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Multi-criteria optimization of an integrated energy system with thermoelectric generator, parabolic trough solar collector and electrolysis for hydrogen production

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ABSTRACT

In this research paper, a newly energy system consisting of parabolic trough solar collectors (PTSC) field, a thermoelectric generator (TEG), a Rankine cycle and a proton exchange membrane (PEM) is proposed. The integration is performed by establishing a TEG instead of the condenser as power generation and cooling unit thereafter surplus power output of the TEG is transferred to the PEM electrolyzer for hydrogen production. The integrated renewable energy system is comprehensively modeled and influence of the effective parameters is investigated on exergy and economic indicators through the parametric study to better understand the system performance. Engineering equation solver (EES) as a potential engineering tool is used to simulate the system and obtain the desired results. In order to optimize the system, a developed multi-objective genetic algorithm MATLAB code is applied to determine the optimum operating conditions of the system. Obtained results demonstrate that at optimum working condition from exergy viewpoint, exergy efficiency and total cost are 12.76% and 61.69 $/GJ, respectively. Multi-objective optimization results further show that the final optimal point which is well-balanced between exergy efficiency and total cost, has the maximum exergy efficiency of 13.29% and total cost of 63.96 $/GJ, respectively. The corresponding values for exergy efficiency and total cost are 10.01% and 60.21 $/GJ for optimum working condition from economic standpoint. Furthermore, hydrogen production at well-balanced operating condition would be 2.28 kg/h. Eventually, the results indicate that establishing the TEG unit instead of the condenser is a promising method to optimize the performance of the system and reduce total cost.

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Nomenclature

A	Area (m^2)
c	Specific exergy cost ($/GJ)
$\dot{C}$	Cost rate ($/h)
Cp	Specific heat (kJ/kg K)
D	Diameter (m)
$\dot{E}$	Exergy rate (kW)
$E_{act,i}$	Activation energy
f	Exergoeconomic factor
F	Faraday constant
F_1	Collector efficiency factor
F_R	Heat removal factor
ΔG	Gibbs free energy (kJ)
G	Solar radiation (kW/m^2)
h	Enthalpy (kJ/kg)
H	Enthalpy (kJ)
$h_{c,ca}$	Convection heat loss coefficient between surrounding and cover
$h_{r,ca}$	Radiation heat loss coefficient between surrounding and cover
$h_{r,cr}$	Radiation heat loss coefficient between reciever and cover
$h_{c,r,in}$	Convection heat loss coefficient between reciever and cover
i_r	Interest rate
J	Current density
$J_{0,i}$	Exchange current density
J_i^{ref}	Pre-exponential factor
l	Thickness
L	Collector length (m)
$\dot{m}$	Mass flow rate
$\dot{Q}$	Heat rate (kW)
R	Resistance
s	Specific entropy
S	Amount of heat collected
ΔT_{lm}	Mean logarithmic temperature
T	Temperature
U_0	Total heat transfer coefficient from the ambient to the working fluid
U_L	Overall heat loss coefficient
V	Voltage
V_0	Reversible potential
W	Collector width (m)
$\dot{W}$	Power (kW)
Z	Investment cost of the components
$\dot{Z}$	Investment cost rate of the components
ZT_M	Figure of merit

Subscripts

0	Dead state
1,2, …,15	State points
a	ambient
act,a	activation over potential of anode
act,c	activation over potential of cathode
ap	Aperture
an	anode
ca	cathode
c	cover
C_i	Cover inner
Co	Cover outer
$cond$	Condenser
$C.V$	Control volume
D	Destruction
ec	Economizer
$ELEGANT$	Efficient liquid based electricity generation apparatus
ev	Evaporator
F	Fuel
H	High
I	First law of thermodynamics
II	Second law of thermodynamics
in	inlet
k	k^{th} component
L	Low
M	Mean
ohm	Ohmic over potential of electrolyte
out	Outlet
p	Pump
P	Product
PEM	Proton exchange membrane
P,P	Pinch point
r	Receiver
r_i	Inlet receiver
r_o	Outlet reciever
r,av	Receiver average
SG	Steam generator
sup	Superheater
t	Turbine
TEG	Thermoelectric generator
tot	Total

Superscripts

CI	Capital investment
OM	Operating and maintenance
n	Operating years

Abbreviations

CETD	Cold end temperature difference
CRF	Capital recovery factor
EES	Engineering equation solver
HHV	Higher heating value
MOO	Multi-objective optimization
Nu	Nusselt number
ORC	Organic Rankine cycle
PTSC	Parabolic trough solar collector
PV	photovoltaic
TEG	Thermoelectric generator

Greek letters

η	Efficiency
β	Mirror reflectance
γ	Intercept factor
ξ	Cover transmittance

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