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Technological improvements in energetic efficiency and sustainability in existing combined-cycle gas turbine (CCGT) power plants

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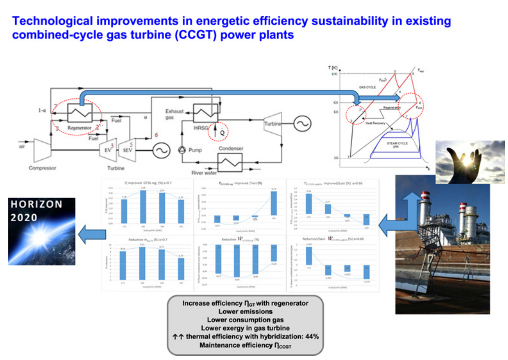
HIGHLIGHTS

- CCGT partially regenerative with solar hybridization maintences the global efficiency like CCGT.
- Recuperation effectiveness is fundamental factor calculation of the regenerator.
- Emissions-fuel consumption decrease considerably with partial regeneration.
- Thermal efficiency obtained in new CCGT hybridized is higher than conventional solar technology.

GRAPHICAL ABSTRACT



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ABSTRACT

Data from an existing combined-cycle gas turbine (CCGT) power plant are used to create a computer simulation to allow efficiency and emission calculations, simulation and assessing improvements that apply partial regeneration with solar hybridization. The proposed amendments to this triple-pressure steam-reheat combined cycle (CCC_{3PR}) with 400 MW of net power incorporates a regenerator and thermal energy, from a source of renewable solar energy up to 50 MW, in order to reduce the energy loss in the gas turbine. The calculation and simulation models were created using Visual Basic code. Regeneration and solar hybridization were found to contribute to increasing efficiencies of around 2.25% to 3.29% depending on the loading point. The reduction of gas consumption was between 6.25% and 9.45% and the overall cycle efficiency loss is minimal due to hybridization. There was a loss of the net power of the new cycle but it is considerably lower if than heat from a renewable source is supplied to the cycle. This net power loss has an average value of 7.5% with regeneration only and of 1% with regeneration and hybridization. The reduction of fuel consumption is significant which could result in saving approximately 4 million €/year. Partial regeneration in the gas turbine and solar thermal power in the existing CCGTs provide an interesting possibility for reducing emissions (by 26,167 t/year). In conclusion, partial regeneration with solar hybridization provides an interesting and proven possibility to increase performance and efficiency whilst reducing emissions from the existing CCC_{3PR}.

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Nomenclature

Symbols

APP	approach point, –
BP	low pressure, –
c_P	specific heat, kJ/(kg·K)
c	cost, €
dT	temperature difference, K
e	exergy, kJ/kg
h	enthalpy, kJ/kg
HP	high pressure, –
I_e	irreversibility, W
LEC	levelized cost, €
$\dot{m}$	mass flow, kg/s
$\dot{m}_a$	mass flow rair, kg/s
$\dot{m}_G$	mass flow exhaust gases, kg/s
$\dot{m}_{v,IP}$	mass flow steam IP, kg/s
$\dot{m}_{v,AP}$	mass flow steam AP, kg/s
$\dot{m}_{v,BP}$	mass flow steam BP, kg/s
$\dot{m}_r$	mass flow reheater steam, kg/s
$\dot{m}_{extrac.}$	mass flow extraction steam, kg/s
p	pressure, bar
LHV	lower heating value, kJ/kg
PP	pinch point, K
$\dot{Q}_gases$	mass flow exhaust gases, kg/s
r_c	compression ratio, –
s	entropy, kJ/(kg·K)
T	temperature, K
$TAT_{HP,BP}$	after turbine temperature, K
$TIT_{HP,BP}$	inlet turbine temperature, k
$T_{sal,\ BP,IP,AP}$	steam turbine temperature BP, IP, AP, K
ΔT	terminal difference temperatures, K
u	internal energy, kJ/kg
U	heat-transfer coefficient, $(W{\cdot}K^{-1}{\cdot}m^{-2})$
UA	UA factor, $(W{\cdot}\ K^{-1})$
$\dot{W}$	power,W

Greek letters

α	recuperative mass fraction, –
ε	effectiveness of the regenerator, –
ϒ	specific heat relation, –
η	efficiency, %
$\eta_{is,C}$	isentropic efficiency compressor, %
$\eta_{m,C}$	mechanic efficiency compressor, %
$\eta_{m,T}$	mechanic efficiency turbine, %
$\eta_{m,bombas}$	mechanic efficiency pumps, %
$\eta_{is,GT}$	isentropic efficiency compressor, %
$\eta_{m,GT}$	mechanic efficiency gas turbine, %
$\eta_{is,TV}$	isentropic efficiency steam turbine, %
$\eta_{m,TV}$	mechanic efficiency steam turbine, %
η_{cc}	efficiency combined cycle, %

Subscripts and acronyms

a	air
amb	ambient conditions
AP	high pressure level
atm	atmospheric pressure
BP	low pressure level
CCC	Combined cycle power plant
CCC_{3PR}	triple pressure HRSG with reheating
$CCC_{3PR,\ reg}$	CCC_{3PR} with regenerator
$CCC_{3PR,\ reg\&HS}$	$CCC_{3PR,\ reg}$ with solar hibridization
CCP	Parabolic cylindrical collector
CComb	combustion chamber
Comp	compressor
Cond.	condensator
CN	carnot factor
DSG	direct steam generation
in	inlet
ext	extraction steam turbine
exh	exhaust gases
ECO	economizer
EV	1ª combustor chamber GT
EVA	evaporator
f	fuel
F	dosing
FW	feedwater
gen	generator
G	gas
GT	gas turbine
GT26	gas turbine Alstom GT26
HTF	heat transfer fluid
HRSG	heat recovery steam generator
IP	intermediate pressure level
ISCC	integrated solar combined cycle
LFR	linear fresnel reflectors
out	out
P	pump
Rh	reheater
Ref	reference
reg	regenerator
sat	saturation
SC	steam cycle
SEV	2ª combustor chamber GT
SH	superheater
ST	steam turbine
TQ	tank
Turb	turbine
V	steam
VGV	variable geometry blades
0	reference conditions

1. Introduction

In the search of an efficient, economical and environmentally friendly energy, there is a clear shift towards renewable energy sources and decreasing emissions. This is an on-going process and the final solution has clearly not yet been reached [1,2].

Present day operating conditions of Combined-Cycle Gas Turbine (CCGT) power plants differ from the base load design conditions (approximately 400 MW), and therefore require performance studies and technological improvements at loading points others than the base load. This research considers practical improvements that can be made inside the existing CCGT plants operating in Spain and how these improvements can be implemented on the system operation conditions achieving emissions and fuel consumptions reductions and improving the system global efficiency. These changes will be in-line with Horizon 2020 directive [1–3]. It is necessary to include novelty improvements to give a response to these clean energy needs inside the existing CCGTs. In this aspect, the improvement of partial regeneration in gas turbine is possible. It is vital to advance research and development projects that deal with the emerging technologies that are needed to achieve these goals. Solar energy is another alternative, because it presents a great number of advanced technological options, such as the solar thermal