Techno-economic assessment of a solar-geothermal multigeneration system for buildings

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Abstract

A techno-economic assessment is conducted for a multigeneration system comprised of two renewable energy subsystems—geothermal and solar—to supply electrical power, cooling, heating, hydrogen and hot water for buildings. The proposed system is evaluated in terms of energy and exergy efficiencies. The simulation results show that the electrolyzer produces 2.7 kg/h hydrogen. A parametric study is carried out to assess the effect of various parameters on the system energy and exergy efficiencies. The economic assessment, performed using the Hybrid Optimization of Multiple Energy Resources (HOMER) software, shows that the net present cost of the optimized electrical power system is $476,000 and the levelized cost of electricity is $0.089/kWh.

Introduction

The increase in energy demand for buildings in many countries and the extensive use of fossil fuels to meet this demand poses many challenges. Efforts are made as a consequence to find more sustainable options for building energy systems. The use of renewable energy and multigeneration systems can assist these efforts. Solar energy is one of the most abundant form of renewable energy available in the nature energy, but it is intermittent. This can in some cases be overcome by integrating it with other renewable energy resources such as geothermal [1–7].

Recently, much research has been reported on the integration of different renewable energy sources. Calise et al. [8] investigate a geothermal and solar based system for producing energy and water. They found that the share for geothermal energy is more prominent than that for solar for their plant supply, as the geothermal source is mostly constant throughout the year for the location considered. Chauhan and Saini [9] examine an integrated renewable energy system for a community, considering nine combinations of renewable energy sources. Ayub et al. [10] demonstrate that a system comprising of solar and geothermal is more economic than solar or geothermal energy alone. Ghasemi et al. [11] show that a hybrid system consisting of solar and geothermal energy is
more efficient than solar or geothermal systems alone. Sule-
man et al. [12] investigate a multigeneration system based on
solar and geothermal sources comprised of two organic
Rankine cycles for electricity and an absorption chiller for
cooling. Through energy and exergy analyses of a multi-
generation system based on solar and geothermal resources,
Ali and Dincer [13] find that the maximum exergy destruction
occurs in the solar collector system. Through an analysis of a
hybrid system using geothermal and solar energy, Zhou et al.
[14] show that the hybrid system can be more efficient on both
energy and exergy bases, and that a 20% reduction in elec-
tricity production cost is possible when the hybrid system is
used instead of a standalone geothermal system. Tempesti
et al. [15] study two micro combined heat and power systems
using organic Rankine cycles based on geothermal and solar
energy, and find that highest exergy destruction occurs in the
parabolic trough collector. Bakos and Tsgas [16] study a sys-
tem comprised of various renewable energy sources for a
house in Greece, while Etamaly [17] examine economically a
renewable energy based hybrid energy system and conclude
that the cost of electricity generation from these systems de-
dpends on such factors as solar irradiation and load profile.
Khalid et al. [18] conducted a thermo-economic assessment of
a solar and biomass based integrated system and concluded that
the integrated system is more advantageous in terms of effi-
ciency and economics compared to a system operating on
single source of energy. The above studies demonstrate that
combining solar with other renewable energy forms such as
geothermal can be advantageous.

In the present study a new hybrid system based on
geothermal and solar energy is proposed, developed and
assessed. The specific objectives of the present study are
provided as follows:

- To develop a new hybrid system based on solar and
geothermal energy for a building, in order to provide mul-
tiple useful outputs such as cooling, electric power, heat-
ing, hydrogen and hot water.
- To perform energy and exergy analyses of the system.
- To carry out a parametric study to determine the effects of
such parameters as ambient temperature on the energy
and exergy efficiencies of the overall system.
- To perform a cost assessment of the electric power system
in terms of levelized cost of electricity and net present

**System description**

A hybrid multigeneration system based on solar and
geothermal energy for a building is developed. The system is
designed to provide electricity, hot water, heating, hydrogen
and cooling. The developed system consists of a parabolic
trough (a type of concentrated solar power (CSP)) collector, a
geothermal source, three Rankine cycles, and an absorption
chiller (see Fig. 1). Duratherm A oil at state 13 enters the solar
collector and, after being heated, exits at state 14. The oil then
enters heat exchanger 2, which also acts as a storage tank and
is utilized in heating the water that enters the storage
tank at state 20 to provide the energy requirement of Rankine
cycle 1.

The oil is then passes to heat exchanger 3 which is used to
heat stream 35 (water) to stream 23 to drive high pressure
steam turbine 2 (HPST 2) in Rankine cycle 2. The heat is
transferred from the hot oil at state 16 to the generator of the
absorption chiller and the oil leaves the generator at state 13
and is pumped back again to the solar collector. Stream 17
(water) enters high pressure turbine 1 (HPST 1) to generate
electricity. A portion of electricity produce by HPST 1 is used to
produce hydrogen by water electrolysis, and which is utilized
later via a fuel cell to produce power (denoted by dashed lines).
After leaving HPST 1, stream 18 is sent to condenser 2. Stream
19 passes through a pump and is returned to heat exchanger 2
in order to be heated by the oil. The stream leaving heat
exchanger 3 (23) is sent to HPST 2 to produce electricity. After
HPST 2, stream 24 is sent to condenser 3, which provides hot
water for the community. The stream leaving condenser is
directed to the reinjection well. The stream from the
geothermal production well (29) is sent to a flash chamber
(FC 1) which is then passed to separator 1 where it is separated
into two streams (31 and 36). Stream 31 (vapor) enters high
pressure steam turbine 3 (HPST 3) and then the mixing
chamber. Stream 36 (water) is further flashed in flash chamber
(FC 2) and then separated in separator 2 and the liquid
portion (stream 39) is directly sent to the reinjection well. The
vapor from the second separator (stream 38) is sent to a low
pressure steam turbine (LPST), from which the exit stream is
conveyed to the mixing chamber along with stream 32. The
outlet of the mixing chamber is condensed and pumped to
heat exchanger 3 in order to be heated and used in high
pressure turbine 2.

**Analysis**

General mass, energy, entropy, and exergy balance equations,
respectively, for the system in Fig. 1 can be written as follows:

\[ \sum_{i} \dot{m}_{i} - \sum_{e} \dot{m}_{e} = \frac{dm_{cv}}{dt} \quad (1) \]

\[ Q - W + \sum_{i} \dot{m}_{i} \left( h_{i} + \frac{v_{i}^{2}}{2} + gZ_{i} \right) - \sum_{e} \dot{m}_{e} \left( h_{e} + \frac{v_{e}^{2}}{2} + gZ_{e} \right) = \frac{dE_{cv}}{dt} \quad (2) \]

\[ \sum_{i} \dot{m}_{i} s_{i} + \sum_{k} \frac{Q_{k}}{T_{k}} - \sum_{i} \dot{m}_{a} s_{a} + S_{gen} = \frac{dS_{cv}}{dt} \quad (3) \]

\[ E_{X_{Q}} + \sum_{i} \dot{m}_{i} (e_{x_{i}}) - \sum_{e} \dot{m}_{e} (e_{x_{e}}) - E_{X_{Q}} - E_{X_{A}} = \frac{dE_{X_{cv}}}{dt} \quad (4) \]

Energy efficiencies can be defined for the system consid-
ered here as the ratio of useful energy output to total energy
input. The energy efficiencies are defined here for Rankine
Cycle 1, the absorption chiller and the overall system as pre-
sented below.
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