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ORIGINAL PAPER

Multi-objective optimization of steam power plants for sustainable generation of electricity

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Abstract A unified framework that combines process simulation and multi-objective optimization is presented to simultaneously maximize the annual profit, while minimizing environmental impact (i.e., greenhouse gas emissions) of steam power plants with fixed flowsheet structures. The proposed methodology includes the selection of suitable primary energy sources (i.e., fossil fuels, biomass, biofuels, and solar energy) for sustainable electricity generation. For solving the problem of optimal selection of energy sources, a linear model is developed and included within a highly nonlinear simulation model for the parameter optimization of steam power plants that is solved by using genetic algorithms. This approach is robust and avoids making discrete decisions. Life cycle assessment technique is used to quantify the greenhouse gas emissions resulting from different combinations of energy sources and operating conditions of the power plants. The thermodynamic properties for liquid water and steam are calculated rigorously using the IAPWS-IF 97 formulation. An example problem of an advanced regenerative-reheat steam power plant is presented to illustrate the proposed method, which provides the Pareto optimal solutions, the types and amounts of primary energy sources as well as the optimal values of the operating conditions of the plant that simultaneously maximize the profit while minimizing environmental impact.

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Keywords Steam power plants · Sustainable electricity generation · Renewable energy · Biofuels · Greenhouse gas emissions · Multi-objective optimization · Life cycle analysis · Solar energy

List of symbols

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bf	Biofuel
bm	Biomass
f	Fossil fuel
h	Heater
NU	Number of pieces of plant equipment
t	Turbine
u	Plant equipment

Parameters

$C_{\mathrm{bf}}^{\mathrm{Biofuel}}$	Unit operating cost for the biofuel bf
$C_{\mathrm{bm}}^{\mathrm{Biomass}}$	Unit operating cost for the biomass bm
C_{f}^{Fossil}	Unit operating cost for the fossil fuel f
C_{E}	Unit electricity cost
$C_{\mathrm{op}}^{\mathrm{Solar}}$	Annual operational cost for the solar collector
$\mathrm{Cu}^{\mathrm{Solar}}$	Unit operating cost for the solar collector
D_t	Seconds per month
f_{pw}	Factor equals to 1 for pressures until 1.03 MPa in cost function (A5)
$\mathrm{FC}^{\mathrm{Solar}}$	Fixed cost for the solar collector
H_{Y}	Operating hours for the plant per year
K_{F}	Factor used to annualize the capital costs
N_{pop}	Number of individuals
Q^{Solar}	Average heat supplied by the solar collector