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Modeling and optimal resources allocation of a novel tri-distributed generation system based on sustainable energy resources

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ABSTRACT

Tri-generation systems with the aim of recycling heat dissipation of equipment and importing the heat into the energy production cycle have been considered by researchers recently because of increasing energy efficiency and decreasing environmental pollution. Many studies have been done in the field of tri-generation systems, but the studies have been more focused on centralized energy sources, such as, steam and gas turbines. Thus, required researches to move the sources of tri-generation systems toward renewable energy resources are not perfect enough. Moreover, the type of operation strategy, which is one of the important issues in investigating tri-generation system, is usually depended on assistant resources, such as, local power grid. In this paper, a novel tri-generation system based on wind and solar renewable energy resources and natural gas as the system prime movers is evaluated. Furthermore, a different operation strategy is considered to minimize the need to auxiliary sources and so the ability to use the system in remote regions, independently. Hence, wind turbines, photovoltaic (PV) modules, and solid oxide fuel cells (SOFCs) are considered as prime movers of the system. Moreover, a battery bank and heat storage tanks (HSTs) are deployed to balance the fluctuations in produced energy by wind and solar renewable resources. Hence, thermal demand management (TDM) and electrical demand management (EDM) operation strategies are considered simultaneously and defined as two possible functions to achieve a system with the ability to operate independently. In order to obtain the optimized solutions for each system component, a genetic optimization algorithm is applied to solve a resources allocation problem. The possibility of implementation in distant regions, considerable reduction in fuel consumption and pollution are the advantages of the proposed system. The numerical results demonstrate that the fossil fuels consumption and the pollution, respectively, are reduced up to 154 and 207 times more than common separated production (SP) systems. Moreover, power grid and other auxiliary systems requirements are reduced to less than 1%.

1. Introduction

Traditional energy production systems provide electrical, cooling and heating energies individually. These systems have high heat losses, low energy production efficiency, high pollution, and cause irreparable consequences of environmental damage. With the aim of eliminating the problems of separated energy production systems, especially environmental concerns, tri-generation systems recycle heat losses to provide other forms of energies, simultaneously. Extensive researches have been done to improve the performance of tri-generation systems. The type of prime mover is one of the most important subjects which has been studied by researchers. Zeng et al. [1] studied a tri-generation system based on a gas engine and ground source heat pump (GSHP) system. They provided power demand using the gas engine and power grid. Heating and cooling demands were produced by recovering heat losses of the engine and the heat pumped from the ground heat source. The Tri-generation system proposed by Acikkalp et al. [2] considered a diesel-gas engine as the prime mover. The power output of the engine provided the power demand and the recycled heat dissipation produced heat and cold energy demands. Sanaye et al. [3] proposed a tri-generation system based on a gas engine. The gas engine with the help of a power grid satisfied power demand, and heat losses of the engine was recovered and used beside a boiler to provide heat and clod demands. Solar renewable energy was applied to a tri-generation system by

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Nomenclature

CCHP	combined cooling, heating and power
SP	separated production
SOFC	solid oxide fuel cell
ICE	internal combustion engine
MGT	micro gas turbine
HST	heat storage tank
HRS	heat recovery system
HC	heating coil
PGU	power generation unit
HTF	heat transfer fluid
COP	coefficient of performance
ATC	annual total cost
CC	capital cost
OMC	operation and maintenance cost
RC	replacement cost
FC	fuel cost
UC	unit cost
PEC	primary energy consumption
SOC	state of charge
EDM	electrical demand management
TDM	thermal demand management
FEL	following electric load
FTL	following thermal load
VER	variable electric cooling ratio
CER	constant electric cooling ratio
FHL	following hybrid load
TSS	thermal storage strategy
DG	diesel generator
Cap	capacity

Symbols

P	power
A	area
ρ	density
v	speed
C	coefficient
η	efficiency
h	height
α	wind shear exponent
I	current
E	solar radiation
T	temperature
e_0	electron charge
a_f	ideality factor
N_s	number of series cell
K	Boltzmann's constant
V	tank volume
R	resistance
E_r	Nernst voltage
MC_P	thermal capacity
τ_t	time constant
σ	self-discharge rate
C	capacity
R	capital recovery factor
i	interest rate
n	system lifetime
f	inflation rate
UC	unit cost
C	specific heat
Q	heat
U	voltage

Subscripts

W	wind
m	mechanical
g	gear
ph	photocurrent
d	diode
s	series
sh	shunt
j	junction
a	ambient
op	normal operation
sat	saturation
g	gap
stack	stack of fuel cell
cell	cell of fuel cell
polarization	polarization losses
act	activation losses
ohm	ohmic losses
con	concentration losses
an	anode
ca	cathode
R	universal gas constant
e	electron
n	number
P	partial pressure
I	current density
bat	battery
PV	photovoltaic panel
WT	wind turbine
n	nominal
w	water
C	cold
H	heat
d	demand
Ch	chiller
Ech	electrical chiller

Rodriguez et al. [4]. Prime movers of the system were included solar thermal collectors and PV panels beside an internal combustion engine (ICE). Electrical demand was provided by PV panels and the ICE. Moreover, the produced heat of solar collectors and the engine heat exhaust were used to produce hot water, heating and cooling demands. Ebrahimi and Keshavarz [5] investigated an ICE and a solar collector as the prime movers to produce power, heat and cold demands. The electrical energy was produced by the engine and the thermal energy to satisfy heating and cooling demands was provided by the heat recovery of the engine and the heat produced in solar collector. Prime mover of a tri-generation system proposed by Farahnak et al. [6] was included an ICE. Thus, power demand was produced by ICE and thermal demand for satisfying heating and cooling requirements was provided by a boiler and the heat recovery of ICE. Fong and Lee investigated a tri-generation system based on ICE as the prime mover [7]. Their system provided power demand by the generator of ICE and heating and cooling demands by the recovery of ICE heat losses.

The performance of tri-generation and cogeneration systems based on a micro gas turbine (MGT) was investigated By Basrawi et al. [8]. The power demand of both systems was provided by MGT. The recovered heat from MGT was used to satisfy heating demand in the cogeneration system. But in tri-generation systems,