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Energy, economic and environmental assessments for gas-turbine integration into an existing coal-fired power plant

Roberto Carapellucci*, Lorena Giordano

Dept. of Industrial and Information Engineering and Economics - University of L'Aquila,
Via G. Gronchi 18, L'Aquila (67100) - Italy

Abstract

The concept of repowering existing power plants has been recently revalued, in the light of the increasing energy needs, combined with the cost and the difficulty in developing new generating capacity. Among technologies for existing steam power plants, feedwater repowering is considered one of the less-intrusive and cost-effective option to expand capacity, improve efficiency and reduce the pollutants emissions. This paper aims to evaluate the effects of feedwater repowering operating conditions on energy, environmental and economic system performances. Considering a 600 MW coal fired power plant as a study case, two feedwater repowering configurations are investigated. In the first case, a simple throttling of high pressure regenerative steam extractions is operated; in the second configuration, the feedwater upstream the boiler inlet is partially preheated using the waste heat of an additional gas turbine. In both cases, a characteristic plane is introduced for comparing energy, economic and environmental performances of feedwater repowering options, at different condenser overloads and fossil boiler modes of operation.

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Keywords: Feedwater Repowering, Gas Turbine, CO_2 Emissions, Off-Design, Coal Saving, Marginal Efficiency, COE

1. Introduction

The growth of world energy consumptions and the need to meet the increasingly stringent environmental regulations make the repowering of existing coal-fired power plants an attractive option for boosting the generating capacity at competitive cost [1-3]. As well known, in the feedwater repowering the exhaust gases of an additional

* Corresponding author. Roberto Carapellucci Tel.: +39 0862 434320; fax: +39 0862 434403.
E-mail address: roberto.carapellucci@univaq.it

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gas turbine are used to preheat a fraction of feedwater upstream the boiler inlet. This leads to a reduction of regenerative steam bleedings and a corresponding rise of steam passing across turbine blades. As a result, the capacity of the existing coal fired power plant boosts, even more than 20%, with a less pronounced efficiency gain [4-6]. Additional benefits of feedwater repowering include the reduction of the electricity generation cost and the carbon dioxide emissions, due to the improved efficiency and to the partial fuel shift from coal to natural gas.

Feedwater repowering of an existing coal-fired power plant has been addressed only in a few studies. In [7] Szargut developed a model to quantify energy and environmental benefits arising from the gas turbine integration. A further study of the same author [8] examined different strategies to reduce the exergy losses related to feedwater-gas heat exchange process. Escosa and Romeo [9] evaluated the CO_2 avoided cost of feedwater repowering, varying the technology and rated capacity of the additional gas turbine. Karellas et al. [10] investigated parallel and feedwater repowering solutions by means of exergy and economic analysis.

The goal of this paper is to evaluate the effects of a feedwater repowering intervention on the energy, economic and environmental performances of an existing steam power plant, considering various condenser overloads and boiler modes of operation (power boosting or coal saving). In the case of power boosting, the boiler operates with a fossil fuel flow higher than or at least equal to design conditions and the corresponding gain of steam power plant capacity is constrained by the maximum permitted overload at low pressure steam turbine and condenser (15-20% of the nominal load) [5,11], in order to avoid the adaptation or the replacement of these equipments. In the case of coal saving, the boiler operates with a fuel flow rate lower than the nominal value, in order to manage the condenser overload, due to partial throttling of steam bleedings. The reduction of the superheated steam flow allows to increase the feedwater deviation with the same condenser overload, thus determining an efficiency enhancement and a reduction of CO_2 emissions.

Two different repowering configurations are investigated in this study. In the first case, steam power plant undergoes a simple throttling of high pressure steam bleedings, thus allowing an increase of steam turbines capacity together with an efficiency penalty, due to lowering of feedwater temperature at boiler inlet. In the second configuration, feedwater is partly deviated from high and low pressure regenerative heaters and preheated by the exhaust gases of an additional gas turbine. The energy analysis of feedwater repowering options, carried out with the commercial General Electric software GateCycle [12], aims to evaluate the power increase and the marginal efficiency, as well as the effects on the specific CO_2 emissions. Moreover, the economic analysis assesses the unit cost of electricity produced by the repowered plant, as well as the unit cost of the additional electricity generated.

In both configurations examined, a characteristic plane is defined: it allows to compare energy, economic and environmental performances of feedwater repowering options, considering different condenser overloads and fossil boiler modes of operation.

Nomenclature

Symbols

C	Fuel cost, \$/GJ
C_{FR}	Feedwater repowering cost, M\$
$CO_{2,em}$	Specific CO_2 emissions, kg/MWh
E	Electricity production, GWh
HR	Heat rate, kJ/kWh
M	Steam flow rate, kg/s
P	Power, MW
Q	Fuel mass flow rate, kg/s

Greek letters

γ	Degree of closing of HP steam bleedings, %
η	Efficiency, %
λ	Feedwater deviation, %

Superscripts

O	Design conditions

Subscripts

CD	Condenser
EXH	Exhaust
GT	Gas turbine
HX	Heat exchanger
HP	High pressure
IRP	Integrated repowered plant
LP	Low pressure
mg	Marginal
SH	Superheated
ST	Steam power plant
th	Thermal

Acronyms

BOP	Balance of plant, M\$
COE	Cost of electricity, \$/MWh
TEC	Total Equipment Cost, M\$