Desalination xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Design and optimization of autonomous solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage by an improved bee algorithm

Akbar Maleki

Department of Renewable Energies, Faculty of New Science & Technologies, University of Tehran, Tehran, Iran

ARTICLE INFO

Keywords:
Grid independent hybrid renewable energy systems
Reverse osmosis desalination
Battery storage
Hydrogen storage
Optimization
Improved bees algorithm

ABSTRACT

Most of the global population are not connected to the electrical grid and one third of these people have no access to potable water sources at the same time. Grid independent hybrid renewable energy systems (GIHRES), specifically wind and solar power, have attracted more attention to supply potable water and electricity requirements. Due to the complexity of this system, optimal balance between wind and solar resources and a convenient storage needs special attention to find a good engineering solution. In this paper for increasing the fresh water availability and to meet the load demand six GIHRES namely solar/battery or/hydrogen/reverse osmosis desalination (ROD), wind/battery or/hydrogen/ROD, and solar/wind/battery or/hydrogen/ROD are designed and modeled. For optimal design of these six systems improved bees algorithm is proposed. The results are compared with the results obtained by harmony search algorithm. From the results it is seen that the GIHRES-based battery energy storage more cost-effective than the GIHRES-based hydrogen energy storage. Also, hybridization of solar power, battery, and ROD at various maximum loss of power supply probability is the most cost-effective energy system. Moreover, the results obtained by proposed method are quite promising.

1. Introduction

Energy and fresh water are necessary for well-being of mankind [1]. However, 10.6% of the global population lacks access to fresh water and 18% of the global population lacks access to electricity [2]. The majority of this population lives in remote area, with wind and/or solar energy potential. Additionally, according to freshwater scarcity, increasing population growth, and also concerns about climate change, the world is facing a great problem for meeting the current needs and the needs of future generations for energy and fresh water [3]. Nowadays the implementation of reverse osmosis desalination (ROD) plants powered by renewable energy technologies such as wind turbines (WT) and photovoltaics (PV) offers a promising technology for providing drinking water [4–7]. However, due to the wind speed and the sun irradiance as uncontrollable parameters, an energy storage system or in other words a convenient storage system is quite necessary.

Reverse osmosis desalination using numerous energy supply combinations have been reported, sometimes using wind energy [8] and solar energy [9,10] (renewable energy) [11–14] and other hybrid energy systems [15,16]. Nevertheless, various systems used for driving RO desalination units have been reported in Table 1.

However, ROD systems powered by hybrid renewable energy systems such as wind and solar energy offer a promising option for many remote areas [27–30], but these systems needs a backup power supply for periods when the demand is high and sunlight and wind speed are not accessible. If these hybrid systems are optimized, they can be more reliable and cost-effective. In other words, compared to an only system, optimal sizing of grid independent hybrid renewable energy systems (GIHRES)-based ROD not only decreases the environmental emissions but also increases the reliability of the system and decreases the costs. Therefore, due to the complexity of this system, optimal balance between wind and solar resources and a convenient storage for supplying a desalination unit and electricity requirements needs special attention to find a good engineering solution [31].

Optimization of ROD-based hybrid renewable energy system is a difficult problem that needs powerful techniques to be effectively solved. Nevertheless, various approaches used for hybrid renewable energy system optimization have been reported [32–36]. However, new generation artificial intelligence algorithms, such as heuristic algorithms, are found to be more acceptable than traditional methods and software tools, such as HOMER (Hybrid Optimization of Multiple Energy Resources) [37,38], for the optimization of renewable based hybrid energy systems because of their ability to search global and local optima, fast convergence and good calculation accuracy [39,40].

E-mail address: a_maleki@ut.ac.ir.

http://dx.doi.org/10.1016/j.desal.2017.05.034
Received 6 March 2017; Received in revised form 26 May 2017; Accepted 28 May 2017

Table 1
Brief review of previous research.

