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Research Paper

Energy, exergy and exergoeconomic (3E) analyses and multi-objective optimization of a solar and geothermal based integrated energy system

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HIGHLIGHTS

- An integrated energy system with geothermal power plant, a PVT and a double-effect absorption chiller is proposed.
- Comprehensive Thermodynamic and exergoeconomic analysis is carried out and a multi-objective optimization is done.
- The optimized value of the overall exergy efficiency and the total product unit cost found to be 12.31% and 35$/GJ.
- The condenser of geothermal system is the major source of irreversibility with the exergy destruction of 32.95 kW.

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ABSTRACT

A complete renewable energy source based on a solar and a geothermal system is proposed to produce desired electricity and cooling. The proposed system consists of a concentrated PVT, a double-effect LiBr-H_2O absorption chiller and a geothermal unit. To better understand the system performance, energy, exergy and exergoeconomic analyses are investigated. The results show that recovering the waste heat of the geothermal unit increases the coefficient operation factor by about 15%. Second law analysis exhibits that one of the main parts of irreversibility occurs in the PVT with 29.6 kW. Results of exergoeconomic analysis show that in the second condenser and the cooling set, the exergy destruction cost has major effect on the component cost rate. In addition, the parametric study of major parameters (i.e., geothermal temperature, high pressure and low pressure turbine inlet pressure, PVT module's temperature and area) is performed thermodynamically and thermoeconomically. In addition, by considering the overall exergy efficiency and the total product unit cost as objective functions, a multi-objective optimization is implemented based on genetic algorithm. From the Pareto frontier diagram, the value of an optimal point for single and multi-objective optimization are determined. Obtained results show that at the optimal point where the overall exergy efficiency and total product unit cost are optimized, the corresponding values are 12.31% and 35 $/GJ, respectively. Scattered distribution of the major parameters reveals that the geothermal temperature is a very sensitive parameter which should be kept at its highest value (i.e., 245 °C).

1. Introduction

Climate change, global warming and greenhouse gases emission are the results of the extra use of fossil fuels. The alternative scenario is to use renewable energies such as solar, wind, biomass and geothermal which need more attentions and sensible policy from the governments. Recently, the Paris climate agreement has requested all the countries to reduce their carbon emission and substituting renewable energies as the major source of energy requirement [1]. According to the predictions provided by the world bank and International Energy Agency (IEA), for proving the next 40 years electrical power, the world needs twice installation capacity [2]. Due to this, more attention is needed to focus on and develop on all kind of renewable energy sources for reducing fossil fuel consumption. In this research work, a complete renewable cogeneration system consisting of the double flash geothermal power plant, a photovoltaic/thermal and a double-effect absorption cooling system is presented. To highlight the importance of using renewable energies for cogeneration systems, the literature survey on the problem is brought in

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Nomenclature

A_{ip}	the cross section area (m^2)
c	concentrated ratio
c	cost per unit exergy ($/GJ)
COP	coefficient of Performance
$\dot{C}$	cost rate ($/h)
C_P	specific heat capacity at constant pressure (kJ/kg K)
D	diameter (m)
D_{ip}	inlet pipe diameter (m)
E	exergy (kJ)
EV	expansion valve
$\dot{E}$	exergy rate (kW)
f	exergoeconomic factor
F	dilution Factor
G	direct solar radiation (kW/m^2)
h	specific enthalpy (kJ/kg)
i_r	interest rate
$\dot{m}$	mass flow rate (kg/s)
ORC	organic Rankin Cycle
P	pressure (kPa)/Power of PVT (kW)
PEM	proton exchange membrane
$\dot{Q}$	heating load (kW)
Q_{Conv}	heat convected to the atmosphere (kW)
Q_{PVT}	net incident concentrated solar radiation on the PV module (kW)
Q_{rad}	heat radiated to the atmosphere (kW)
Q_{Th}	heat absorbed by the PV cells (kW)
Q_{vs}	volumetric steam flow (m^3/s)
R	ideal gas constant (kJ/kg K)
s	specific entropy (kJ/kg·K)
T_{gl}	cover glass temperature (°C)
T_{ins}	insulation temperature (°C)
T_{PVT}	cell's temperature (°C)
T_{ref}	cell's reference temperature (°C)
T_{Sky}	sky temperature (°C)
T_{Sun}	the sun temperature (°C)
TIP	turbine inlet pressure (kPa)
u_{Wind}	Wind velocity (m/s)
V_T	terminal velocity (m/s)
$\dot{W}$	power (kW)
X_i	mole fraction of the ith component
Z	investment cost of components ($)
$\dot{Z}$	investment cost rate of component ($/h)

Subscript and abbreviations

0	dead state
a	atmosphere
1,2,3,…,26	state points
Abs	absorber
Ch	chemical
CI	capital investment
COND	condenser
COP	coefficient of performance
CS	cooling set
CRF	capital recovery factor
Dest	destruction
E.V	expansion valve
f	fuel
GA	genetic algorithm
HPG	high pressure generator
HPT	high pressure turbine
HTHEX	high temperature heat exchanger
i	inlet
L	loss
l	liquid
LPG	low pressure generator
LPT	low pressure turbine
LTHEX	low temperature heat exchanger
o	outlet
OM	operation and maintenance
ORC	organic Rankin cycle
PVT	photovoltaic/thermal
P	product
Ph	physical
Pm	pump
T	turbine
tot	total
RH	reheat exchanger
v	vapor
w	water

Greek symbols

η_{II}	exergy efficiency
η_I	energy efficiency
η_{inv}	inverter's efficiency
η_{is}	isentropic efficiency
η_{OPT}	optimal efficiency
η_{PVT}	module's efficiency of PVT
η_{Tref}	module's efficiency at reference time
ε_i	exergy efficiency of the ith component
ρ	density (kg/m^3)
τ	annual plant operation hours (h)
σ	Stefan-Boltzmann constant (kW/m^2 K)

following sections.

1.1. Photovoltaic/Thermal system

Among all kind of renewable energy resources, solar energy which is emanated from the sun is the most available and abundant source it is also one of the cleanest renewable energies. Solar energy technologies are divided into passive and active technology. The passive technology is when the solar heat is being used without changing the active form technologies on the other hand, is when the solar energy converts the originated heat and light of the sun into the electricity. Photovoltaic collectors (PV) are one of the examples of technology which converts heat and light of the sun into electricity. A better PV performance and higher efficiency can be obtained by the reduction of cells temperature [3]. To decrease the cell temperature Photovoltaic/Thermal (PVT) technology which is an active method for recovering waste heat for other consumption is used [4]. In order to evaluate the effect of cell temperature on the overall efficiencies and power, the performance of PV module with and without cooling water was investigated by Gaur and Tiwari [5]. They showed that the thermal efficiency with and without water is 7.36% and 6.85%, respectively and the daily average electrical power with and without cooling water is 32.5 W and 31 W, respectively. Notton et al. [6] concluded that the physical variables of the PV cell material, the module and the environment condition have a direct effect on the PV cell temperature and efficiency.