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Development and analysis of a solar and wind energy based multigeneration system

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Abstract

This paper concerns development and analysis of a solar-wind hybrid multigeneration system. Energy, exergy, exergoeconomic and exergoenvironmental analyses are performed. The analysis studies are undertaken by developing and constructing the codes in Engineering Equation Solver software. The effects of various input conditions on the system performance are investigated through both energy and exergy efficiencies, and an optimization study is undertaken of system efficiency and power output are obtained. The average number of Toronto suites that the system can supply is calculated. As a result, it is seen that energy and exergy efficiencies are higher than equivalent single energy systems. The system has 43% maximum energy efficiency and 65% maximum exergy efficiency. Maximum turbine output is 48 kW, while cooling effect is 28 kW and heating effect is 298.5 kW. There is resultant savings of 1614 tons of CO_2 per year by the system. This multigeneration system is capable of supplying at least at a minimum 49 suites.

Keywords: Solar energy; Wind energy; Hybrid; Absorption chiller; Rankine cycle; Renewable energy

1. Introduction

Renewable energy sources (solar, wind, etc.) are attracting more attention as alternative energy sources to conventional fossil fuel energy sources. This is not only due to the diminishing fuel sources, but also due to environmental pollution and global warming problems (El-Shatter et al., 2002). Renewable energy sources are the only clean and continuous energy solution to satisfy current and future requirements. A system that can utilize more than three sources is called a multigeneration energy system. The efficiency of multigeneration systems are higher than the combined efficiency of separate units. Multigeneration systems that use renewable sources combine the power of clean energy with high efficiency. Moreover, they help to supply different needs of a public unit such as a multi-suite building or a neighborhood.

One of the main challenges in this subject is the lack of study, especially a totally renewable based multigeneration energy system to produce electricity, cooling, heating, hot water and hydrogen simultaneously. This has made the proposed system quite interesting. Efforts to develop more efficient multienergy systems, attracts many researchers.

Another challenge is the scheduling and modeling of the sources, solar and wind in this case. Solar energy is not constant, the intensity changes during the day and throughout the year. There is no sun at all at night. Moreover, neither wind presence nor wind speed is a factor that can be guaranteed. The problem can be simplified by making some assumptions such as taking the average solar intensity and wind speed.

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Nomenclature

A	area, m^2
c	specific heat, kJ/kgK
C	power coefficient
D	diameter, m
$\dot{E}_x$	exergy rate, kW
F	view factor
F'	collector efficiency factor
g	gravitational acceleration, 9.81 m/s^2
G	solar radiation rate, W/m^2
h	specific enthalpy, kJ/kg; heat transfer coefficient, W/m^2 K
k	conductivity of the absorber tube material, W/m K
L	length, m
m	mass, kg
$\dot{m}$	mass flow rate, kg/s
P	pressure, kPa
Q	heat, kJ
$\dot{Q}$	heat transfer rate, kW
s	specific entropy, kJ/kg
S	absorbed solar radiation per unit aperture area, W/m^2
$\dot{S}$	entropy rate, kW
t	time, s
T	temperature, K
U	heat transfer coefficient, W/m^2 K
V	velocity, m/s
W	work, kJ; width, m
$\dot{W}$	work rate, kW
z	elevation, m

Subscripts

abs	absorption
ap	aperture
con	condenser
cs	cold storage
cv	control volume
d	destructed
dwh	domestic water heater
e	exit stream
en	energy
eva	evaporator
ex	exergy
exp	expander
gen	generator
hs	hot storage
hx	heat exchanger
i	inlet
L	overall
p	pump; pressure
Q	heat
r	receiver; Rankine
rc	ammonia–water Rankine cycle
sc	solar cycle; solar collector
t	tube
ts	thermal storage
u	unshaded; useful
w	wind; water
wt	wind turbine
0	ambient or reference condition
1…70	state numbers

Greek letters

α	absorptivity
η	efficiency
ξ	insulation thickness, m
ρ	density, kg/m^3; specular reflectance of the concentrator
τ	effect of angle of incidence

Acronyms

COP	coefficient of performance
EES	Engineering Equation Solver
ORC	Organic Rankine Cycle
PR	pump pressure ratio
PV	photovoltaic

The amount of solar energy that reaches earth's upper atmosphere is about 1350 W/m^2. The atmosphere reflects, scatters and absorbs some of the energy. In Canada, depending on sky conditions, peak solar intensity varies from about 900 W/m^2 to 1050 W/m^2. Peak solar intensity is at solar noon, when the sun is due south (Cengel et al., 2011). The amount of the sun's energy reaching the surface of the earth also depends on cloud cover, air pollution, location and the time of year. An active solar system uses mechanical equipment to collect, store and distribute heat from the sun. Active systems consist of solar collectors, a storage medium and a distribution system. Active solar systems are commonly used for; water heating, space conditioning, producing electricity, processing heat and solar mechanical energy.

When higher temperatures are required, concentrated solar collectors are used. Solar energy falling on a large reflective surface is reflected onto a smaller area before it is converted into heat. This is done so that the surface absorbing the concentrated energy is smaller than the surface capturing the energy and as a result can attain higher temperatures before heat loss due to radiation and the convection wastes of the energy that has been collected (Pavlas et al., 2006).