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Sensitivity analysis of STIG based combined cycle with dual pressure HRSG

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Abstract

Thermodynamic evaluation has been carried out for a combined cycle with STeam Injected Gas Turbine (STIG) having dual pressure heat recovery steam generator (HRSG). Steam from high-pressure steam turbine is injected into the combustion chamber at a pressure higher than the combustion pressure to improve the exergy efficiency of combined cycle. The effect of steam injection mass ratio, deaerator pressure (or temperature ratio), steam reheat pressure ratio, HP steam turbine pressure, compressor pressure ratio and combustion temperature on combined cycle exergy efficiency has been investigated. It has been found that advantage from steam injection to combined cycle is obtained at high steam reheat pressure and high steam turbine inlet pressure. At this condition, the increasing effect of gas cycle output exceeds the decreasing effect of steam cycle output. The major exergetic loss that occurs in combustion chamber decreases with introduction of steam injection in to the combustion.

Keywords: Combined cycle power generation; Steam injection; Exergy; Heat recovery steam generator; Exergy analysis

1. Introduction

The STIG method stands for steam injected gas turbine. The steam from the high-pressure (HP) steam turbine is injected into the combustion chamber. Air from the compressor and steam from the heat recovery steam generator (HRSG) both receive fuel energy in the combustion chamber and both expand inside the same turbine to boost the power output of turbine. In addition, the specific heat of superheated steam is almost double the value of air and the enthalpy of steam is higher than that of air at a certain temperature. Therefore, the STIG method is a very effective way to boost the net power output and increase the overall efficiency of gas turbines. Presently the STIG technology is applied only to the gas turbine cycle and it is not extended to the combined power cycle. The reason may be due to the decreased steam turbine output with steam injection. The combined cycle is now well established and offers superior performance to any of the competing systems. Not much information is reported in the literature about the combined cycle with the steam injection. Steam injection in the combined cycle increases the gas cycle output but the steam cycle output decreases. But proper selection of parameters for combined cycle such that the rise in gas cycle output is more than the drop in steam turbine output; the combined cycle output can be increase with the steam injection.

In 1978, Cheng [1] proposed a gas turbine cycle in which the heat of the exhaust gas of the gas turbine is used to produce steam in a HRSG. This steam is injected in the combustion chamber of the gas turbine, resulting in an efficiency gain and a power augmentation. Rice [2] developed a steam injected gas turbine cycle with a topping in which a HP steam is first expanded in a back-pressure steam turbine, producing power, and then is injected into the combustion chamber of the gas turbine. Borat [3] found that the efficiency and the net output of the gas turbine increased considerably, of the order of 20–40 percent with the steam injection. Poullikkas [4] reviewed the gas turbine technologies and emphasized on various advance cycles involving heat recovery from the gas turbine exhaust, such as, the gas to gas recuperation cycle, the combined cycle, the chemical recuperation cycle, the Cheng cycle, the humid air turbine cycle, etc. Gigliucci et al. [5] pre-

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Nomenclature

e	specific exergy	$kJ\,kg\,mol^{-1}$
h	specific enthalpy	$kJ\,kg\,mol^{-1}$
i	specific irreversibility	$kJ\,kg\,mol^{-1}$
M	molecular weight	
m	mass	$kg\,kg\,mol^{-1}$ fuel
P	pressure	bar
R	universal gas constant	$kJ\,kg\,mol^{-1}\,K^{-1}$
s	specific entropy	$kJ\,kg\,mol^{-1}\,K^{-1}$
T	temperature	K
w	work	$kJ\,kg\,mol^{-1}$
η	efficiency	
ε	specific exergy at ground state	$kJ\,kg\,mol^{-1}$
θ	excess temperature ratio	

Suffix

cc	combined cycle
ch	chemical
de	deaerator
OA	over all
ph	physical
sat	saturation
0	reference point
1	first law
2	second law

Acronyms and abbreviations

CEP	Condensate Extraction Pump
CPH	Condensate Pre-Heater
DSH	Degree of Super-Heat
ECO	Economiser
EVAP	Evaporator
FP	Feed Pump
GT	Gas Turbine
GTCC	Gas Turbine Combustion Chamber
HAT	Humid Air Turbine
HP	High-Pressure
HRSG	Heat Recovery Steam Generator
LP	Low-Pressure
LHV	Lower Heating Value
PP	Pinch Point
RH	Reheater
SH	Superheater
ST	Steam Turbine
STIG	STeam Injected Gas turbine
TTD	Terminal Temperature Difference

sented the main results of thermodynamic analysis of a cogenerative cycle, which deals with a hydrogen-fed, with steam injection in the gas turbine itself to couple high process efficiencies with very low nitrous oxide emissions. Steam injection also allows for a more flexible steam-production to power-production ratio [6]. Wang and Chiou [7] proved that the techniques namely steam injection gas turbine and inlet air-cooling are very effective features that can use the generated steam to improve the power generation capacity and efficiency.

There are many methods developed to improve the efficiency of the combined cycle. Heppenstall [8] described and compared several power generation cycles, which were, developed to take advantage of the gas turbine's thermodynamic characteristics. Chmielniak et al. [9] discussed the effectiveness of various technological configurations with gas turbines, which are to be applied during modernization projects of already existing conventional combined heat and power plants. Pelster et al. [10] presented a thermo environmental methodology to deal the complexity of analysis to the combined cycles. Franco and Casarosa [11] identified the key element to obtain high efficiency of combined cycle, which is the optimization of HRSG with the use of parallel sections and of limit sub-critical conditions (up to 220 bar). Gallo [12] compared the HAT cycle (humid air turbine) with the simple cycle gas turbine, recuperated gas turbine cycles, steam injection gas turbines and also with the combined cycle. Korobistyn [13] overviewed the improvements that can be implemented within the basic and combined cycles. Huang et al. [14] used an exergy analysis for a combination of steam injected gas turbine cogeneration system and forward feed triple effect evaporation process, with and without vapor recompression. Nishida et al. [15] analyzed the performance characteristics of the regenerative steam injected gas turbine system. Araki et al. [16] studied the characteristics of a humidification tower, which is used as a humidifier for the advanced humid air turbine system. Haselbacher [17] investigated the performance differences in terms of thermal efficiency and specific power output of the combined cycle power plants. Bassily [18] modeled a dual pressure reheat combined cycle and optimized.

Introduction of STIG to gas cycle without including steam turbine proves to be economically competitive in power range under 150 MW [19]. The expansion of steam in the gas turbine proceeds to the atmospheric pressure whereas in the combined cycle plant steam leaves the steam turbine at much lower pressures, thus providing more power. Therefore, a gas turbine with steam injection will have a lower efficiency than that in combined cycle operation. But if the increasing effect of gas cycle output is more than the decreasing effect of steam cycle output, the combined cycle efficiency increases with the steam injection.

The main aim of this work is to find the combined cycle system parameters at which the exergy efficiency of overall system improves with introduction of steam injection. For this, a sensitivity analysis has been carried out with the steam injection to fuel mass ratio, deaerator temperature ratio, steam reheat pressure ratio, steam turbine inlet pressure, gas cycle pressure ratio and combustion chamber temperature on exergy efficiency of the combined cycle.