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Size optimization for hybrid photovoltaic–wind energy system using ant colony optimization for continuous domains based integer programming

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ABSTRACT

In this paper, ant colony optimization for continuous domains (ACO_R) based integer programming is employed for size optimization in a hybrid photovoltaic (PV)–wind energy system. ACO_R is a direct extension of ant colony optimization (ACO). Also, it is the significant ant-based algorithm for continuous optimization. In this setting, the variables are first considered as real then rounded in each step of iteration. The number of solar panels, wind turbines and batteries are selected as decision variables of integer programming problem. The objective function of the PV–wind system design is the total design cost which is the sum of total capital cost and total maintenance cost that should be minimized. The optimization is separately performed for three renewable energy systems including hybrid systems, solar stand alone and wind stand alone. A complete data set, a regular optimization formulation and ACO_R based integer programming are the main features of this paper. The optimization results showed that this method gives the best results just in few seconds. Also, the results are compared with other artificial intelligent (AI) approaches and a conventional optimization method. Moreover, the results are very promising and prove that the authors' proposed approach outperforms them in terms of reaching an optimal solution and speed.

1. Introduction

The earth's capacity for supplying fossil energy will not last long. So it is beneficial to employing inexhaustible energy sources to avoid the depletion of fossil fuels. Hence, solar and wind energies can be appropriate alternatives. Solar energy is the one of the most inexhaustible energy using all over the world. Due to the fact that these energies are abundant, renewable and clean without producing greenhouse gases, numerous researches carried out to optimize the size of hybrid photovoltaic and wind power generating systems in recent years.

One of the earliest researches was performed by Kellogg et al. [1], who presented a simple numerical algorithm to determine the optimum generation capacity and storage needed for a stand-alone, wind, PV, and hybrid wind PV system. Also, an economic analysis carried out for these systems and employed to justify the use of renewable energy versus constructing a line extension from the nearest existing power line to supply the load with conventional power. Another study conducted by Habib et al. to meet a certain load distribution demand in the city of Dhahran, Saudi Arabia [2]. This analysis applied to satisfy a constant load of 5 kW required for cathodic protection in offshore platforms. Rajendra Prasad and Natarajan performed an analysis to optimize the size of integrated wind, photovoltaic system with battery backup system for the site Pompuhar, Tamil Nadu state in India [3]. In this study, deficiency of power supply probability, relative excessive power generated, unutilized energy probability and levelized energy cost of power generation with battery bank selected as the decision variables. Yang et al. presented the hybrid solar-wind system optimization sizing model to optimize the sizing of the hybrid solar-wind power generation system employing a battery bank [4]. The model of the hybrid system, the model of loss of power supply probability and the model of the levelized cost of energy were three main parts of this study. The size of a PV–wind hybrid energy conversion system with battery storage optimized by Ekren and Yetkin using Box–Behnken design and the response surface methodology

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based on an hourly operating cost [5]. Also, the objective function was taken as the hybrid system cost and the PV size, the wind turbine rotor swept area and the battery capacity considered as the decision variables. Hakimi and Moghaddas-Tafreshi [6], employed the particle swarm optimization method to optimize sizing of a stand-alone hybrid power system for Kahnouj area in south-east of Iran. The system included fuel cells, some wind units, some electrolyzers, a reformer, an anaerobic reactor and some hydrogen tanks. The aim of this study was to minimize the total costs of the system such that the demand was met. Ekren and Ekren applied the simulated annealing algorithm for optimizing size of a PV–wind integrated hybrid energy system with battery storage [7]. The proposed methodology is a heuristic approach which uses a stochastic gradient search for the global optimization. The objective function was the hybrid energy system total cost which should be minimized. Also, PV size, wind turbine rotor swept area and the battery capacity considered as the decision variables. Belfkira et al. used the DIRECT optimal sizing methodology for a stand-alone hybrid wind/PV/diesel energy system [8]. This algorithm employed to minimize the total cost of the system while guaranteeing the availability of the energy. Also, the optimum numbers and the types of wind turbines, of PV panels and of batteries determined in the optimization procedure. Moreover, the total cost of the hybrid wind/PV/diesel energy system with batteries compared with the hybrid wind/PV/diesel energy system without batteries.

