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Modeling a novel CCHP system including solar and wind renewable energy resources and sizing by a CC-MOPSO algorithm

Saman Soheyli [a], Mohamad Hossein Shafiei Mayam [b,*], Mehri Mehrjoo [c]

[a] Department of Mechanical Engineering, Sistan and Baluchestan University, Zahedan, Iran
[b] Department of Mechanical Engineering, Bozorgmehr University of Qaenat, Qaen, Iran
[c] Department of Telecommunications Engineering, Sistan and Baluchestan University, Zahedan, Iran

HIGHLIGHTS

- Considering renewable energy resources as the main prime movers in CCHP systems.
- Simultaneous application of FEL and FTL by optimizing two probability functions.
- Simultaneous optimization the equipment and penalty factors by CC-MOPSO algorithm.
- Reducing fuel consumption and pollution up to 263 and 353 times, respectively.

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ABSTRACT

Due to problems, such as, heat losses of equipment, low energy efficiency, increasing pollution and the fossil fuels consumption, combined cooling, heating, and power (CCHP) systems have attracted lots of attention during the last decade. In this paper, for minimizing fossil fuel consumption and pollution, a novel CCHP system including photovoltaic (PV) modules, wind turbines, and solid oxide fuel cells (SOFC) as the prime movers is considered. Moreover, in order to minimize the excess electrical and heat energy production of the CCHP system and so reducing the need for the local power grid and any auxiliary heat production system, following electrical load (FEL) and following thermal load (FTL) operation strategies are considered, simultaneously. In order to determine the optimal number of each system component and also set the penalty factors in the used penalty function, a co-constrained multi objective particle swarm optimization (CC-MOPSO) algorithm is applied. Utilization of the renewable energy resources, the annual total cost (ATC) and the CCHP system area are considered as the objective functions. It also includes constraints such as, loss of power supply probability (LPSP), loss of heat supply probability (LHSP), state of battery charge (SOC), and the number of each CCHP component. A hypothetical hotel in Kermanshah, Iran is conducted to verify the feasibility of the proposed system. 10 wind turbines, 430 PV modules, 11 SOFCs, 106 batteries and 2 heat storage tanks (HST) are numerical results for the spring as the best season in terms of decreasing cost and fuel consumption. Comparing the results of the system with a common separated production (SP) system shows that the fossil fuels consumption and the pollution can be reduced up to 263 and 353 times, respectively.

1. Introduction

Purchasing the electricity from a local grid, burning the fuel by a boiler and, using the electrical chiller, are a common way to provide electricity, heat and cold demands, respectively. During the last decade, the combined cooling, heating and power (CCHP) systems have attracted lots of attention due to decrease heat losses and pollution and increasing energy efficiency. The CCHP system simultaneously generates the power demand by using power generation prime movers and satisfies the heating and cooling demand by recovering heat losses of equipment.

CCHP systems can be deployed in the range of 1 kW to more than 500 MW and are mainly classified into two groups: First, traditional large-scale CCHP systems that are exerted in power plants and large industries, and second, distributed CCHP systems that are used in the commercial, institutional, residential and small industrial sections. CCHP systems are managed by either electrical or

* Corresponding author.
E-mail address: shafiei@buqaen.ac.ir (M.H. Shafiei Mayam).

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Nomenclature

ATC	annual total cost
C	cost
CB	constrained binary
CCHP	combined cooling, heating and power
COP	coefficient of performance
FEL	following electric load
FTL	following thermal load
HRS	heat recovery system
HTF	heat transfer fluid
PGU	power generation unit
PSO	particle swarm optimization
PV	photovoltaic
SOC	state of charge
SOFC	solid oxide fuel cell
SP	separated production
WT	wind turbine

Symbols

A	area
C	acceleration coefficient
C	specific heat/capacity
e_0	electron charge
E	solar radiation
E_r	Nernst voltage
f	probability distribution function/inflation rate
h	height/penalty factor
H	penalty value
i	interest rate
I	current
k	Weibull's shape parameter
K	Boltzmann's constant
MC_P	thermal capacity
N	system lifetime
N_s	number of series cell
P	power
p_i	best personal position
p_g	best particle of swarm
Q	heat
r	random number
R	capital recovery factor/universal gas constant
T	temperature
U	voltage
v	speed
V	tank volume
W	inertia factor
x	position of a particle

Greek symbols

α	wind shear exponent
a_f	ideality factor
γ	power of the penalty function
η	efficiency
ρ	density
σ	self-discharge rate
τ_t	time constant

Subscripts

a	ambient
Act	activation losses
An	anode
Bat	battery
C	cold
Ca	cathode
Ch	chiller
Con	concentration losses
d	diode/demand
e	electron
Ech	electrical chiller
g	gear/gap
h	heat
Hc	heating coil
J	junction
M	mechanical
N	number/nominal
Ohm	ohmic losses
Op	normal operation
P	partial pressure
Ph	photocurrent
Polar	polarization losses
S	series
Sat	saturation
Sh	shunt
U	unit
w	wind

thermal demand operation strategies. In the following electrical load (FEL) strategy, all power demands must be satisfied by the power generation unit (PGU). Hence, lack of the heat is provided by thermal equipment such as a boiler. In the following thermal load (FTL) strategy, the recovered heat losses must always be equal to the heat that is needed to provide the heating and cooling demands. Hence, lack of the power is usually provided by the local power grid.

Extensive studies were down to meet the energy demands at the site of consumption or close to it which are called distribution generation (DG) systems. A large part of these studies is related to the power DG systems that only focused on power generation. Ren et al. [1] developed a distributed generation systems including photovoltaic, fuel cell, and gas turbine with economic and environmental goals. According to results, the costs and environmental function are interdependent and negatively correlated. Hence, increasing the use of distributed system and so less emission CO_2, leads to increased costs. Finally, the compromise programming method was used to select the best solution from the set of possibly optimal solutions. Huneke et al. [2] considered a hybrid power system including photovoltaic array, wind turbine, diesel generator, and battery. They optimized the system by using linear programming method and developed it as an off-grid system. Their results illustrated the use of renewable energy resources in combination with batteries is effective to reduce the cost of energy compared to stand-alone diesel generator sets. It is because the PV and wind energy systems can use from batteries and costs can be shared. A set of wind turbine, PV module, fuel cell, and battery was designed as a hybrid power plant by Cozzolino et al. [3]. Sizing the system components was down by HOMER software and Matlab/Simulink was used for simulations and power management strategy design. Although wind and solar energy resources were used as the main components of the power generation system but they were utilized 10.2% and 15.9%, respectively. Hence, the diesel engine as an auxiliary system must be sometimes turned on to satisfy the power demand. A hybrid generation system comprising PV panels, wind turbines, batteries, and diesel generator was proposed and optimized by Suchitra et al. [4]. They applied a