Reference/YEAR of study	Plant capacity m^3/day	Location	Systems studied	Technique	Highlights
Joyce et al. [17] /2001	0.1–0.5	Lisbon, Portugal	Stand-alone PV–ROD system	Mathematical model	Economic analysis
Helal et al. [18] /2008	20	United Arab Emirates	PV-diesel-ROD unit for remote areas	Mathematical model	Economic analysis
Soric et al. [19] /2012	1	Marseille, southern France	Battery-less PV-ROD, using super capacitor as electrical regulator, using Clark pump as energy recovery device	Experimental	Economic analysis with environmental impact
Mokheimer et al. [20] /2013	5	Dhahran, Saudi Arabia	Hybrid wind–solar-battery-powered ROD system	Mathematical model, HOMER	Economic analysis
Kumarasamy et al.[21]/2015	2.4–6	India	Battery-less PV powered ROD, with and without using permeate storage	Fmincon solver (a local optimizer) available in MATLAB	Control strategy
He et al. [22]/2015	Not mentioned	Perth Australia	Stand-alone ROD powered by PV system	Mathematical model	Thermodynamically analyzed
Esfahani and Yoo [23]/2016	10	South Korea	Off-grid battery less photovoltaic-powered ROD with a water storage tank	Genetic algorithm	Freshwater pinch analysis
Caldera et al. [24]/2016	Not mentioned		Stand-alone hybrid PV–wind–battery-ROD system	Linear optimisation method	Economic analysis
Jones et al. [25]/2016	Not mentioned	Jordan Valley	A PV powered pumping and desalination system without energy storage	HOMER, MATLAB	Economic analysis; Sensitivity analysis
Alghoul et al. [26]/2016	5.1	Malaysia	PV-ROD with batteries in remote areas	HOMER	Economic analysis
Kyriakarakos et al. [2]/2017	200–500 m^3/year	An island in the Cyclades complex, Aegean Sea of Greece	Autonomous PV-battery-ROD systems	Particle swarm optimization	Economic analysis

HOMER energy modeling software is a particularly powerful tool for designing and analyzing hybrid energy system, but this method can require excessive calculation time, when the number of possible design points is very high [3,40].

Although studies on various aspects of ROD-based hybrid renewable energy system (HRES) and various approaches used for optimization of HRES have been reported in the literature, informative models of autonomous solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage and efficient optimization tools for optimal sizing of this problem to meet both electric load and water desalination needs are seldom found.

In this paper for increasing the fresh water availability and to meet the load demand six grid independent hybrid renewable energy systems (GIHRES)-based ROD are designed and modeled; namely wind turbine (WT)/hydrogen storage system (HSS)/ROD, photovoltaic (PV)/WT/HSS/ROD, PV/HSS/ROD, WT/battery storage (BS)/ROD, PV/WT/BS/ROD, and PV/BS/ROD. For this aim, an objective function is defined based on satisfy the maximum loss of power supply probability ($LPSP$*) and minimize the life cycle cost (LCC) of hybrid systems subject to technical constraints. This problem includes the integer decision variable (number of batteries and number of hydrogen tanks) and the continuous decision variables (swept area of wind turbines and the photovoltaic area) in the optimization model. For optimal design of these six systems an efficient version of heuristic algorithms is needed. Bee algorithm is a metaheuristic optimization technique which was invented by the swarm behavior of honey bees. Bee algorithm use different moving patterns with different kinds of bees to explore the search space [41]. The effectiveness of bee algorithm has led to its applications to optimization problems in various systems. Furthermore, numerous uses of the bee algorithm for optimization problems in various systems have been reported, demonstrating its superiority [42–46].

Bee algorithm is an efficient version of heuristic algorithms which has easy implementation, simple concept, and high efficiency. As a result, bee algorithms are promising metaheuristic optimization techniques that have more chance than the other metaheuristic techniques to solve optimization problems in various systems. Due to the features of bee algorithm, in this paper, an improved version of the bee algorithm is proposed for optimal sizing of hybrid energy systems in the remote area of eastern Iran, South Khorasan. The results are compared with the results obtained by harmony search algorithm [47].

2. Mathematical modeling

To determine optimal values of the structure of the hybrid power system (Fig. 1), the modeling of the system components and optimization framework of the hybrid systems, namely WT/HSS/ROD, PV/WT/HSS/ROD, PV/HSS/ROD, WT/BS/ROD, PV/WT/BS/ROD, and PV/BS/ROD, is described in detail in this section. The wind turbines and the PV panels work together for increasing the fresh water availability and to meet the load demand. If the total electric energy generated by the renewable energy sources is more or less than the load, the storage systems (battery storage, hydrogen storage system, including fuel cell, electrolyzer, and hydrogen tanks) is used. Also, for increasing the fresh water availability and to store the surplus desalinated-water produced, a water storage tank is used. The energy generated by each component of the hybrid power systems is determined by modeling the component mathematically. In the following, the modeling of the components is detailed.

2.1. Wind turbine (WT) system: Power and economic

The WT power generation P_{WT} can be written as follows [48,49]: