiler
BFP	Boiler Feed Pump
CLFR	Compact Linear Fresnel Reflector
CT	Cooling Tower
CWP	Cooling Water Pump
DE	Deaerator
DP	Drip Pump
DSG	Direct Steam Generator
e	Specific Energy (kJ/kg)
E	Total Energy (kJ)
EC	Economizer
EV	Evaporator
EnPI	Energy Performance Index
ExPI	Exergy Performance Index
EX	Flow exergy
f	Darcy-Weisbach Coefficient
G	Generator
g	The Gravity Acceleration (m/s^2)
GT	Gas Turbine
GTCC	Gas Turbine Combined Cycle
h	Specific Enthalpy (kJ/kg)
HPH	High-Pressure Heater
HPT	High-Pressure Turbine
HRSG	Heat Recovery Steam Generator
$\dot{I}$	Destroyed Exergy (kW)
IPT	Intermediate Pressure Turbine
IPP	Isfahan Power Plant
ISCCS	Integrated Solar Combined Cycle System
LCoE	Leverised Cost of Electricity
LFR	Linear Fresnel Reflector
LPH	Low-Pressure Heater
LPT	Low-Pressure Turbine
$\dot{m}$	Mass Flow Rate (kg/s)
P	Pressure (bar)
PCC	Combustion Carbon Capture
PTC	Parabolic Trough Collector
Q	Heat (kW)
$\bar{R}$	World Constant for gases
RC	Rankine Cycle
s	Specific Entropy (kJ/kg K)
SAPG	Solar Aided Power Generation
SC	Simple Cycle
SD	Solar Dishes
SEGS	Solar Electric Generation System
SH	Superheating
ST	Steam Turbine
T	Temperature (°C)
TSS	Thermal Storage System
v	Velocity (m/s)
W	Work (kW)
z	Elevation (m)
Ql	Heat loss (kW)

Greek symbols

η_1	First low efficiency
η_2	Second low efficiency
ζ	Exergy of fuels
ψ	Specific exergy (kW/kg)

Subscripts and superscripts

a	air
c	solar collector
c.ch	Combustion chamber
d	direct
des	destroyed
f	fuel
fw	Feed water
g	gas
gen	generation
i	Inlet
o	outlet
reh	reheater
s	solar
th	thermal

- Feed water heating (FWH)
- Full repowering (FR) convert the SC to CC by eliminating existing boiler

One of the methods with adequate advantages compared to other methods and relatively lower costs is FWH method [14]. In this method, GT's output heat is used for preheating boiler feed water and extracted steam of turbines is decreased or totally cut. Thus, necessary steam discharge for generating specified amount of power in the steam turbine is reduced. Of course, steam discharge to condenser is also increased and it is not suitable for fixing pressure of the condenser [14].

3. Solar energy in steam power plants

The solar energy can be used in two ways to generate electricity: using photovoltaic panels and solar concentrator systems. In the first method, Silicon photovoltaic cells are used as direct electrical converters. In the second method, solar energy is used to heat the working fluid. The second method is more efficient and more convenient for large-scale solar power plants. To heat the fluid in solar farms, several types of solar concentrators are used, each with specific characteristics. In previous studies, two types of PTC and LFR were evaluated as superior options [2]. The results of these studies suggested that PTC type is the best option for applications in the temperature range of 400–450 °C (like present study).

One of the main disadvantages of renewable energy sources such as solar and wind powers are their fluctuation. This flaw does not cause much negative impact in the performance of solar photovoltaic systems and wind turbines, but in solar thermal systems, it causes temperature variations in the cycle and must be prevented. There are two methods to fix this flaw in thermal solar power plants: using a backup boiler, and thermal storage system (TSS). The backup boiler used in these cycles is usually of fossil fuel type. In cycle with TSS, a large part of the initial investment is dedicated to TSS [15]. One of the most appropriate ways to remove the backup boiler or TSS is the integration of thermal solar power plants with existing fossil fuel power plants. This reduces the initial cost for construction of the solar sector and also increases the output of fossil fuel power plants.

Using solar heat energy in combination with existing thermal power plants is attractive issue which has been studied over last three decades. There are many methods for combine solar energy and existing steam power plants, like:

1. Air preheating
2. Steam evaporation