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Research Paper

Evaluation of supply boiler repowering of an existing natural gas-fired steam power plant

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HIGHLIGHTS

- We analysed Supply Boiler Repowering (SBR) an existing NG-Fired Steam Power Plant.
- Three different HRSG configurations have been used and examined.
- The layout arrangement of existing boiler and the influence of SBR on its performance are examined.
- Best HRSG configuration and required gas turbine are chosen.
- The performance of the new combined cycle is evaluated energetically and exergetically.

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ABSTRACT

Using supply boiler to repower existing steam power plants (also known as parallel repowering) is one of the awesome repowering methods for almost all types of steam power plants. In this way, the capacity of the gas turbine and heat recovery steam generator (HRSG) can be designed in different ranges. Choosing the best number of HRSG pressure levels and the appropriate way to integrate the generated steam in the HRSG with the existing cycle are important steps during the cycle design. In this paper, we analyse the effects of HRSG pressure levels on the performance of existing boiler and turbines for Montazeri Steam Power Plant in Iran. To do this, we present three separate HRSG configurations and a multi-parameter analysis is provided. For each case, the effects on existing boiler, steam turbines and the condenser are examined. The results show that using HRSG with higher pressure levels (2 or 3) are caused an imbalance in mass flow rate of steam in steam turbines and different parts of the existing boiler. Therefore, using a single-pressure level HRSG with a reheat is recommended for this aim. If we use one HRSG and a gas turbine model Mitsubishi-701G2, net energy and exergy efficiencies and produced power will increases % 52.19, %50.9 and 485.8 MW, respectively.

1. Introduction

The issue of energy and increasing the efficiency of energy conversion systems are currently the main challenges face by researchers. Today, the efficiency increase and energy loss reduction are considered during the design of every single sub-system of a power plant. In recent years, integration of different cycles of power generation and refrigeration have been seriously studied as a good way to increase the output of the complex systems [1]. One of the first methods used to increase the efficiency and produced power of Rankine cycles was to integrate them with GT. This project was introduced by entry of GTs to the power generation industry, resulting in the GTCCs. In recent years, the majority of designs of thermal power plants were based on GTCCs. Since the past few years in Iran, all fossil fuel power plants have been designed and built as GTCCs [2]. On the other hand, there is still a large number of simple Rankine cycle power plants in the power generation network. Studies show that this type of power plants will be exploited until the next few decades in countries like Iran [3]. Hence, a method of increasing the output of such power plants must be identified and implemented. One of the most appropriate solutions is to integrate GT (or GTs) with these power plants. Of course, there will be many problems in implementing it because much of the cycle equipment of these power plants is designed and built for simple Rankine cycles.

The negative growth of the efficiency of fossil fuel power plants in Iran over the past years, which highlights ever-increasing

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Nomenclature

A	area (m^2)
app	approach point (°C)
B	boiler
CT	cooling tower
CWP	cooling water pump
e	specific energy (kJ/kg)
E	total energy (kJ)
EX	flow exergy
GT	Gas Turbine
GTCCPP	Gas Turbine Combined Cycle Power Plant
g	the gravity of earth (m/s^2)
h	specific enthalpy (kJ/kg)
HPT	high-pressure turbine
HR	Heat Rate (kJ/kW h)
$\dot{I}$	destroyed exergy (kW)
IPT	intermediate-pressure turbine
LPT	low-pressure turbine
MSPP	Montazeri Steam Power Plant
$\dot{m}$	mass flow rate (kg/s)
P	pressure (bar)
pp	pinch point (°C)
Q	heat (kW)
RC	Rankin Cycle
s	specific entropy (kJ/kg K)
SC	simple cycle
SH	superheating
SOFC	solid oxide fuel cell
SPP	steam power plant
T	temperature (°C)
v	velocity (m/s)
W	work (kW)
z	elevation (m)

Greek symbols

η_1	first low efficiency (energy efficiency)
η_2	second low efficiency (exergy efficiency)
$\eta_{2,f}$	functional exergy efficiency
$\eta_{2,u}$	universal exergy efficiency
ψ	specific exergy (kW/kg)

Subscripts and superscripts

a	air
des	destroyed
f	fuel
g	Gas
i	inlet
o	outlet
p	primary flow
s	secondary flow
r	relative

erosion, calls for a need for investment on improving their efficiency [4]. The rise in energy prices in recent years, deterrent laws of environmentalists about the prevention of industrial and environment emissions, limitations of available fossil fuel resources and attention to economic production cycle are among the factors that are essential for planning to increase the efficiency of electricity production network, especially steam cycle power plants.

In recent years, it has been observed that government's approach revolved around the combined cycle power plants, and new power plants have been combined cycle power plants. However, with regard to the explanation about the steam cycle power plant and recent Energy Ministry's plans, repowering of steam power plants is on the agenda. With repowering of steam power plants, more targets can be followed simultaneously: Increasing the power plants' production capacity and the performance of new cycle, decreasing the emissions and increasing the efficient life of power plants are the main benefits of the repowering of the steam power plants [5,6]. According to this, many studies have been performed on natural gas-fired steam power plants in Iran [7].

According to the results of the other studies, repowering the old cycle of an existing fossil fuel power plant can be chosen as a good and practical option. By adding gas turbines to this power plants, the efficiency and produced power will increase and the rate of producing pollutant gases will decrease.

1.1. Review of literature

In this section, a gist of the studies conducted about repowering of the existing thermal power plants have been reviewed. Shahnazari et al. [8] studied the repowering of steam power plant. They described minor repowering procedures and calculated the efficiency of Lushan, a new power plant cycle in each repowering procedure. They also expressed technical constraints of all general repowering types and performed an economic analysis for each procedure in Lushan Power Plant. Zeki et al. [9] investigated the repowering efficiency of a steam power plant with hot wind box and production rate of CO_2. This research has been performed with simulation thermoflex software and gas turbines with unit capacity of 10–22 percent of available steam cycle. An approximate increase of 11–27% production power rate in a decrease of 7% production rate of CO_2 has occurred because of this simulation.

Wołowicz et al. [10] simulated feed water heating repowering of a power plant in India with a unit capacity of 800 MW. They used gas turbine model (A PG7161-EC). With these changes, the entire cycle through the gas turbine inlet is added to production cycle and the steam turbine power is increased by increasing the steam flow through the steam turbine. The results of this research showed that by executing repowering, the production power increased by 20%. The nominal efficiency of the system increased 1% and continued from 43.5% to 45.5%.

In a research, Baghestani et al. [11] simulated Shahid Rajaee Power Plant cycle in *Iran* using thermoflex software. They proposed the best repowering conditions by using exergy and economic exergy analyses procedures. Matthias [12] investigated the best repowering conditions for a 300 MW steam power plant in Russia. He investigated all available repowering methods and suggested a complete repowering procedure after studying all repowering procedures because of *Power Plant* Life Exhaustion, and proposed gas turbine (SGT4000– F5). According to their calculations, the efficiency of the power plant will be increased from 38% to 56%.

In a study, Haghighi et al. [13] technically investigated the repowering of Besat Power Plant using the feed water heating procedure. They investigated the way of repowering impact on the efficiency of the new cycle and the increase level of the production power by using the thermodynamical simulation. They concluded that the repowering function in the power plant is a necessary activity. In addition, replacing all heat exchangers is more effective in the efficiency and productivity of power. They suggested the gas turbine, model V 94.2 to achieve the maximum production power