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Effect of a real steam turbine on thermoeconomic analysis of combined cycle power plants

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ABSTRACT

The continuing depletion of fossil fuels and the growing restrictions for greenhouse emissions, leads to reprocess wasted heat generated by power plants. For this purpose, Combined Cycles Gas Turbine (CCGT) represent a strong technology to obtain, an increase of performances and competitive costs within global market.

To design the CCGT configuration, energy engineering companies should define and analyze the performances of bottomer cycle, imposing operating parameters of steam turbine and heat recovery boiler. Usually, these plant components are supplied by different manufacturers so the plant could not be globally optimized.

Considering a steam turbines manufacturer as GE Oil&Gas, a high level of components integration, is a chance to optimize globally the bottomer cycle, determining the best machine in terms of efficiency and improving plant productivity. This aim could be obtained through the development of a high level of combination between company simulation codes and energy balance codes.

In this paper, a two-pressure level combined cycle is examined and optimized. The best thermoeconomic configuration is obtained: first, imposing steam turbine efficiency and using literature costs correlations; then, acquiring the efficiency by a steam turbine industrial tool and considering real machines costs. Therefore, two distinct best configurations could be determined and compared.

1. Introduction

Nowadays, the continuing depletion of fossil fuels coupled together with emissions restrictions attributable to greenhouse gases, steers to reprocess wasted heat generated by power plants with the aim of enhance global efficiency. One of the technology employed for advancements is the combined cycle power plant. In a progressively competitive market, managed by profits, cutting costs for generating electricity is coming to be crucial, in order to ensure a fast return on investment, however without reducing the power plant reliability and flexibility. Currently, available power-generation combined-cycle plants achieve net plant thermal efficiency typically in the 50–55% LHV range. Further development of gas turbine, high-temperature materials and hot gas path cooling technology, show promise for near-term future power generation combined-cycle systems, capable of reaching 60% or greater plant thermal efficiency [1].

Often, an energy engineering company should define and to analyze the performances of bottomer steam cycle, imposing the operating parameters of the steam turbine and of the heat recovery boiler. Usually two or more distinct manufacturers fabricate these elements. Due to this, the plant could not be globally optimized, because the energy-balance designer can get the real steam turbine performance and cost only after the entire bottomer cycle is defined.

Considering a steam turbines manufacturer's point of view, as GE Oil&Gas, the integration between a property simulation code and an energy balance code is a chance to evaluate globally the bottomer cycle in order to determine the best plant configuration and to help the final customer to operate properly the plant.

Fig. 1 shows the stream cycle of the process followed to optimize the bottomer plant in the two cases: standard case, using literature costs correlations and a constant value for the efficiency of ST; the

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Nomenclature

A	Final section area, [m^2]
c	Cost, [M$]
COE	Cost of Energy, [$/MWh]
E	Energy, [kW]
m	Mass flow, [kg/s]
p	Pressure, [Pa]
T	Temperature, [K]
x	steam quality, [−]
W	Power, [kW]
η	Efficiency, [−]

Subscript

app	Approach
bott	Bottomer
CC	Combined Cycle
Cond	Condenser
eco	Economizer
eva	Evaporator
f	fuel
gas	gas
HP	High pressure
HRSG	Heat recovery steam generator
in	Inlet
inj	Injection
is	Isentropic
l	Liquid
lim	Limit
LP	Low pressure
LTE	Low Temperature Economizer
O&M	Operating and Maintenance
pp	Pinch Point
pump	Pump
sh	Superheater
ST	Steam turbine
stack	Stack
sub	Subcooling
TCR	Total Capital Requirement
tot	Total
v	Vapor

Acronyms

BOP	Balance of Plant
C	Compressor
CC	Combustion Chamber
CCGT	Combined Cycle Gas Turbine
COE	Cost of Energy
GT	Gas Turbine
HP	High Pressure
HRSG	Heat Recovery Steam Generator
LTE	Low Temperature Economizer
LP	Low Pressure
O&M	Operating and Maintenance Cost
SPRINT	Spray inter-cooled turbine
ST	Steam Turbine
T	Turbine/expander
TEC	Total Equipment Cost

case proposed in this paper, where real parameters of ST costs and efficiency are used.

In the standard case the process will stop at the first cycle, when the bottomer cycle is optimized from a thermodynamic point of view, without considering variation of efficiency and real models of ST. In the new case, first cycle is the same of the previous one, when first attempt of best plant configuration is found, combining the industrial tool with the energy balance code, a new configuration of ST is found. So, is possible to discover new best plant configurations.

A thermodynamic and economic analysis of combined cycle power plants was carried out by several authors [2–23]. Attala et al. [2] have developed a tool aimed at thermo-economic valuation and optimization of thermal power plants. Roosen et al. [3] considered the optimization of a combined cycle, proceeding with a strict direct cost assessment. Rao and Francuz [4] found and evaluated advanced improvements for combined cycle that will manage to get considerable performance improvements in coal based power systems. Carapellucci and Giordano [5] made a comparison between two different approaches for optimizing CCGTs. Zhu et al. [6] considered the effect of solar addition to describe the combination of solar thermal energy with a natural gas combined-cycle (NGCC) power plant. Tică et al. [7] showed a method to convert a CCGT physical model designed for simulations in an optimization-oriented model, which can be further used with efficient algorithms to improve start-up performances. Ganjehkaviri et al. [8]

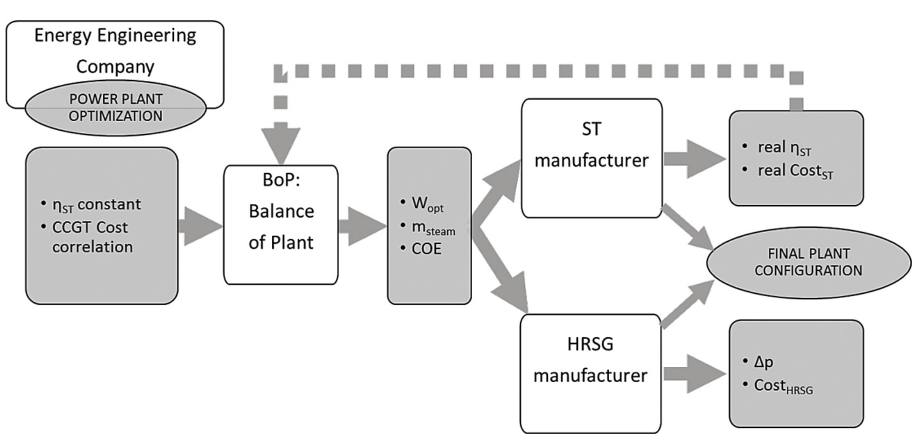

Fig. 1. Stream cycle of the two processes adopted (dashed line is new iterative procedure).