Boonbumroong et al. employed the TRNSYS 16 software in assistance with particle swarm optimization (PSO) to optimize the model configuration of a typical AC-coupling stand alone hybrid power system [9]. An existing PV/wind/diesel hybrid power system at Chik Island, Thailand, considered as a reference system. The total cost through the useful life of the system is taken the objective function which should be minimized. Nasiraghdam and Jadid used a novel multi-objective artificial bee colony algorithm to optimize sizing of the distribution system reconfiguration and hybrid (photovoltaic/wind turbine/fuel cell) energy system [10]. The objective functions of this paper were the total power loss, the total electrical energy cost, the total emission produced by hybrid energy system, the grid minimization and the voltage stability index of distribution system maximization. Also, the authors compared the proposed algorithm with NSGA-II and MOPSO methods and showed that there was a good quality and a better diversity of the Pareto front compared with those of NSGA-II and MOPSO methods. Size optimization for a hybrid photovoltaic–wind energy system carried out by Geem [11]. The total design cost which consists of total capital cost and total maintenance cost are taken as objective function. And, the number of solar panels, number of wind turbines and the number of batteries considered as the decision variables. This study applied Branch-and-Bound (B&B) and Generalized Reduced Gradient (GRG) methods to optimize the numerical example which had a regular optimization formulation. Abbes et al. reported a new approach to design an autonomous hybrid wind–photovoltaic (PV)-batteries system in order to assist the designers to take into consideration both the economic and ecological aspects [12]. In this study, the primary embodied energy (EE) introduced as a new criterion for hybrid systems, designing with the objective to minimize loss of power supply probability (LPSP). Also, single and multi-objective optimization algorithms employed to optimize the sizing of a wind-PV-batteries system. Ant colony optimization for continuous domains (ACO_R) based 0–1 integer programming is proposed by Fetanat and Shafipour to find the optimal solution of the generation maintenance scheduling in power systems [13]. The objective function of this algorithm considered the effect of economy as well as reliability. Various constraints such as spinning reserve, or duration of maintenance crew are being taken into account. The ACO_R formulation developed applied on a power system with six generating units. Liao et al. presented an ant colony optimization algorithm for mixed-variable optimization problems [14]. The proposed algorithm included three solution generation mechanisms including a continuous optimization mechanism, a continuous relaxation mechanism for ordinal variables and a categorical optimization mechanism for categorical variables which allowed tackling mixed-variable optimization problems. Also, the authors introduced a novel procedure to generate artificial and mixed-variable benchmark function. Huang et al. incorporated continuous ant colony optimization (ACO_R) with particle swarm optimization (PSO) to improve the search ability, investigating four types of hybridization including sequence approach, parallel approach, sequence approach with an enlarged pheromone-particle table and global best exchange [15]. These hybrid systems employed to data clustering. The experimental results showed that the performances of the proposed hybrid systems were superior compared to those of the K-mean, standalone PSO, and standalone ACO_R. Mostapha Kalami Heris and Hamid Khaloozadeh proposed an intelligent particle filter, namely ant colony estimator (ACE) to improve the estimation performance and overcome the well-known problems of Degeneracy and Sample Impoverishment [16]. In this paper, ACO_R is used for implementing an adaptive proposal density function, which improves the performance of the estimation algorithm. Zengqiang Chen and Chen Wang employed the neural network method to model the Radio Frequency Identification reflected signal strength distribution [17]. In order to achieving a satisfied solution, a continuous ant colony optimization algorithm that can overcome the defect of back propagation (BP) algorithm combined with neural network. The results showed that this method had a good performance.

In this paper, size optimization is carried out for hybrid photovoltaic–wind energy system (Fig. 1) using ant colony optimization for continuous domains based integer programming. The objective function of this system design is the total design cost which is the sum of total capital cost and total maintenance cost. The number of solar panels, wind turbines and batteries are considered as the decision variables. Also, one of the purposes of this paper is to introduce a full data set for the design of a basic PV–wind system. In addition, the results of this problem are compared with other artificial intelligent (AI) and conventional optimization techniques. This study proves a better optimization formulation and solving technique.

The remainder of this paper is organized as follows: Section 2 reviews the modeling of problem in details. Section 3 describes ant colony optimization for continuous domains. Section 4 presents the integer programming problem. Section 5 explains the case study. Section 6 provides the results and discussion. Finally, the conclusions summarize in Section 7.

2. Modeling of problem

The optimization problem is specified as follows:
Minimize $f(\vec{x})$
Subject to

$$\begin{aligned} & g_i(\vec{x}) \geq 0 \quad i = 1, 2, \ldots, M_{ine} \\ & h_j(\vec{x}) = 0 \quad j = 1, 2, \ldots, P_{eq} \\ & {}_L x_r \leq x_r \leq {}_U x_r \quad r = 1, 2, \ldots, N_{dv} \end{aligned} \tag{1}$$

where $f(\vec{x})$ is the objective function, M_{ine} is the number of inequality constraints and P_{eq} is the number of equality constraints. $\vec{x} = (x_1, x_2, \ldots, x_{N_{dv}})$ is the set of each decision variable x_r and N_{dv} is the number of decision variables. The lower and upper bounds for each decision variable are ${}_L x_r$ and ${}_U x_r$, respectively.

Infeasible solutions that violate the constraints have a chance to be included in the feasible solution area. Static penalty functions