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ScienceDirect

Solar Energy 107 (2014) 728–745

SOLAR ENERGY

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Development and analysis of a new integrated solar-wind-geothermal energy system

S. Ghosh *, I. Dincer

Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario L1H 7K4, Canada

Received 9 February 2014; received in revised form 3 June 2014; accepted 5 June 2014

Communicated by: Associate Editor Mukund R. Patel

Abstract

A new integrated system, which combines three renewable energy sources and generates five different commodities as useful outputs, is proposed and analyzed energetically and exergetically. The mass, energy, entropy and exergy balance equations for the major components of the integrated system are written and analyzed. The energy and exergy efficiencies for the integrated system and its subsystems are defined and calculated. Parametric studies are conducted by varying dead state properties and operating conditions to investigate their effects on the system performance. Some meteorological and system data from various previous studies are used in the analyses and assessments. The results show that the energy and exergy efficiencies of the integrated system become 36.67% and 25.075% respectively.

Keywords: Solar; Wind; Geothermal; Energy; Exergy; Efficiency

1. Introduction

Energy is critically important for the survival and growth of humanity and hence becomes a center of dispute in global politics, economy, environment, military alertness, etc. To reduce the impact of conventional energy sources on the environment, much attention should be paid to the development of renewable energy resources. Therefore, the demand for the use of renewable energy sources to its maximum potential has been one of major efforts in the past decades.

Solar energy is recognized as not only renewable but also environment friendly. Hence, it is treated as a most sustainable and most powerful source. The common agreement is that the most significant renewable-based replacement for fossil fuels is solar energy. However, it brings some challenges due to its fluctuating nature depending on the daytime and location. Such as fluctuation in its potential is an issue and needs potential solutions (Al-Sulaiman et al., 2011).

Similar kind of energy source to the sun is the wind. Wind energy researches on its applications and effects have briskly amplified in the world, so efficiency of wind energy constructions is getting significance. Theoretically, maximum benefit is from 59.2% blowing wind according to the Betz Criteria. Today, available wind energy ratio reaches about on average 40–45% in modern wind turbine types. In order to extract the maximum possible power, it is important that the blades of small wind turbines start rotating at the lowest possible wind speed (Dincer and Zamfirescu, 2011).

* Corresponding author. Tel.: +1 6477707799.
E-mail addresses: sayantan.ghosh@uoit.ca (S. Ghosh), ibrahim.dincer@uoit.ca (I. Dincer).

http://dx.doi.org/10.1016/j.solener.2014.06.006
0038-092X/

Nomenclature

$\dot{E}$	exergy rate (kW)
ex	specific exergy (kJ/kg)
$\dot{E}xD$	exergy destruction rate (kW)
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (P)
$\dot{Q}$	heat rate (kW)
R	Reynolds Number
s	specific entropy (kJ/kg K)
T	temperature (K)
V	velocity (m/s)
$\dot{W}$	work rate (kW)
X	concentration (kg/m^3)

Greek letters

η	energy efficiency
ψ	exergy efficiency
ω	humidity ratio (kg$_{water}$/kg$_{air}$)
ρ	density (kg/m^3)
w	salinity

Subscripts

act	actual
G	generator
Geo	geothermal
L	absorber
LPT	low pressure turbine
min	minimum
P	pump
RC	Rankine cycle

Acronyms

COP_{en}	coefficient of performance
COP_{ex}	exergy coefficient of performance
n	number of moles
RC	Rankine cycle
ppm	parts per million
RO	reverse osmosis
SPM	suspended particulate matter
RSPM	respirable particulate matter

Dincer and Rosen (2013) stated the relationships between energy and exergy, exergy and the environment, energy and sustainable development, and energy policy making and exergy in detail. Exergy analysis (or second law analysis) has proven to be a powerful tool in thermodynamic analyses of energy systems. In other words, it has been widely used in the design, simulation and performance evaluation of energy systems. Exergy analysis method is employed to detect and to evaluate quantitatively the causes of the thermodynamic imperfection of the process under consideration. Therefore, it can indicate the possibilities of thermodynamic improvement of the process under consideration. However, only an economic analysis can decide the expediency of a possible improvement. The concepts of exergy, available energy, and availability are fundamentally alike. The concepts of exergy destruction, exergy consumption, irreversibility, and lost work are also essentially similar. Exergy is a measure of the maximum useful work that can be done by a system interacting with an environment which is at a constant pressure P_0 and a temperature T_0 (Koroneos et al., 2003).

A number of single and integrated systems has been analyzed by many researchers. Ozgener (2010) made use of solar assisted geothermal heat pump and small wind turbine systems for heating agricultural and residential buildings. Popovski et al. (1992) proposed a geothermal Rice drying unit in Kotchany. Romero-Ternero et al. (2005) did thermoeconomic analysis of a wind powered seawater reverse osmosis desalination in the Canary Island. Fadigas and Dias (2009) did desalination of water by reverse osmosis using gravitational potential energy and wind energy. Dincer and Sahin (2004) proposed a new model for thermodynamic analysis of a drying process. In this paper, the exergy efficiencies are derived as a function of heat and mass transfer parameters using an illustrative example. Dincer et al. (2006) also performed the thermodynamic analysis of wind energy. In this paper, parameters that affect the wind turbine efficiency for electrigeneration is considered, for instance the air temperature and wind chill effect. Singh et al. (2000) performed the exergy analysis of a solar thermal power system. In this paper, basic energy and exergy analysis for the Rankine heat engine was done energetically and exergetically. Rashad and El Maihy (2009) and Kaushik et al. (2011) also performed energy and exergy analyses of a steam power plant in Egypt. This shows that a lot a work has been done with respect to utilization of these renewable resources individually for special applications. However, no study is reported in the open literature, focussing on integrating three most valuable renewable resources, namely, solar, wind and geothermal energy for an integrated system for multi outputs. The present aims to achieve this. Therefore, the specific objectives of this study are stated as follows:

- To develop and analyse a new integrated system using these three renewable sources which can simultaneously produce multi outputs.
- To determine and calculate energy losses and exergy destruction at all major components.